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PROMOTING INDUSTRIAL SUSTAINABILITY THROUGH THE DEVELOPMENT OF A COLLABORATIVE ECOSYSTEM IN LAZIO'S NAVAL AND AEROSPACE SECTORS

Pubblicato il21 Maggio 2025 di Varone Alberto, Diana Gabriele e Bolici Francesco



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This study proposes a four-phase framework to implement circular economy practices in Lazio's aerospace and naval sectors. By overcoming barriers in thermoset recycling, the framework enhances industrial sustainability, improves stakeholder coordination, and promotes economically viable circular practices. These advancements hold significant

1. Introduction

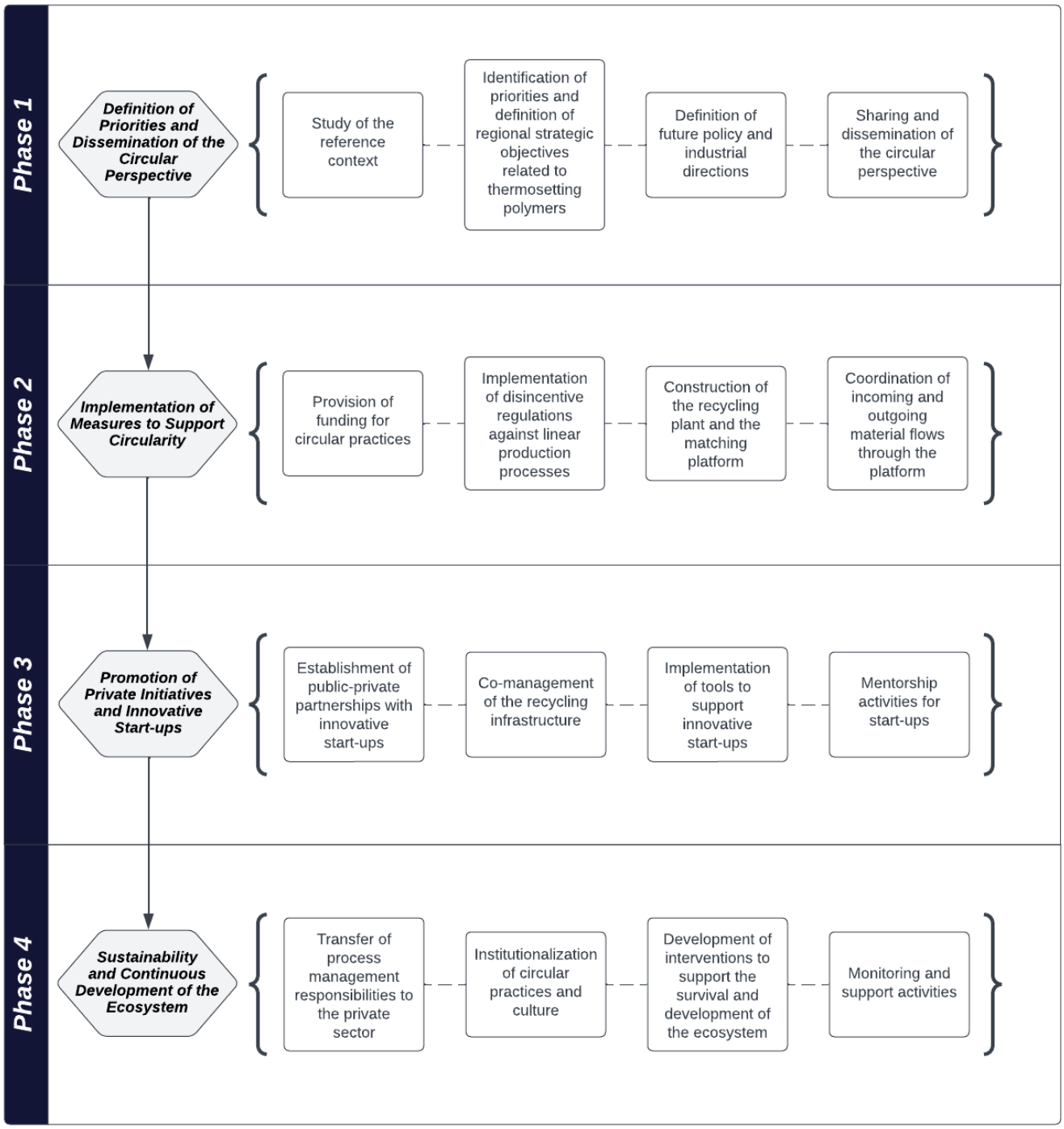
Promoting industrial sustainability through collaborative networks represents a contemporary challenge with significant economic and social implications.

Traditional linear production systems, characterized by a "take-make-dispose" paradigm, have proven inadequate in addressing contemporary sustainability challenges. In contrast, circular models emphasizing reuse, regeneration, and recycling offer a more sustainable alternative. These approaches facilitate the transition toward what the Ellen MacArthur Foundation (2013, p. 7) defines as a circular economy – an industrial system intentionally designed to be restorative and regenerative. This system fundamentally reconceptualizes the notion of "end of life," replacing it with the principle of "restoration". It encompasses comprehensive strategies including the promotion of renewable energy, elimination of toxic chemicals, and waste minimization through enhanced design of materials, products, systems, and business models. Beyond environmental benefits, circular business models provide strategic advantages, particularly in mitigating risks associated with volatile raw material prices and improving production efficiency (Ellen MacArthur Foundation, 2013).

Despite these potential advantages, the implementation of circular strategies remains suboptimal across many industries (Rosa et al., 2019). Several structural barriers impede effective adoption, including business fragmentation, insufficient inter-organizational coordination, limited knowledge sharing regarding circular practices, inadequate financial resources for innovation, and underdeveloped regulatory frameworks (Berghuis et al., 2023; Planing, 2015).

The RIMATER project emerges as a response to these challenges, proposing an organizational solution specifically tailored to the technical and territorial characteristics of the Lazio Region (Italy). This initiative aims to cultivate and sustain an industrial ecosystem within the Region, emphasizing the critical interdependencies among stakeholders and the essential coordinating role of public institutions (Bolici et al., 2022). The project's governance model and ecosystem dynamics draw upon the Triple Helix model, which advocates for systemic collaboration among industry, Regional public authorities, and Universities (Leydesdorff & Etzkowitz, 1998).

Figure 1: Overview of the ecosystem solution


Phase 1
Definition of Priorities and Dissemination of the Circular Perspective
Study of the reference context
Identification of priorities and definition of regional strategic objectives related to thermosetting polymers
Definition of future policy and industrial directions
Sharing and dissemination of the circular perspective
Phase 2
Implementation of Measures to Support Circularity
Provision of funding for circular practices
Implementation of disincentive regulations against linear production processes
Construction of the recycling plant and the matching platform
Coordination of incoming and outgoing material flows through the platform
Phase 3
Promotion of Private Initiatives and Innovative Start-ups
Establishment of public-private partnerships with innovative start-ups
Co-management of the recycling infrastructure
Implementation of tools to support innovative start-ups
Mentorship activities for start-ups
Phase 4
Sustainability and Continuous Development of the Ecosystem
Transfer of process management responsibilities to the private sector
Institutionalization of circular practices and culture
Development of interventions to support the survival and development of the ecosystem
Monitoring and support activities

2. Theoretical Background: The Ecosystemic Perspective

The theoretical framework for this study encompasses two primary domains: circular business models and industrial ecosystems. This section examines their conceptual foundations and interconnections, providing the theoretical foundation for our research.

2.1 The Circular Business Model: Internal and External Perspectives

Circular business models represent a fundamental shift in business operations, implementing cycling, extending, intensifying, and dematerializing measures to optimize resource utilization and minimize waste (Geissdoerfer et al., 2020). The analysis of these models has evolved along two distinct trajectories: internal and external perspectives. While both approaches pursue economic and sustainability objectives (Zucchella & Previtali, 2019), they differ significantly in their analytical focus and methodological foundations.

The internal perspective concentrates on individual business units, predominantly employing the business model canvas framework as its design tool (Lewandowski, 2016; Osterwalder et al., 2010; Rosa et al., 2019). However, this approach has faced criticism for constraining business model boundaries within organizational limits, potentially overlooking broader systemic interactions (Zucchella & Previtali, 2019). In contrast, the external perspective emphasizes organization-environment interactions, drawing from stakeholder and network theories, and more recently, ecosystem theory, which encompass the complex relationships between organizations and their environment (Geissdoerfer et al., 2020). The ecosystem perspective proves particularly pertinent for circular business models, as their successful implementation necessitates inter-organizational collaboration rather than isolated initiatives (Zucchella & Previtali, 2019).

2.2 Industrial Ecosystem: Conceptual Framework and Principles

The ecosystem concept, originally rooted in ecological science, has evolved significantly in its application to industrial networks (Korhonen, 2001). Frosch & Gallopoulos (1989) pioneered the industrial ecosystem concept, defining it as an integrated system that optimizes energy and material usage while minimizing waste through cross-process utilization. This framework parallels biological ecosystems through four fundamental principles: roundput, diversity, locality, and gradual change (Korhonen, 2001).

Roundput describes the retention and transformation of vital resources within ecosystems, analogous to industrial systems' utilization of renewable and recycled materials. The principle of diversity manifests through varied species, interdependencies, and cooperation patterns, promoting ecosystem resilience through adaptability. The locality principle suggests that environmental conditions significantly influence ecosystem configuration, often resulting in regionally specific industrial ecosystems (Gamidullaeva et al., 2022). Finally,

gradual change promotes sustainable resource utilization within natural renewal capacities (Korhonen, 2001).

Industrial symbiosis, mirroring biological mutualism, characterizes how traditionally unrelated businesses exchange resources for mutual benefit (Chertow, 2000). This symbiotic relationship generates collective advantages that exceed individual benefits, often manifesting in eco-industrial parks—communities of businesses that cooperate internally and with local communities to share resources efficiently while generating both economic and environmental gains (PCSD, 1996).

2.3 Organizational Dynamics of Industrial Ecosystems

Industrial ecosystems comprise heterogeneous, hierarchically independent, and interconnected actors, including businesses, startups, government entities, and investment funds (Aarikka-Stenroos et al., 2021; Tolstykh et al., 2020). These diverse participants fulfill distinct roles and contribute varying inputs and outputs within waste exchange mechanisms (Korhonen, 2001; Tsujimoto et al., 2018). While fundamentally self-organized, these ecosystems require coordination through network orchestrators who facilitate collaborative practices through shared vision, trust, and transformational leadership (Tolstykh et al., 2020; Zucchella & Previtali, 2019). The orchestrator promotes sustainable ecosystem development by facilitating technological, innovative, and economic transformations (Tolstykh et al., 2020). Regional sustainable development can be described as following Communities-of-Practice (CoPs) logic, involving Innovators, Influencers, and Initiators (Liu et al., 2023). These networks, commonly led by research or government entities, support knowledge co-creation through practice (Brown & Duguid, 2001). Industrial platforms facilitate ecosystem operation through modular architectures (Gawer, 2014), incorporating resource providers, consumers, intermediaries, and coordinators (Benedict et al., 2018; Mukhopadhyay & Bouwman, 2019). Notably, local authorities have evolved from supervisors to facilitators, increasingly cooperating with private sectors while providing organizational resources, knowledge, funding, and infrastructure support (Berghuis et al., 2023; Von Malmborg, 2004).

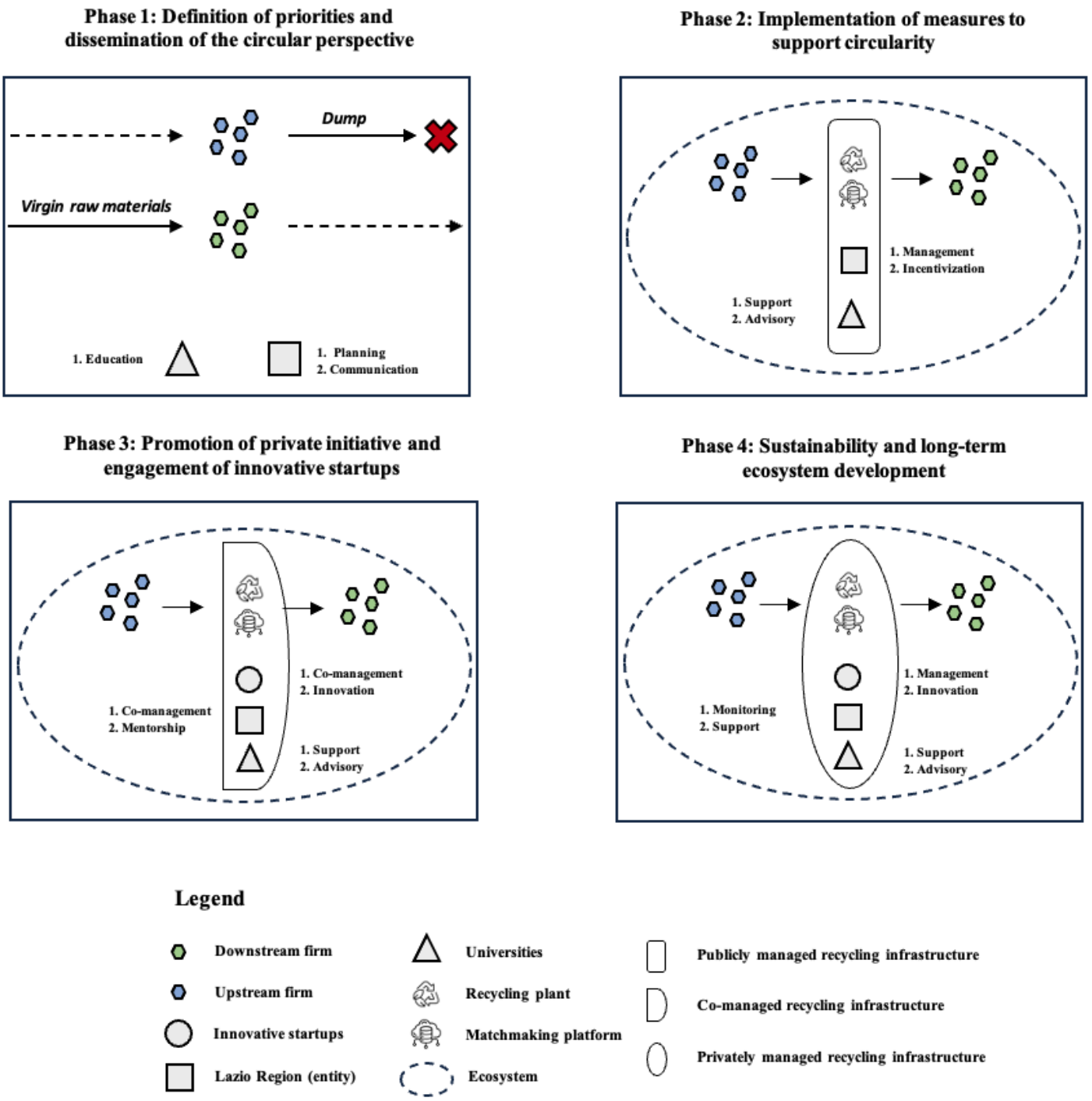
3. Ecosystemic Solution: A Four-Phase Implementation Plan

Analysis of the Lazio entrepreneurial landscape through the RIMATER project has identified significant barriers to implementing circular strategies for thermosetting material waste recycling at an ecosystem level. These impediments, exacerbated by the Region's fragmented industrial context, manifest across technical, financial, and systemic dimensions, creating a scenario where landfill disposal remains more economically viable than composite material recycling.

To address these multifaceted challenges, we propose a comprehensive four-phase implementation plan designed to foster industrial ecosystem development. This approach leverages stakeholder complementarity (Cuel et al., 2021) and synergetic interdependencies to generate integrated economic, environmental, and

social value. The proposed solution encompasses both upstream and downstream companies, innovative startups, regional authorities, and the scientific community, and is structured across four macro-interventions: i. defining priorities and disseminating the circular perspective; ii. implementing circularity support measures; iii. promoting private initiative and innovative startups; iv. promoting ecosystem sustainability and continuous development (Figure 1 and 2).

Figure 2: Visual representation of the ecosystem development plan



3.1 Phase 1: Definition of priorities and dissemination of the circular

perspective

The initial phase focuses on three primary objectives: industrial context mapping, strategic priority establishment, and circular objective articulation for thermosetting materials recycling. These interventions align strategically with the Lazio Region's Ecological Transition Plan guidelines (Regione Lazio, 2023), advocating for a systemic, interdisciplinary approach to circular production systems.

Building on RIMATER analyses, the Regional authority conducts targeted interviews with ecosystem-compatible enterprises to proactively identify potential obstacles and opportunities. This engagement serves dual purposes: establishing critical touchpoints between regional authorities and key ecosystem actors while addressing potential resistance to change. Simultaneously, it reinforces the Region's commitment to implementing circular policies.

Concurrent with mapping activities, the Region develops a comprehensive framework of transition objectives for relevant materials and industries, establishing clearly defined intervention areas across medium and long-term horizons. Information dissemination occurs through multiple channels, including institutional websites, social media platforms, dedicated newsletters, and industry events. This multi-channel approach facilitates direct industry-Region dialogue and promotes the development of a shared vision for circular transformation.

The scientific community assumes a crucial role in this phase through the development and delivery of specialized circular economy training courses and workshops, conducted in collaboration with regional authorities. These educational initiatives serve dual purposes: establishing fundamental knowledge bases and catalyzing interaction between industry professionals. This interaction facilitates the development of collaborative networks and potential symbiotic relationships among participants.

The priority-setting and perspective-dissemination process represents a crucial foundation for developing regional consensus on industrial directions, establishing essential groundwork for subsequent implementation phases.

3.2 Phase 2: Implementation of measures to support circularity

The second phase encompasses a comprehensive approach to establishing the fundamental infrastructure and regulatory mechanisms necessary for circular economy implementation. This phase manifests through three primary dimensions: regulatory initiatives, infrastructure development, and industrial matching platform implementation.

Recognizing the absence of private sector first-movers, the Region assumes direct managerial responsibility for

recycling facility operations. This intervention addresses a critical market gap while ensuring the integrity of recycling processes and promoting the economic-financial viability of circular practices. The strategic location decision for the recycling infrastructure favors the Province of Rome, supported by RIMATER project analyses demonstrating the highest concentration of ecosystem-compatible businesses in this area.

Central to this phase is the development and implementation of an industrial matching platform that facilitates ecosystem development through the aggregation of upstream and downstream actors. This platform serves multiple functions (see Table 1): i. facilitating supply-demand matching for recycled materials; ii. enabling operational information sharing regarding material availability, logistics, and recycling processes; iii. promoting industrial partnerships and innovative practices; iv. supporting knowledge dissemination across the ecosystem.

Public control of the platform aligns strategically with the Region's enabling role, allowing for balanced ecosystem development while maintaining stability. Additionally, the Region leverages its procurement capacity by utilizing the platform to source secondary raw materials for compatible public works projects.

The scientific community assumes a crucial supporting role in this phase, providing expertise across two critical dimensions: i) technical support for recycling facility development and management; ii) strategic guidance for platform coordination and optimization. This collaboration ensures that both physical and digital infrastructure development benefits from academic expertise while maintaining practical applicability.

The Region promotes three key objectives through these integrated strategies: i) enhanced collaboration among complementary actors; ii) improved scalability of recycling processes; iii) and systematic reduction in operational costs. Collectively, these interventions create a cohesive ecosystem focused on the revalorization of thermoset material waste, specifically targeting the aerospace and naval sectors in Lazio.

Table 1: Benefits arising from the matchmaking platform

Category	Benefits	Description
Economic	Reduction in Operational Costs	Companies can access secondary raw materials at competitive prices via the matching platform, lowering production costs and increasing profitability
	Scalability of Recycling Processes	The platform supports the scaling of recycling operations, enabling efficient management of higher waste volumes and fostering ecosystem growth
Environmental	Promotion of Circularity	The platform accelerates the shift towards circular production processes by reducing reliance on virgin materials and promoting the recycling of thermoset composites
	Environmental Sustainability	Participation in the platform helps reduce environmental impact, aligning companies with sustainability goals and ensuring compliance with stricter regulations
Support and Collaboration	Support from the Scientific Community	Collaboration with the scientific community ensures the integration of theoretical, technical, and managerial expertise, forming a solid foundation for strategic and operational decision-making within the ecosystem
	Active Industry Participation	The platform encourages companies to actively engage, creating business opportunities in recycling and the purchase of recycled materials.
	Industrial Collaboration and Innovation	The platform fosters collaboration among companies, enabling the exchange of best practices and joint innovation, which drives sector growth and strengthens competitiveness

3.3 Phase 3: Promotion of Private Initiatives and Engagement of Innovative Startups

The third phase marks a strategic transition in ecosystem development, focusing on private sector integration and innovation promotion following the successful implementation of core infrastructures. This phase represents a crucial evolution in the Region's role from primary infrastructure manager to co-manager and mentor, manifested through strategic public-private partnerships with innovative startups focused on ecosystem material flow management.

Startups serve as critical agents of ecosystem renewal and flexibility, distinguished by their innovative capacity and rapid market adaptation capabilities. Their operational agility supports the essential collaboration, integration, and dynamism required within the circular economy context. Through targeted funding calls, the Region actively incorporates these enterprises into ecosystem material flow coordination, facilitating shared coordination and intermediation functions through the established matching platform. These innovative entities promote novel approaches to enhance recycling process efficiency and sustainability, simultaneously supporting creative solution design and sustainable ecosystem development.

Concurrent with innovative design processes, the co-management strategy enables systematic knowledge transfer from the public to private sector, particularly regarding plant management expertise and ecosystem

interaction dynamics. The scientific community maintains its crucial technical-management support role, providing startups with essential competencies in engineering and innovative project management. This knowledge transfer mechanism ensures the preservation and enhancement of accumulated expertise while facilitating private sector capability development.

3.4 Phase 4: Sustainability and Continuous Development of the Ecosystem

The final phase focuses on transitioning infrastructure management to the private sector, ensuring long-term ecosystem sustainability, and establishing mechanisms for continuous growth and development. Building on the capability development achieved in Phase 3, the Region systematically reduces its direct operational involvement while maintaining essential support and oversight functions. The Region introduces regulations promoting circular initiatives and economic incentives to foster a favorable institutional environment for the ecosystem's survival and growth.

The Region promotes circular economy culture through awareness campaigns, best practice exchanges, and continuous training programs. These initiatives foster a cycle of ongoing improvement while strengthening the foundational understanding of circular economy principles among stakeholders. A comprehensive monitoring framework evaluates the ecosystem's environmental, social, and economic impacts, enabling timely identification and correction of operational inefficiencies while optimizing ecosystem performance.

Innovative startups remain fundamental to the ecosystem's development. The Region, in collaboration with the scientific community, continues to provide funding, resources, and networking opportunities. This partnership drives research incentives, promoting collaboration between industry and Universities through applied research projects and shared laboratories. This multi-faceted approach ensures the ecosystem's economic sustainability while institutionalizing circular practices and promoting continuous research and development activities.

The fourth phase thus establishes the foundation for long-term ecosystem viability, combining private sector leadership with ongoing public sector support to maintain momentum in circular economy development. Through this carefully orchestrated transition, the ecosystem achieves both operational independence and sustainable growth potential, while maintaining the innovative capacity essential for continuous improvement in circular practices.

4. Conclusions and Implications

This research presents an organizational framework designed to facilitate the adoption of circular practices in the Lazio Region, with specific emphasis on thermoset material waste recycling in the naval and aerospace

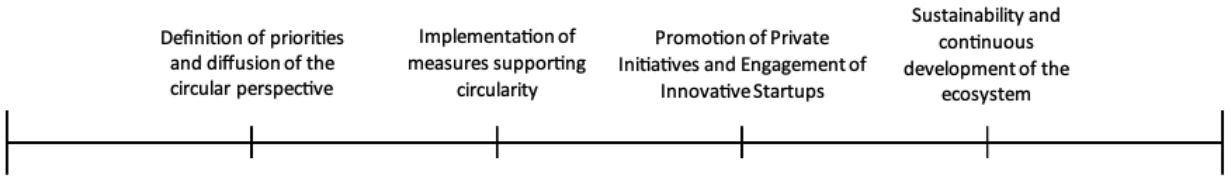
sectors. While the framework maintains inherent flexibility, its targeted approach addresses specific challenges within these strategic sectors.

The proposed solution adopts a systematic four-phase approach: priority setting and circular perspective promotion; circularity support measure implementation; private initiative and innovative startup encouragement; and ecosystem sustainability and continuous development facilitation. This structured progression aims to catalyze the formation, expansion, and innovation of an industrial ecosystem within the target sectors.

The framework is anticipated to strengthen Lazio's industrial capacity across four strategic dimensions: circularity enhancement, stakeholder coordination optimization, industrial innovation acceleration, and economic-financial sustainability of circular practices (Figure 3). Upon full implementation, the initiative is expected to yield an industrial ecosystem characterized by several distinctive features. These include widespread adoption of circular economy principles ensuring long-term sustainable development, autonomous private sector management of processes and ecosystem interactions, sustained focus on continuous growth, and financial sustainability of circular processes driven by collaborative innovation and coordinated stakeholder engagement.

This research contributes to the practical implementation of circular economy principles at a regional level. The proposed framework offers a structured approach to addressing the complex challenges of industrial transformation while maintaining flexibility for adaptation to specific sectoral needs. Future research might explore the framework's applicability to other industrial sectors and regional contexts, as well as examine the long-term impacts of such ecosystem-based approaches on regional industrial development.

Figure 3: Expected impacts of the proposed solution on the Industrial Context of Lazio



Dimension	Current State (AS IS)	Post-Implementation Phase 1	Post-Implementation Phase 2	Post-Implementation Phase 3	Desired State (TO BE)
Circularity	Predominantly linear production processes with limited involvement in thermoset material recycling.	Growing awareness of circular practices among companies	Companies adopt circular industrial practices (roundput), supported by regional financial assistance.	Circular practices expand as innovative startups engage in managing material flows.	Stakeholders embrace a circular and ecosystemic culture, driving sustainable industrial development in the long term.
Coordination	Limited communication among stakeholders and lack of a systemic vision.	The Region identifies key obstacles and coordination mechanisms needed through industrial	The Region establishes recycling infrastructure and acts as a network orchestrator, managing material flows and launching a matching platform.	Innovative startups co-manage the matching platform in collaboration with the Region and universities.	The ecosystem is privately managed, supported by a suitable regulatory framework and well-established interactions.
Innovation	Predominantly linear processes with little incentive for innovation.	Training and networking initiatives provide companies with foundational knowledge for managing innovative practices.	The Region acts as a first-mover, building recycling infrastructure and promoting the adoption of recycling and future innovation practices.	Innovative startups managing recycling infrastructure develop new approaches to ecosystem processes.	The ecosystem fosters continuous development through collaboration between companies, startups, the Region, and universities.
Economic-Financial Sustainability	Recycling of thermoset materials offers low economic and financial feasibility.	The Region identifies sustainable economic models based on analysis of Lazio's industrial landscape.	Circular practices are promoted through funding and the establishment of recycling infrastructure by the Region.	Financial sustainability improves as innovative startups contribute to co-managing material flows.	The ecosystem operates on circular, economically sustainable practices enabled by the coordination, collaboration, and innovation of involved stakeholders.

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