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Article

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Article

Strengthening Smart Specialisation Strategies (S3) Through Network Analysis: Policy Insights from a Decade of Innovation Projects in Aragón

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Abstract

This paper applies a multi-level social network analysis to examine Aragón's innovation ecosystem, focusing on a decade of competitive public projects (2014–2023) aligned with the region's Smart Specialisation Strategy (S3) 2021–2027. By mapping and weighting the participation of regional entities across regional, national, and European calls, the study uncovers how all types of local actors organise themselves around key specialisation areas. Moreover, a comparative benchmark is introduced by analysing more than 33,000 Horizon 2020 and Horizon Europe initiatives without Aragonese partners, revealing how to fill structural gaps and enrich the regional ecosystem through international collaboration. Results show strong funding concentration in four fields—Energy, Health, Agri-Food, and Advanced Technologies—while other historically strategic areas like Hydrogen and Water remain underrepresented. Although leading institutions (UNIZAR, CIRCE, ITA, AITIIP) play central roles in connecting academia and industry, direct collaboration among them is limited, pointing to missed synergies. Expanding previous SNA-based assessments, this study introduces a diagnostic tool to guide policy, proposing targeted actions such as challenge-driven calls, dedicated support programs, and cross-border consortia with top EU partners. Applied to two contrasting specialisation areas, the method offers sector-specific recommendations, helping policymakers align Aragón's innovation capabilities with EU priorities and strengthen its position in both established and emerging domains.

Keywords: regional innovation; smart specialisation strategy; Aragon; competitive public projects; social network analysis; innovation ecosystem



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1. Introduction

In recent years, smart specialisation strategies (S3) have become key tools for promoting regional competitiveness, sustainability, and inclusiveness in Europe (European Commission, Joint Research Centre, 2021; European Committee of the Regions et al., 2023). Instead of simply funding isolated innovation projects, S3 encourages regions to identify and build on their unique strengths through collaborative governance, knowledge sharing, and ongoing entrepreneurial discovery (Asheim, 2019; Gheorghiu et al., 2016). This holistic approach views regional innovation systems as complex, adaptive networks shaped by

policy structures, social capital, and place-based strategies that influence how ideas emerge, spread, and generate sustainable advantage (Barbero et al., 2022; Mascarenhas et al., 2021).

Despite this conceptual evolution, questions remain about how effectively S3 strategies capture and steer these underlying collaboration dynamics in practice. A growing body of literature highlights the importance of moving beyond funding and governance indicators to better understand the relational patterns within innovation ecosystems (Balland et al., 2019; Talias, 2019; Wibisono, 2022). This paper addresses that gap by proposing multi-level social network analysis (SNA) to diagnose the structure and dynamics of Aragón's innovation ecosystem.

We apply this framework to Aragón, a region that illustrates both the strengths and limitations of S3 strategies. Despite rising R&D investment and strong GDP per capita, Aragón faces persistent challenges in technology transfer, fragmented R&D capacity, and weak collaboration among research centres. The S3 Aragón 2021–2027 strategy prioritises digitalisation, sustainability, and service innovation linked to industry, alongside improved governance and monitoring (Aragón Government, 2024). However, major gaps remain: nearly 60% of local organisations report no access to public R&D funding, research institutions remain poorly coordinated, and large firms tend to engage universities and technology centres through limited, bilateral collaborations rather than broad partnerships.

Moving from an Aragón perspective to that of other European regions, a critical gap in S3 implementation lies in the lack of detailed, empirical insight into how regional innovation systems operate in practice. While existing evaluations often focus on funding outputs, strategic planning documents, or stakeholder consultation processes, they tend to explore collaboration patterns only indirectly or in a fragmented manner. As highlighted by Talias (2019), there is a pressing need to deepen our understanding of how innovation actors interact, particularly in terms of knowledge flows and structural positioning within networks. This mismatch between S3's conceptual goals (dynamic, place-based, participatory innovation) and the limited tools available to monitor, diagnose and adapt these strategies effectively creates a fundamental gap in tailoring interventions that respond to the real-world challenges of regional innovation networks.

Building on earlier work (Calvo-Gallardo et al., 2021, 2022; Rodríguez Ochoa et al., 2023, 2025), which applied one-mode network analysis to examine R&D project collaborations within Aragón's RIS3 (2014–2020) context, the present study expands this scope by adopting a multi-domain, comparative framework based on Aragón's S3 (2021–2027) key areas. The prior research revealed patterns of institutional centrality and identified bottlenecks in regional knowledge diffusion but was limited to addressing the differences between projects funded at different geographical levels. Here, we broaden the analysis by: (i) mapping and weighting participation in competitive public projects from 2014 to 2023 across regional, national, and European levels, using funding as a proxy for collaboration intensity; (ii) classifying these projects according to Aragón's S3 priority domains to assess whether actors are concentrated or fragmented across areas; and (iii) benchmarking Aragón's network structures against Horizon 2020 and Horizon Europe projects that exclude Aragonese partners, identifying external models of connectivity that could help fill local gaps. This approach provides policymakers with an evidence-based view of the region's collaborative architecture, enabling more targeted and adaptive interventions aligned with S3 goals.

The remainder of this study is organized as follows: Section 2 analyses the theoretical frameworks of the paper's contributions. Section 3 describes the data collection and SNA-based methodology, specifying how projects are classified and weighted. Section 4 presents the findings from our participation, cohesion, and centrality analyses, highlighting their implications for innovation bottlenecks across key specialisation areas. Section 5 discusses

how these empirical results inform theoretical and policy debates on regional innovation strategies, with special attention to bridging institutional gaps. Finally, Section 6 concludes by synthesising the study's contributions to both scholarly literature and practice, outlining limitations and suggesting avenues for future research.

2. Literature Review and Conceptual Framework

2.1. *Innovation Through Knowledge Flows and Interactive Learning: Regional Innovation Systems and Smart Specialisation Strategies*

Innovation a systemic process, not an individual one. It emerges from dynamic interactions among diverse stakeholders, rather than isolated R&D projects (Edquist, 1997; B. A. Lundvall, 1992; Nelson & Rosenberg, 1993). Rooted in the systems of innovation tradition, this view stresses that innovation—especially in knowledge-intensive settings—requires collaboration, as no single actor holds all the necessary expertise. Both smart specialisation strategies (S3) and regional innovation systems (RIS) follow this logic, treating innovation as the outcome of coordinated activity across institutions, not just business-level performance.

Knowledge is distributed and socially embedded. It resides not in isolated labs, but in the networks, norms, and routines that shape how information is shared (Asheim & Gertler, 2005; Freeman, 1995). Access to this knowledge depends on institutional frameworks and proximity, which enable collaboration to bridge gaps in technical and organisational expertise. RIS theory highlights how geographic and institutional closeness fosters learning, while S3 builds on this by urging regions to map and connect their embedded knowledge assets.

Interactive learning lies at the core of innovation. It evolves through formal and informal, trust-based exchanges among businesses, universities, governments, and intermediaries (Jensen et al., 2007; B.-Å. Lundvall & Johnson, 1994). This learning is cumulative and context dependent. While face-to-face interaction accelerates tacit knowledge exchange, cognitive and relational proximity can substitute for physical distance (Breschi & Lissoni, 2001). Regions, in this sense, become arenas for dense knowledge interaction—making place a key factor in both RIS and S3 frameworks.

Introduced in 1997 (Cooke et al., 1997), the RIS approach conceptualizes regions as networks of businesses, universities, intermediaries, and governance structures that support innovation. A well-functioning RIS fosters collaboration, knowledge exchange, and shared access to skilled labour and support systems (Asheim & Gertler, 2005; Pinto et al., 2024). Yet many regions face systemic challenges, causing them to struggle to build cohesive systems.

Common barriers include coordination failures (Rossoni et al., 2024), institutional fragmentation, especially in large metropolitan areas where numerous organizations exist but their interactions remain siloed (Tödtling & Trippl, 2005), and 'organizational thinness' in peripheral regions with scarcity of innovation actors (Isaksen et al., 2022; Isaksen & Trippl, 2016). These conditions highlight that a "one size fits all" innovation policy is inadequate and, accordingly, innovation policy must adapt to specific contexts.

Smart specialisation emerged as a policy response to these challenges. Building on RIS principles, S3 was introduced in the 2014–2020 EU programming period as a condition for cohesion funding (McCann & Ortega-Argilés, 2015). It required regions to create research and innovation strategies for smart specialisation (RIS3) aligned with their unique strengths (Foray, 2014, 2016; Joint Research Centre (European Commission) et al., 2021). Rather than spreading resources thin, S3 encourages regions to focus investments on priority domains with high innovation potential.

The entrepreneurial discovery process (EDP) is a defining feature of S3. It brings together businesses, academia, and government to jointly identify promising niches (Gheorghiu et al., 2016; Marinelli & Perianez, 2017). This iterative process echoes RIS principles by grounding strategic choices in local knowledge (Szerb et al., 2020). S3 is also place-based: it recognises that top-down policies often miss local nuances (Demblans et al., 2020). By analysing economic structure and institutional capacity, S3 helps regions concentrate resources, build critical mass, and align investments with real strengths (Suedekum, 2025). Collaborative governance, in turn, reduces fragmentation (Kroll, 2017).

In summary, S3 does not replace RIS; it operationalises it. S3 transforms RIS concepts into policy action, giving regions a practical framework to mobilise assets and address systemic weaknesses (Bevilacqua et al., 2015; Rossoni et al., 2024). It offers a focused, participatory approach to strengthening regional innovation systems through strategy, collaboration, and place-based investment.

2.2. From Theory to Practice: Challenges in S3 Implementation

The smart specialisation strategy was conceived as a place-based, bottom-up approach to innovation policy, but putting this into practice has proven challenging (Capello & Kroll, 2016). Early experiences showed that the entrepreneurial discovery process (EDP) must be continuous and iterative (Marinelli & Perianez, 2017), yet many regions struggle to sustain this engagement. Translating S3's dynamic, collaborative principles into real governance often clashes with institutional inertia and practical constraints. As recent literature notes, this gap between theory and implementation continues to limit the strategy's full potential (Esparza-Masana, 2022; Foray, 2017; Laranja et al., 2022; Molica et al., 2025; Polido et al., 2019; Reid & Maroulis, 2017).

A key barrier is weak collaboration among the quadruple helix actors—industry, government, academia, and civil society. These ties often remain fragmented, leading stakeholders to operate in silos that undermine trust and limit meaningful interaction. Limited stakeholder engagement beyond S3's initial design phase compounds the problem. While sustained participation is essential for effective discovery, many regions rely on narrow or symbolic consultation.

Inadequate monitoring mechanisms adds to the challenge. S3, as a policy-learning experiment, needs robust feedback systems to track strategic progress and assess the impact of funded projects. Misalignment between S3 priorities and available funding instruments further disrupts implementation. If R&D programs or investment schemes do not support identified priorities, strategies can stall. Institutional inertia also plays a role—networked governance demands new practices from public agencies, but entrenched bureaucracies often resist these changes.

Tackling these obstacles is crucial to making S3 work in practice. Here, social network analysis (SNA) offers valuable insights. It allows policymakers to map how actors interact within a regional innovation system and to identify hidden patterns, gaps, and bottlenecks (Calvo-Gallardo et al., 2022; Fernandez de Arroyabe et al., 2021; Rodríguez Ochoa et al., 2025). For instance, it can reveal isolated institutions or overcentralized “gatekeeper” nodes that hinder collaboration.

SNA is not just analytical; it is a diagnostic and policy-oriented tool. By exposing weak links and structural imbalances, it helps design targeted interventions, connecting disconnected actors, strengthening inter-organizational ties, or diversifying the governance base. Rather than replacing the EDP, SNA complements it by tracking the network's health and inclusiveness over time. It turns the abstract idea of innovation networks into actionable data, supporting more adaptive, evidence-based S3 implementation.

This approach aligns with recent calls for more sustainable, inclusive, and adaptive S3 ([European Committee of the Regions et al., 2023](#)), and contributes to the emerging “S3 2.0” agenda, which stresses challenge-oriented, systemic transformation through improved governance and policy alignment ([Foray, 2023](#)). Likewise, the OECD ([OECD, 2023](#)) emphasises stronger coordination and monitoring tools to support regions in industrial transition. In this context, SNA offers a practical method to diagnose structural gaps and support more responsive, evidence-based S3 implementation.

In this context, Aragón is well suited to examine these challenges. As a “moderate innovator” in the EU’s 2023 Regional Innovation Scoreboard ([Hobza et al., 2023](#)), it shares traits with many other European regions: a strong industrial base, active rural sectors, and a diverse institutional landscape ([Aragón Government, 2025](#)). These characteristics make it a representative case for studying the barriers and opportunities in S3 implementation.

2.3. The Case of Aragon: Innovation Ecosystem and Strategic Priorities

Aragón offers a timely and illustrative case of a regional innovation ecosystem under a modern smart specialisation strategy. According to the Spanish National Statistics Institute, the region’s R&D spending rose to 1.16% of GDP in 2023—its highest level since 2003—surpassing previous peaks in 2008–2010. While this marks significant progress, it remains below the EU average (2.2%) and the 3% target. Employment in R&D also reached a record 13.2%, closely aligned with the national figure of 13.3%, and up from 12.6% in 2010.

Aragón combines a solid economic base with favourable demographics. With 1.35 million residents (2.8% of Spain’s population), the region contributes 3.1% to national GDP, with a GDP per capita of EUR 31,051. Its S3 Aragón 2021–2027 strategy focuses on digitalisation, sustainability, and industry-linked services, identifying key domains such as Energy, Advanced Technologies, Agri-Food, and Health and Wellbeing. It adopts a more collaborative governance model aligned with the UN Sustainable Development Goals and introduces improved monitoring to support adaptive policy ([Aragón Government, 2024](#)).

However, implementation challenges persist. The region’s industrial share of gross value added dropped from 22.4% in 2000 to 17.8% in 2019, while services rose from 58.3% to 66%. Many companies struggle to find funding aligned with their technological needs, and collaboration between large companies and R&D centres remains limited. The innovation ecosystem includes many scientific and technical actors, but this diversity has not translated into a coherent, coordinated R&D offering.

Fragmentation is evident in the low number of collaborative regional projects and the absence of tools to effectively connect companies, researchers, and technology providers. Nearly 60% of organisations report not receiving public R&D support, especially in rural areas, revealing weak outreach and gaps in technology transfer. These issues call for more targeted, coordinated interventions to unlock the region’s innovation potential.

Aragón’s context reflects the broader landscape of many mid-sized European regions. As a “Moderate Innovator” in the EU Regional Innovation Scoreboard ([Hobza et al., 2023](#)), it blends a strong industrial base with extensive rural areas and an emerging R&D system. At the same time, it brings unique assets. It leads in renewable energy, which now accounts for over 80% of electricity generation ([Red Eléctrica, 2024](#)), and its rising R&D investment signals growing political and institutional commitment. The region also engages actively in the S3 Community of Practice and related EU networks, using peer learning to refine its approach ([European Commission, 2025](#)).

This combination of shared challenges and distinctive momentum makes Aragón a valuable case study. Its experience offers relevant lessons for designing and implementing smart specialisation strategies in comparable regions across Europe.

2.4. Research Questions

Recent literature on RIS3 and S3 has provided a range of qualitative and quantitative insights into the dynamics of innovation at a regional level (Balland et al., 2019; Calvo-Gallardo et al., 2022). However, several critical gaps remain. First, few studies provide multi-level, long-term benchmarks of competitive public project networks. Most focus on static snapshots rather than the evolution of innovation ecosystems across regional, national, and European scales. Second, although SNA is gaining traction, it is rarely applied in RIS contexts with an eye toward feedback loops for policy adaptation. Finally, few analyses link empirical network metrics to specific policy interventions, leaving a disconnect between theory and actionable strategies.

This study addresses these gaps by applying SNA to public R&D project networks in Aragón. Focusing on projects funded through regional, national, and European calls from 2014 to 2023, and classified by S3 2021–2027 specialisation areas, the research generates multi-level benchmarks and actionable insights to inform regional policy. The following research questions guide the analysis:

- RQ1: How do the features of competitive public project networks from 2014 to 2023 within the S3 2021–2027 specialisation areas reveal the structure and dynamics of Aragón’s innovation ecosystem?

This question maps Aragón’s innovation network over a decade, addressing the first research gap. By analysing participation, cohesion and centrality metrics, the study reveals how stakeholders interact—highlighting well-connected clusters, isolated nodes, and structural vulnerabilities. These findings offer a systemic view of local strengths and weaknesses and assess whether current strategies effectively mobilise the region’s capacities.

- RQ2: What roles do key entities play in knowledge transfer within these specialisation areas, and how do their centrality positions influence the dynamism of Aragón’s regional innovation ecosystem?

While prior work often neglects the influence of individual actors, this question examines how central entities shape innovation dynamics. Using degree, betweenness, closeness, and eigenvector centrality measures, we identify which actors act as bridges and knowledge hubs. These insights link structural network data to knowledge flows and support more targeted, evidence-based policy interventions.

- RQ3: How can the analysis of the last decade innovation networks involving non-Aragonese partners enhance Aragón’s innovation policies and strengthen its position in a targeted specialisation area?

A novel aspect of this work, compared to our earlier study (Rodríguez Ochoa et al., 2025), is the detailed analysis of participation metrics by both specialisation area and type of entity for projects funded under H2020 and Horizon Europe (EU Framework Program calls) during 2014–2023, specifically excluding Aragonese partners. These projects account for 78% of the region’s total innovation funding.

By benchmarking Aragón’s networks against European examples, we highlight opportunities to enhance local practices through transnational collaboration. This analysis explores how cross-border partnerships contribute to innovation and offers clear, transferable lessons to improve regional policy and strategic alignment.

3. Materials and Methods

3.1. Data

The present study examines the innovation networks established in the Aragón region over the past decade, categorising them according to different specialisation areas. To achieve this, our analysis builds upon the dataset presented in our previous work (Rodríguez Ochoa et al., 2025), which encompasses all competitive public projects at regional, national, and European levels that involved at least one partner from the Aragón region during the period 2014–2023.

In this study, we further refined the dataset by labelling each project according to the specialisation areas defined in the Aragón Smart Specialisation Strategy 2021–2027 (Aragón Government, 2024). The strategy document was also examined in detail to incorporate its identified bottlenecks into our analysis.

Additionally, to establish a benchmark for the Aragonese innovation ecosystem, our current research extends the previous approach by incorporating data from all projects funded under the Horizon 2020 and Horizon Europe programs (Framework Program projects) during the same period (2014–2023), excluding those projects that involved Aragonese partners. This comparative analysis facilitates a broader understanding of regional performance relative to the European context.

3.1.1. Data Sources, Collection and Preparation

All funding programs examined in this study are based on competitive public calls, in which multiple independent entities submit proposals to secure financing, with selection decisions made according to the merits of their projects and alignment with predefined objectives. This competitive process is distinct from nominative funding, where projects are directly financed without a competitive evaluation—often earmarked for specific entities or initiatives without the need for proposal submission and review. Based on this framework, the primary data sources for this study are shown in Figure 1.



Figure 1. Project data sources considered in the analysis.

All the calls considered in the study are specified in our previous research study (Rodríguez Ochoa et al., 2025). Moreover, Appendix A includes additional information on the different databases consulted and the reasoning behind choosing these datasets.

To ensure the accuracy and relevance of the data to Aragón's innovation ecosystem, several rigorous processing steps were taken, as shown in Figure 2:

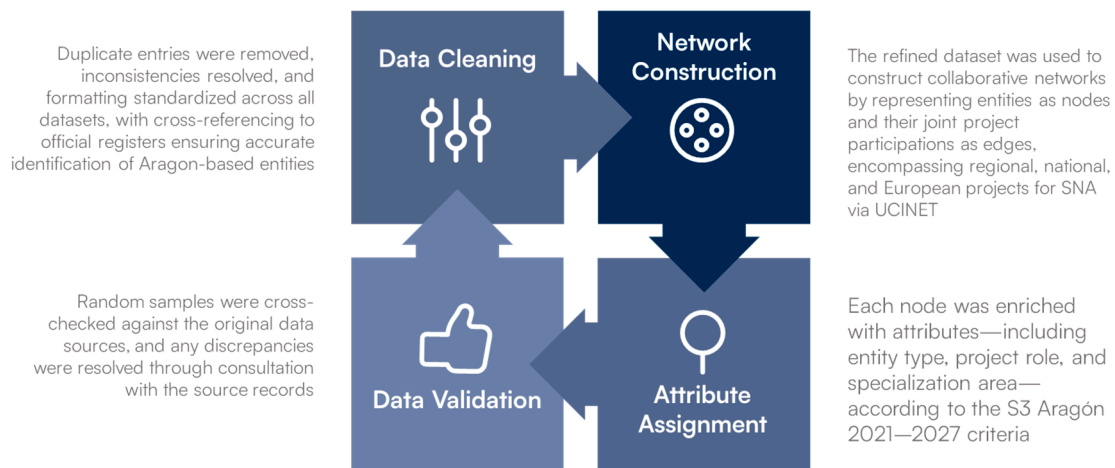


Figure 2. Data treatment process.

These systematic steps ensured that the data prepared for analysis is both precise and relevant, thereby allowing our evaluation of Aragón’s innovation ecosystem and the provision of policy recommendations to address the bottlenecks identified in the S3 2021–2027 and improve the positioning of the region at European level in targeted specialisation areas.

3.1.2. Entities and Projects Attributes

In order to classify the participating entities based on their inherent characteristics and primary activities, we have defined six distinct categories:

- **Public Sector (PUB):** This category comprises governmental authorities at the national, regional, and local levels, along with energy agencies.
- **Higher Education Institutions (HES):** This category mainly consists of universities that are actively engaged in both teaching and research.
- **Research Organizations (REC):** This group includes two main types: publicly funded national research centres and predominantly private, non-profit research and technology organizations.
- **Private Companies:** This category is further divided into:
 - **Large Private Companies (PRC):** Enterprises that exceed the criteria for small and medium-sized companies.
 - **Micro, Small, and Medium-sized Enterprises (PRC-SME):** Businesses classified as micro, small, or medium according to the standards set by EU Recommendation 2003/361 (European Commission, 2003).
- **Others (OTH):** This group encompasses sector-specific associations and may also include certain research institutes organised as associations.

With respect to the roles of entities within projects, each consortium is managed by a coordinator, while the other members are considered participants. This classification does not distinguish between full partners, who sign the grant agreement, and third parties that have a legal or financial link to a beneficiary, as the number of such third parties is negligible and will not be analysed separately in this study.

In a novel extension to our previous research, each entity participation within the network has been assigned to one of the specialisation areas appearing in Figure 3 (as stated in the Aragón S3 2021–2027) to delineate the thematic focus of the entities involved:

Aragón S3 2021–27 specialization areas

Aerospace	Energy and Green Fuels	Health and Wellbeing
Agri-Food and Circular	Hydrogen	Security and Defence
Economy	Cultural and Creative Industries	Advanced Technologies
Water	Artificial Intelligence	
Climate Change	Sustainable Mobility	

Additional specialization areas

Biodiversity	Basic Science	Governance and Business Development
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Figure 3. Specialisation areas considered in the study.

The inclusion of Biodiversity, Basic Science, and Governance and Business Development ensures comprehensive coverage of all projects while preserving thematic coherence. Notably, each project is categorised under a single, most-representative area. This single-categorisation approach simplifies the analysis by maintaining focus on the dominant thematic element—for instance, assigning AI developments within the water sector to the AI category underlines the technological emphasis, which is consistent with the objectives of thematic network analysis.

Furthermore, acknowledging that partners contribute to projects in varying ways—ranging from receiving significant funding to participating solely in an advisory capacity without financial remuneration—each project participation was assigned a monetary value. Specifically, this value corresponds to the funding granted by the funding authority, the budget allocated when acting as a subcontractor, or a nominal amount of EUR 1 when no financial compensation is provided. This approach enables the weighting of inter-entity links within the networks according to the expected contribution of each partner to the project.

3.2. Methodology

Social network analysis is a widely used approach to examine innovation ecosystems, but prior evaluations often focused narrowly on European Framework Program projects, neglecting multi-level networks and failing to weight collaborative ties by funding (Abreu & Nunes, 2020; Calvo-Gallardo et al., 2021, 2022; Fernandez de Arroyabe et al., 2021; Morisson et al., 2020; Rodríguez Ochoa et al., 2023). This is problematic, given that evidence links stronger network connectivity to improved innovation outcomes and less fragmentation, underscoring the need for a more comprehensive network perspective.

To address these gaps, the present study employs SNA, using UCINET 6 software (Borgatti et al., 2002), to analyse Aragón's innovation ecosystem, targeting its first two research questions on network structure and actor interactions. The methodology constructs a two-mode network linking diverse entities (e.g., businesses, universities, research centres) to the portfolio of regional, national, and European innovation projects they participate in, with each entity–project tie weighted by the amount of funding involved.

This bipartite network is then projected into a one-mode collaboration network among entities, where the weight of each inter-entity link reflects the total funding those entities jointly secured in shared projects, indicating the strength of their collaboration. This choice reflects the availability and consistency of funding data across regional, national, and European levels. However, we acknowledge that funding levels may not always correlate

directly with the depth or quality of collaboration. For example, a participant may receive substantial funding for tasks that require limited coordination with other partners, while another may play a central integrative role in a smaller project. Although imperfect, the funding-based weighting provides a useful approximation of involvement, especially when applied consistently across network layers. We mitigate this limitation by focusing not solely on tie strength, but also on network-level patterns of participation, centrality, and cohesion across different funding sources and policy scales.

Finally, each node (entity) is enriched with attributes such as organisation type, geographic location, smart specialisation domain, and project role (coordinator or partner), allowing analysis of network patterns across different categories of actors.

Using this enriched network representation, the study assesses overall network cohesion through global metrics and computes node-level centrality measures to identify influential actors and potential structural gaps (Borgatti et al., 2023; Wasserman & Faust, 1994).

Cohesion metrics provide insight into the overall interconnectedness of the network—a critical factor for enabling knowledge exchange and leveraging specialized research capabilities within the regional innovation ecosystem. The following metrics were evaluated:

- **Average Degree:** This is computed as the mean number of direct connections per node, serving as an indicator of the network's overall activity.
- **H-Index:** This metric identifies the maximum number of nodes that each have at least that number of connections, offering a robust measure of network cohesion while mitigating the impact of outliers.
- **Density:** Calculated by dividing the total observed connections (or sum of weighted ties) by the maximum possible connections, density provides a measure of how tightly interlinked the network is.
- **Connectedness:** This indicator assesses the extent of both direct and indirect linkages among nodes, typically expressed as the average number of steps required to connect any two nodes. Higher connectedness is generally associated with more efficient knowledge sharing.
- **Closure:** This metric measures the tendency of nodes to form complete triads—if node A is connected to node B and node B is connected to node C, closure is achieved when node A is also directly connected to node C.
- **Diameter:** Representing the longest of all the shortest paths between any two connected nodes, the diameter signifies the overall spatial extent of the network.
- **Average Tie Strength Between Groups:** This is determined by calculating the mean of weighted connections between nodes with different attributes, providing insights into the strength of inter-group linkages.

On the other hand, centrality metrics offer a more detailed understanding of the influence and connectivity of individual entities within the network. These measures are crucial for identifying key players and potential bottlenecks, thus informing decisions on resource allocation and stakeholder engagement. The centrality metrics considered comprise:

- **Degree:** In a weighted network, this is the sum of all tie values associated with a node, indicating the immediate likelihood of that node receiving information or resources.
- **Closeness:** Calculated as the average of the shortest path lengths from a node to all other nodes, closeness reflects how centrally located a node is and its potential to quickly interact with other entities.
- **Eigenvector:** This metric assesses a node's prominence by assigning scores based on the influence of its neighbouring nodes, meaning that nodes connected to highly influential neighbours attain higher eigenvector values.

- **Betweenness:** This measures how frequently a node appears on the shortest paths between pairs of other nodes, indicating its role as a bridge or broker in facilitating information flows across the network.

Together, these metrics offer a structured framework for evaluating both the global structure and the individual roles within the network, thereby providing a deeper understanding of how collaborative projects and key entities drive the regional innovation ecosystem.

4. Analysis and Results

Following the previous methodology, this section systematically dissects the innovation ecosystem through three analytical lenses. First, the participation analysis quantifies the engagement across projects by assessing the number of projects, unique participants, and funding allocations in each specialisation area, offering insights into regional dynamics and their comparison with EU benchmarks not considering Aragonese partners. Next, the cohesion properties analysis examines the structural integrity of the networks, using metrics such as average degree, density, or average tie strength to reveal how tightly entities are connected and the overall network integration. Finally, the centrality properties analysis evaluates the strategic importance of individual actors by applying measures like degree, closeness, eigenvector, and betweenness centrality, thereby identifying key hubs and bridging nodes. Together, these three degrees of analysis provide a comprehensive understanding of the collaborative patterns and structural dynamics shaping the region's innovation landscape.

To structure the results and provide analytical clarity, each of the three research questions is addressed by a specific layer of the analysis. The participation, cohesion, and centrality properties of Aragón's innovation networks—examined at regional, national, and European levels—respond directly to RQ1, by identifying who participates, how collaborations form, and how actors are positioned. RQ2 is addressed through a closer analysis of the collaboration profiles of key regional entities, highlighting how these actors are embedded across S3 domains. Finally, RQ3 is tackled by benchmarking Aragón's network structures against European consortia that do not include Aragonese partners, identifying external models of connectivity that may inform future regional policy interventions.

Furthermore, to provide a representative and detailed analysis, we selected two specialisation areas: Advanced Technologies and Security and Defence. The former includes projects related to information and communication technologies, industrial digitalisation, robotics, and materials research, and it represents a consolidated, mature field. In contrast, Security and Defence is examined as an emerging field. Analysing these two areas offers critical insights into both the established and evolving dimensions of Aragón's smart specialisation strategy.

4.1. Participation Analysis

Prior to analysing the different specialisation areas of the Aragonese ecosystem and its EU Framework Programme projects benchmark, it is useful to show the main participation figures from both networks. Thus, Table 1 shows the main figures from the Aragonese ecosystem networks addressing different geographic scope levels, as gathered in a previous study (Rodríguez Ochoa et al., 2025).

Moreover, in order to compare this ecosystem with a benchmark, Table 2 shows the figures of the projects funded by the Horizon 2020 and Horizon Europe programs, without considering those projects with Aragonese partners, during the same period (2014–2023).

Table 1. Data from the projects analysed during the period 2014–2023.

Calls Scope	Number of Projects	Number of Unique Participants	Number of Participations	Total Funding Received	% Over the Network's Total Funding
Europe	781	6712	13,134	4,325,344,254 €	85.95%
Spain	1126	1118	3163	669,228,934 €	13.30%
Aragon	557	932	1828	38,047,347 €	0.76%
Totals	2464	8233	18,125	5,032,620,536 €	100%

Table 2. H2020 and HE projects data during the period 2014–2023.

Call	Number of Projects	Number of Unique Participants	Number of Participations	Total Funding Received
Horizon 2020	26,050	4422	90,924	EUR 43,380,073,636
Horizon Europe	7883	2092	28,514	EUR 13,984,876,983
Totals	33,933	5741	119,438	EUR 57,364,950,619

The Aragonese innovation ecosystem comprises 2464 projects, engaging 8233 unique participants in a total of 18,125 participations, securing a total funding of EUR 5.03 billion. The EU Framework Programme projects (excluding those with Aragonese partners) during the same period includes 33,933 projects, involving 5741 unique participants with 119,438 participations, receiving a total funding of EUR 57.36 billion.

Although the total number of analysed projects in the EU Framework Programme is more than 14 times higher than in Aragón, and the funding received by EU projects is nearly 12 times greater than that of the entire Aragonese innovation ecosystem, it is particularly striking that the number of unique participants in the Aragonese innovation ecosystem (8233) is higher than the one of the EU Framework Programme projects (5741) over the same period.

Following analysis of the general participation data, Table 3 shows the main participation figures by specialisation area.

Table 3. Aragonese ecosystem 2014–2023 data by specialisation area.

Specialisation Area	Number of Projects	Number of Unique Entities	Number of Participations	Funding (EUR)	Funding Ratio
Advanced Technologies (ICT and Industry)	588	1556	2733	651,873,468	12.95%
Aerospace	28	90	131	64,056,985	1.27%
Agri-Food and Circular Economy	549	1820	3119	583,558,623	11.60%
Artificial Intelligence	58	349	439	119,652,202	2.38%
Basic Science	45	557	1346	476,349,361	9.47%
Biodiversity	9	63	67	13,377,498	0.27%
Climate Change	32	239	280	85,364,513	1.70%
Cultural and Creative Industries and Sectors	145	525	663	104,837,172	2.08%
Energy and Green Fuels	384	2139	3501	1,089,423,533	21.65%
Governance and Business Development	122	816	1080	212,884,319	4.23%
Health and Wellbeing	227	1322	2352	947,280,853	18.82%
Hydrogen	59	425	570	207,819,617	4.13%

Table 3. *Cont.*

Specialisation Area	Number of Projects	Number of Unique Entities	Number of Participations	Funding (EUR)	Funding Ratio
Security and Defence	51	213	266	108,145,546	2.15%
Sustainable Mobility	101	793	1086	266,935,962	5.30%
Water	66	385	492	101,060,884	2.01%

The Energy and Green Fuels specialisation area emerges as the most prominent network within the Aragonese innovation ecosystem, representing 20% of all projects and accounting for over 21% of total funding. This is followed by the Health and Wellbeing sector, which secures nearly 19% of total funding, reinforcing its significance within the region's research and innovation landscape.

Notably, a small number of specialisation areas dominate the funding distribution, with Energy, Health, Agri-Food, and Advanced Technologies collectively receiving over 65% of the ecosystem's total funding. In contrast, Hydrogen, Artificial Intelligence, Security and Defence, and Water collectively account for only 10% of both the number of projects and total funding allocation.

Table 4 shows the classification by specialisation area of the projects from the EU Framework Program funded during the same period, as a comparison reference.

Table 4. EU Framework Program non-Aragonese projects 2014–2023 data by specialisation area.

Specialisation Area	Number of Projects	Number of Unique Entities	Number of Participations	Funding (EUR)	Funding Ratio
Advanced Technologies (ICT and Industry)	1201	1511	7424	3,302,408,124	5.76%
Aerospace	1038	533	2843	1,805,289,385	3.15%
Agri-Food and Circular Economy	1700	1761	9215	3,393,800,576	5.92%
Artificial Intelligence	1136	983	4529	2,211,205,017	3.85%
Basic Science	7303	1260	15,986	9,848,358,667	17.17%
Biodiversity	802	464	1678	848,833,754	1.48%
Climate Change	1198	885	4651	2,057,411,880	3.59%
Cultural and Creative Industries and Sectors	2744	1010	5648	2,372,315,836	4.14%
Energy and Green Fuels	3646	3041	19,362	9,208,524,239	16.05%
Governance and Business Development	2403	1918	9723	3,741,761,063	6.52%
Health and Wellbeing	7946	1859	23,848	12,870,814,775	22.44%
Hydrogen	291	535	1373	670,392,089	1.17%
Security and Defence	930	969	4379	1,730,321,499	3.02%
Sustainable Mobility	828	1332	5355	2,015,109,985	3.51%
Water	767	982	3424	1,288,403,730	2.25%

Reflecting broader European trends, Health and Wellbeing and Energy and Green Fuels dominate Aragón's innovation ecosystem, each receiving around 40% of total funding—mirroring their weight at the EU level.

By contrast, Basic Science (notably particle physics) and Governance and Business Development are more prominent across Europe, driven by the EU's strategic emphasis on commercializing research outcomes.

Advanced Technologies, Agri-Food, and Circular Economy represent about 10% of EU funding but exceed 20% in Aragón, indicating a stronger regional focus. Security and

Defence, along with Water, show similar funding levels in both contexts, suggesting aligned policy agendas.

Notably, Hydrogen receives four times more proportional funding in Aragón than across Europe (4% vs. 1%). This highlights Aragón's strategic bet on hydrogen, underpinned by dedicated infrastructure and innovation investments.

4.1.1. Key Entities' Collaboration Analysis

To assess the collaborative dynamics of the Aragonese innovation ecosystem, this section analyses internal collaborations among four key Aragonese institutions, as identified in a previous research study (Rodríguez Ochoa et al., 2025), as well as their partnerships with major non-Aragonese entities participating in the ecosystem. Prior to analysing the results found, it is important to begin with a short description of these four key entities:

UNIZAR (University of Zaragoza, HES)—This is the leading higher education institution in Aragón and a key player in the regional innovation ecosystem. It plays a significant role in research and development, securing substantial public funding for projects at the regional, national, and European levels. UNIZAR acts as a major hub for knowledge generation, technology transfer, and collaboration with both public and private entities.

CIRCE (Research Centre for Energy Resources and Consumption, REC)—This is a private technology centre specialising in energy, digitalization and sustainability. It has a strong presence in European research programs and serves as a key bridge between academia and industry, supporting innovation in the energy transition and decarbonisation efforts.

ITA (Aragón Institute of Technology, REC)—This is a public research institute focused on applied technological development and industrial innovation. It provides support to businesses through R&D projects, technology transfer, and advanced engineering solutions, playing a strategic role in boosting Aragón's industrial competitiveness and digital transformation.

AITIIP (AITIIP Foundation, REC)—This is a private technology centre specializing in advanced manufacturing, materials science, and circular economy solutions in the plastics sector. It supports industrial innovation by developing cutting-edge technologies in robotics, 3D printing, and sustainable materials, collaborating closely with companies in Aragón and across Europe.

Building on this information, the following tables provide a detailed overview of two key aspects of the Aragonese innovation ecosystem. Table 5 illustrates the intensity of collaboration among the region's key institutions, highlighting the extent to which they engage in joint research and innovation initiatives. Table 6 shows the main external partners contributing to the ecosystem, assessing their levels of integration with Aragón's leading research and innovation actors. This analysis offers valuable insights into both the internal dynamics of regional cooperation and the broader network of external collaborations that shape the region's innovation landscape.

Table 5. Number of common projects between the Aragonese innovation ecosystem key entities.

	UNIZAR	CIRCE	ITA	AITIIP
UNIZAR	126	4	2	1
CIRCE	4	114	2	5
ITA	2	2	59	2
AITIIP	1	5	2	35
Total collaborations	7	11	6	8
Collaboration ratio	5.56%	9.65%	10.17%	22.86%

Table 6. Collaborations between the non-Aragonese entities of the ecosystem and the key entities.

#	Entity	Country	Entity Type	Projects in the Ecosystem	Collaborations with the Ecosystem's Key Entities			
					UNIZAR	CIRCE	ITA	AITIIP
1	AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS	ES	REC	89	25	5	3	1
2	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	DE	REC	79	14	4	11	4
3	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS (CERTH)	EL	REC	58	4	22	2	0
4	FUNDACION TECNALIA RESEARCH & INNOVATION	ES	REC	56	6	5	3	0
5	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	FR	REC	52	19	0	5	2
6	CONSIGLIO NAZIONALE DELLE RICERCHE	IT	REC	45	15	1	1	1
7	UNIVERSITAT POLITECNICA DE VALENCIA	ES	HES	43	5	1	2	0
8	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	FR	REC	42	9	6	4	2
9	RINA CONSULTING SPA	IT	PRC	40	0	38	1	1
10	UNIVERSIDAD POLITECNICA DE MADRID	ES	HES	38	5	0	2	1
11	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	FI	REC	31	7	4	2	1
12	DANMARKS TEKNISKE UNIVERSITET	DK	HES	30	11	1	2	0
13	TECHNISCHE UNIVERSITEIT DELFT	NL	HES	30	13	3	3	2
14	ALMA MATER STUDIORUM—UNIVERSITA DI BOLOGNA	IT	HES	29	9	0	1	0
15	FUNDACION CARTIF	ES	REC	28	0	9	3	0
16	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO	NL	REC	28	7	2	2	1
17	FUNDACIO EURECAT	ES	REC	26	2	0	2	0
18	RISE RESEARCH INSTITUTES OF SWEDEN AB	SE	REC	26	4	1	7	2
19	ASOCIACION DE INVESTIGACION METALURGICA DEL NOROESTE	ES	REC	23	0	1	8	4
20	INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE	FR	REC	23	6	0	1	0
Totals				816	161	103	65	22

As Table 5 shows, the key players within Aragón's innovation ecosystem engage in limited collaboration among themselves. However, among the few joint initiatives that do exist, private research centres have the highest number of projects in common with the four key entities, with CIRCE involved in 11 shared projects and AITIIP in eight. Notably, five of these projects involve direct collaboration between CIRCE and AITIIP. In relative terms, nearly one-fourth of the projects in which AITIIP participates are carried out in partnership with the other three key entities, highlighting this organisation's greater dependence on these ties for its research activities.

Conversely, public innovation institutions appear less inclined to collaborate with the other key players. A possible explanation for this trend is the existence of specific regional funding programs that promote direct partnerships between public research organizations and private companies. These targeted calls may reduce the need for public entities to engage in knowledge exchange with other R&D agents, as they already have dedicated mechanisms for fostering innovation through industry collaborations.

On the other hand, Table 6 highlights that the principal non-Aragonese participants in the ecosystem are predominantly European research centres and universities. Notably, seven of these entities are based in Spain, with the Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC) emerging as the most integrated external partner, participating in 89 projects. Following CSIC, Fundación Tecnalia Research & Innovation and Universitat Politècnica de Valencia have significant involvement, engaging in 56 and 43 projects, respectively.

Beyond Spanish institutions, several prominent research centres stand out for their collaborations with Aragonese entities. Fraunhofer from Germany has participated in 79 projects, primarily collaborating with UNIZAR and ITA. The Greek Research Centre CERTH has engaged in 58 projects, mainly in partnership with CIRCE. Additionally, the French National Centre for Scientific Research (CNRS) and the Italian National Research Council (CNR) have been frequent collaborators with UNIZAR, participating in 52 and 45 projects, respectively. The French Alternative Energies and Atomic Energy Commission (CEA) has also been notably active, collaborating mainly with UNIZAR and CIRCE across 42 projects.

Among the top 20 collaborators, RINA Consulting S.p.A. from Italy is the sole corporate entity, participating in 40 projects, with a notable 38 collaborations involving CIRCE.

Within the Aragonese institutions, UNIZAR distinguishes itself by engaging in 161 collaborative projects with major non-Aragonese participants. CIRCE follows with 103 such collaborations. ITA, while less involved than UNIZAR and CIRCE, has still participated in 65 projects with all of the top 20 non-Aragonese entities. In contrast, AITIIP focuses on more specialised partnerships within its area of expertise, accounting for 22 collaborations with these leading external participants.

4.1.2. Analysis by Entity Type

Tables 7 and 8 illustrate the distribution of funding and participations among different types of entities within the Aragonese innovation ecosystem, while Tables 9 and 10 provide a comparative benchmark from the European Union Framework Program projects (Horizon 2020 and Horizon Europe) spanning the period 2014–2023, excluding those projects with Aragonese entities. The comparison offers critical insights into the alignment of the Aragonese ecosystem with broader European trends, highlighting structural strengths and potential gaps in collaboration patterns.

The distribution of funding across entity types in the Aragonese ecosystem (Table 7) reveals distinct patterns based on specialisation areas. Research organizations (REC) emerge as the most prominent funding recipients across nearly all domains, receiving on average 27.67% of total funding. This trend aligns with their role as key enablers of innovation,

particularly in research-intensive areas such as Basic Science (33.30%), Biodiversity (27.97%), and Climate Change (33.84%). Higher education institutions (HES) also secure substantial funding (20.17% overall), with their strongest presence in Basic Science (43.39%), Biodiversity (48.81%), and Artificial Intelligence (29.01%).

Table 7. Funding distribution by entity type in the Aragonese ecosystem.

Specialisation Area	HES	OTH	PRC	PRC-SME	PUB	REC
Advanced Technologies (ICT and Industry)	17.77%	5.09%	29.87%	21.59%	0.74%	24.94%
Aerospace	4.69%	1.58%	55.83%	12.80%	0.13%	24.98%
Agri-Food and Circular Economy	20.22%	7.93%	14.93%	25.89%	2.43%	28.59%
Artificial Intelligence	29.01%	3.88%	16.83%	22.42%	1.09%	26.77%
Basic Science	43.39%	3.38%	13.03%	6.81%	0.09%	33.30%
Biodiversity	48.81%	2.00%	8.20%	12.72%	0.30%	27.97%
Climate Change	20.36%	7.06%	15.06%	16.13%	7.55%	33.84%
Cultural and Creative Industries and Sectors	16.76%	17.14%	20.34%	12.17%	18.81%	14.79%
Energy and Green Fuels	12.79%	6.09%	30.71%	21.75%	2.79%	25.88%
Governance and Business Development	26.45%	13.17%	10.88%	13.48%	6.57%	29.44%
Health and Wellbeing	24.28%	6.67%	7.06%	9.35%	19.50%	33.14%
Hydrogen	5.81%	3.24%	47.39%	21.47%	3.13%	18.96%
Security and Defence	13.24%	4.04%	26.84%	21.26%	11.50%	23.12%
Sustainable Mobility	10.69%	8.62%	29.72%	19.32%	10.75%	20.89%
Water	14.60%	7.70%	11.32%	12.51%	24.77%	29.10%
Total average	20.17%	6.46%	21.42%	17.36%	6.93%	27.67%

Table 8. Participation distribution by entity type in the Aragonese ecosystem.

Specialisation Area	HES	OTH	PRC	PRC-SME	PUB	REC
Advanced Technologies (ICT and Industry)	15.59%	12.48%	18.26%	32.16%	1.72%	19.80%
Aerospace	9.92%	9.16%	22.14%	20.61%	2.29%	35.88%
Agri-Food and Circular Economy	16.54%	16.83%	11.89%	31.42%	4.10%	19.20%
Artificial Intelligence	22.10%	9.57%	15.03%	32.35%	2.28%	18.68%
Basic Science	39.90%	2.53%	19.61%	13.15%	2.01%	22.81%
Biodiversity	25.37%	19.40%	8.96%	13.43%	10.45%	22.39%
Climate Change	16.07%	15.00%	12.50%	18.93%	12.86%	24.64%
Cultural and Creative Industries and Sectors	14.78%	27.00%	5.58%	11.76%	30.17%	10.71%
Energy and Green Fuels	12.88%	10.48%	26.91%	24.79%	4.71%	20.22%
Governance and Business Development	22.69%	19.17%	7.87%	15.00%	13.61%	21.67%
Health and Wellbeing	28.57%	10.25%	8.93%	15.56%	12.50%	24.19%
Hydrogen	10.18%	9.30%	27.02%	23.33%	4.74%	25.44%
Security and Defence	14.29%	9.77%	19.17%	26.32%	11.28%	19.17%
Sustainable Mobility	10.22%	14.00%	27.44%	20.17%	11.88%	16.30%
Water	12.40%	20.12%	9.96%	20.93%	14.23%	22.36%
Total average	18.68%	12.87%	17.09%	23.53%	7.28%	20.55%

In contrast, private companies (PRC) and SMEs (PRC-SME) exhibit higher participation in technology-driven sectors, with notable funding shares in Aerospace (55.83% PRC, 12.80% PRC-SME), Hydrogen (47.39% PRC, 21.47% PRC-SME), and Sustainable Mobility (29.72% PRC, 19.32% PRC-SME). These figures suggest a concentration of industrial innovation in high-tech and applied research fields, particularly those with strong market applications.

Public sector entities (PUB) display a more limited role, accounting for only 6.93% of total funding. Their involvement is slightly higher in governance-related fields, such as Water (24.77%), Cultural and Creative Industries (18.81%), and Health and Wellbeing (19.50%), likely reflecting public policy priorities and regulatory-driven research agendas.

Examining participation patterns (Table 8) reinforces these observations, demonstrating the degree to which different entity types engage in collaborative project networks. The research and higher education sectors again dominate, with HES (18.68%) and REC (20.55%) showing strong engagement across all domains. Notably, HES participation peaks in Basic Science (39.90%), Artificial Intelligence (22.10%), and Health and Wellbeing (28.57%), suggesting these areas benefit from strong academic involvement.

Private sector engagement follows a distinct pattern, with PRC (17.09%) and PRC-SME (23.53%) demonstrating a broader footprint in Advanced Technologies (ICT and Industry) (18.26% PRC, 32.16% PRC-SME), Hydrogen (27.02% PRC, 23.33% PRC-SME), and Security and Defence (19.17% PRC, 26.32% PRC-SME). These figures highlight the relevance of SMEs in the Aragonese ecosystem, positioning themselves as the entity type with most participation, even if, regarding funding, large companies and research centres and universities allocate greater amounts.

The comparison with the EU Framework Program (Tables 9 and 10) provides further insight. In the broader European landscape, HES and REC exhibit stronger dominance, both in participation (50.84% HES and 27.93% REC) and funding allocation (51.93% HES and 31.70% REC). This highlights a greater reliance on academic and research institutions at the European level, where private sector participation in high-risk research remains lower. Conversely, PRC entities receive relatively higher funding in the Aragonese ecosystem (21.42% PRC versus 8.86% PRC in EU projects), indicating that industry-led innovation plays a more prominent role at the regional level.

Table 9. Funding distribution by entity type in the EU Framework Program projects.

Specialisation Area	HES	OTH	PRC	PRC-SME	PUB	REC
Advanced Technologies (ICT and Industry)	38.74%	2.20%	15.91%	6.53%	0.18%	36.44%
Aerospace	37.42%	0.64%	24.28%	1.09%	0.10%	36.47%
Agri-Food and Circular Economy	44.65%	5.15%	4.24%	7.62%	2.33%	36.02%
Artificial Intelligence	52.86%	1.67%	9.52%	5.16%	0.31%	30.48%
Basic Science	65.19%	0.58%	2.39%	1.09%	0.13%	30.62%
Biodiversity	64.23%	0.90%	0.41%	0.44%	3.57%	30.46%
Climate Change	53.37%	1.78%	3.94%	1.73%	2.36%	36.82%
Cultural and Creative Industries and Sectors	80.32%	0.64%	1.94%	1.83%	0.73%	14.55%
Energy and Green Fuels	32.78%	3.33%	12.76%	7.24%	2.11%	41.78%
Governance and Business Development	47.88%	8.77%	11.51%	5.06%	3.11%	23.67%
Health and Wellbeing	63.61%	0.99%	3.06%	2.18%	3.12%	27.04%
Hydrogen	24.99%	1.64%	25.82%	15.59%	0.86%	31.09%
Security and Defence	46.47%	1.09%	13.50%	7.30%	1.17%	30.49%
Sustainable Mobility	31.14%	5.67%	24.33%	5.82%	4.34%	28.70%
Water	45.59%	3.01%	3.10%	4.12%	3.70%	40.48%
Total average	51.93%	2.37%	8.06%	4.07%	1.88%	31.70%

Another takeaway from this analysis is the higher funding allocation of the Aragonese public sector and intermediary organizations (OTH) compared to EU benchmarks. Public institutions at the EU level secure an average of 2.53% of funding, compared to 6.93% in Aragón, suggesting a stronger regulatory and governance role at the regional level. Similarly, intermediary organisations (OTH) exhibit three times more involvement regionally

(6.46%) than at the European scale (2.37%). The significant number of sectoral clusters in the Aragón region, coupled with their active participation in specific national funding calls essential for financial sustainability, may account for these figures. For instance, in 2023, the Ministry of Industry and Tourism allocated EUR 10.6 million to support 59 projects from Aragonese business associations through the Program for Supporting Innovative Business Clusters. This made Aragón the second-highest recipient of such funds among Spanish regions (El Periódico, 2023).

Table 10. Participation distribution by entity type in the EU Framework Program projects.

Specialisation Area	HES	OTH	PRC	PRC-SME	PUB	REC
Advanced Technologies (ICT and Industry)	40.06%	2.21%	18.64%	10.18%	0.54%	28.37%
Aerospace	49.70%	1.30%	10.52%	2.78%	0.56%	35.14%
Agri-Food and Circular Economy	42.09%	7.93%	5.85%	9.63%	3.20%	31.30%
Artificial Intelligence	49.17%	1.77%	11.81%	7.49%	0.79%	28.97%
Basic Science	63.79%	0.86%	4.14%	2.35%	0.31%	28.55%
Biodiversity	61.80%	1.67%	0.60%	0.89%	4.23%	30.81%
Climate Change	53.82%	2.21%	2.49%	2.56%	3.31%	35.61%
Cultural and Creative Industries and Sectors	75.51%	1.31%	2.58%	2.78%	2.14%	15.67%
Energy and Green Fuels	35.94%	5.61%	14.80%	10.77%	2.86%	30.02%
Governance and Business Development	50.35%	6.57%	6.64%	6.88%	3.89%	25.66%
Health and Wellbeing	62.11%	1.72%	4.65%	3.64%	3.17%	24.70%
Hydrogen	29.06%	4.44%	19.81%	13.47%	1.68%	31.54%
Security and Defence	43.41%	1.67%	14.75%	9.45%	2.56%	28.16%
Sustainable Mobility	32.64%	7.47%	22.40%	7.95%	4.99%	24.55%
Water	44.29%	4.93%	4.61%	5.23%	4.41%	36.53%
Total average	50.84%	3.51%	8.86%	6.33%	2.53%	27.93%

4.1.3. Advanced Technologies Analysis

Tables 11–13 show the top 10 entities with the highest amounts of funding achieved, participation in projects and coordinated initiatives, respectively in the Aragonese ecosystem and the specialisation area of Advanced Technologies, while Tables 14–16 show the same information for the benchmark from the European Union Framework Program.

Table 11. Top 10 entities by funding achievement in Advanced Technologies within the Aragonese ecosystem.

#	Entity Name	Type	Country	Funding Achieved (EUR)
1	INSTITUTO TECNOLÓGICO DE ARAGÓN	REC	ES	22,335,621
2	UNIVERSIDAD DE ZARAGOZA	HES	ES	19,668,424
3	BSH ELECTRODOMESTICOS ESPAÑA SA	PRC	ES	18,935,696
4	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM	REC	BE	12,591,788
5	FUNDACION AITIIP	REC	ES	10,533,492
6	FRAUNHOFER GESELLSCHAFT ZUR FÖRDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	9,930,329
7	INFINEON TECHNOLOGIES AG	PRC	DE	7,520,076
8	FUNDACION CIRCE CENTRO DE INVESTIGACION DE RECURSOS Y CONSUMOS ENERGÉTICOS	REC	ES	7,335,004
9	TELTRONIC, S.A.	PRC	ES	6,743,792
10	SOCIEDAD ANÓNIMA INDUSTRIAS CELULOSA ARAGONESA	PRC	ES	6,691,261

ITA emerges as the leading entity in Aragón in terms of funding secured, receiving EUR 22.3M, followed closely by the UNIZAR (EUR 19.6M) and BSH Electrodomésticos España (EUR 18.9M). These figures highlight the strong presence of both research institutions (REC) and higher education establishments (HES) in attracting project financing, with the private sector also playing a prominent role. Other notable recipients include AITIIP (EUR 10.5M) and CIRCE (EUR 7.3M), reinforcing the strategic position of private research centres in securing competitive project funding.

Table 12. Top 10 entities by number of projects in Advanced Technologies within the Aragonese ecosystem.

#	Entity Name	Type	Country	Number of Projects
1	INSTITUTO TECNOLOGICO DE ARAGON	REC	ES	154
2	UNIVERSIDAD DE ZARAGOZA	HES	ES	106
3	FUNDACION AITIIP	REC	ES	36
4	ASOCIACION CLUSTER DE AUTOMOCION DE ARAGON	OTH	ES	25
5	ASOCIACION ESPANOLA DE FABRICANTES EXPORTADORES DE MAQUINARIA PARA CONSTRUCCION, OBRAS PUBLICAS Y MINERIA	OTH	ES	25
6	ASOCIACION LOGISTICA INNOVADORA DE ARAGON	OTH	ES	22
7	AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS	REC	ES	21
8	FUNDACION CIRCE CENTRO DE INVESTIGACION DE RECURSOS Y CONSUMOS ENERGETICOS	REC	ES	18
9	BSH ELECTRODOMESTICOS ESPANA SA	PRC	ES	17
10	CLUSTER DE EMPRESAS DE TECNOLOGÍAS DE LA INFORMACIÓN, ELECTRÓNICA Y TELECOMUNICACIONES DE ARAGÓN	OTH	ES	17

In terms of the number of participations, ITA again leads with 154 projects, followed by UNIZAR (106 projects). AITIIP is the most active private technology centre, with 36 project participations, while clusters and sector associations such as CAAR (automotive cluster, 25 projects) and ALIA (logistics cluster, 22 projects) demonstrate the role of intermediary organizations (OTH) in fostering industrial collaboration.

Table 13. Top 10 entities by number of coordination actions in Advanced Technologies within the Aragonese ecosystem.

#	Entity Name	Type	Country	Coordination Actions
1	ASOCIACION ESPANOLA DE FABRICANTES EXPORTADORES DE MAQUINARIA PARA CONSTRUCCION, OBRAS PUBLICAS Y MINERIA	OTH	ES	23
2	ASOCIACION CLUSTER DE AUTOMOCION DE ARAGON	OTH	ES	22
3	ASOCIACION LOGISTICA INNOVADORA DE ARAGON	OTH	ES	14
4	BSH ELECTRODOMESTICOS ESPANA SA	PRC	ES	13
5	CLUSTER DE EMPRESAS DE TECNOLOGÍAS DE LA INFORMACIÓN, ELECTRÓNICA Y TELECOMUNICACIONES DE ARAGÓN	OTH	ES	12
6	Cluster de la Salud de Aragón (ARAHEALTH)	OTH	ES	11
7	ASOCIACION CLUSTER PARA EL USO EFICIENTE DEL AGUA-ZINNAE	OTH	ES	10
8	SOCIEDAD ANONIMA INDUSTRIAS CELULOSA ARAGONESA	PRC	ES	10
9	CLUSTER ESPAÑOL DE PRODUCTORES DE GANADO PORCINO	OTH	ES	9
10	INSTITUTO TECNOLOGICO DE ARAGON	REC	ES	8

Coordination actions provide a measure of leadership within collaborative projects. As shown in Table 13, OTH organisations dominate coordination efforts, with sector clusters taking the top three positions, due to their role as promoters in Spanish national calls for innovative companies' clusters. The presence large companies among the top coordinators highlights how industry-led initiatives play an integral role in project leadership. Interestingly, ITA (eight coordination actions) ranks lower in coordination than in funding and participation, suggesting a preference for participation over project leadership.

Table 14. Top 10 entities by funding achievement in Advanced Technologies within the EU Framework Program projects.

#	Entity Name	Type	Country	Funding Achieved (EUR)
1	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	147,192,091
2	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM	REC	BE	116,664,074
3	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	REC	FR	110,988,667
4	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	REC	FR	58,115,888
5	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	REC	FI	53,547,020
6	CHALMERS TEKNISKA HOGSKOLA AB	HES	SE	53,044,483
7	TECHNISCHE UNIVERSITEIT EINDHOVEN	HES	NL	36,136,424
8	BARCELONA SUPERCOMPUTING CENTER CENTRO NACIONAL DE SUPERCOMPUTACION	REC	ES	35,193,681
9	THE UNIVERSITY OF MANCHESTER	HES	UK	31,789,091
10	FUNDACION TECNALIA RESEARCH & INNOVATION	REC	ES	29,740,228

As shown in Table 14, at the European level, the dominance of major research and technology institutions is evident. Fraunhofer (EUR 147.1M, Germany), Interuniversity Microelectronics Centre (IMEC, EUR 116.6M, Belgium), and CEA (EUR 110.9M, France) lead in total funding received. Notably, Spanish representation is seen in Barcelona Supercomputing Center (EUR 35.1M) and Tcnalia (EUR 29.7M), highlighting Spain's competitive position in supercomputing and applied research.

Table 15. Top 10 entities by number of projects in Advanced Technologies within the EU Framework Program projects.

#	Entity Name	Type	Country	Number of Projects
1	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	199
2	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	REC	FR	113
3	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	REC	FR	113
4	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM	REC	BE	95
5	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	REC	FI	69
6	CHALMERS TEKNISKA HOGSKOLA AB	HES	SE	63
7	POLITECNICO DI MILANO	HES	IT	54
8	TECHNISCHE UNIVERSITEIT EINDHOVEN	HES	NL	53
9	IDRYMA TECHNOLOGIAS KAI EREVNAS	REC	EL	52
10	CONSIGLIO NAZIONALE DELLE RICERCHE	REC	IT	52

When compared to the top Aragonese recipients, it is evident that regional actors operate on a significantly smaller financial scale. ITA, Aragón's highest-funded entity (EUR 22.3M), would rank outside the top 10 at the European level, demonstrating the funding gap between regional and EU-wide research networks.

Table 15 shows that Fraunhofer again leads in project participation (199 projects), followed by CEA (113 projects) and CNRS (113 projects). IMEC (95 projects) and Teknologian Tutkimuskeskus VTT (69 projects, Finland) further exemplify the role of major European research institutes in shaping technological advancement.

By comparison, the highest-ranked Aragonese entity, ITA (154 projects), would be third on the European list, demonstrating strong regional engagement despite funding disparities. UNIZAR (106 projects) also shows significant activity, reinforcing its role in Aragón's innovation landscape.

Finally, Table 16 shows that European coordination efforts are also led by research organisations, with Fraunhofer (23 actions), CNRS (22 actions), and CEA (21 actions) demonstrating their leadership.

Table 16. Top 10 entities by number of coordination actions in Advanced Technologies within the EU Framework Program projects.

#	Entity Name	Type	Country	Coordination Actions
1	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	23
2	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	REC	FR	22
3	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	REC	FR	21
4	EREVNITIKO PANEPISTIMIAKO INSTITOUTO SYSTIMATON EPIKOINONION KAI YPOLOGISTON	REC	EL	18
5	CHALMERS TEKNISKA HOGSKOLA AB	HES	SE	18
6	INTERUNIVERSITAIR MICRO-ELECTRONICA CENTRUM	REC	BE	16
7	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY	REC	FI	14
8	UNIVERSITEIT GENT	HES	BE	12
9	TECHNISCHE UNIVERSITEIT EINDHOVEN	HES	NL	12
10	DANMARKS TEKNISKE UNIVERSITET	HES	DK	12

To summarise, a notable contrast emerges when comparing Aragón's innovation ecosystem to the broader European Union framework. In Aragón, clusters and industry organizations predominantly lead coordination efforts, whereas at the EU level, public research institutions primarily assume project leadership roles.

4.1.4. Security and Defence Analysis

In contrast to the well-established Advanced Technologies sector, the Security and Defence domain in Aragón is currently in an emergent phase. Following the same format as the previous analysis, Tables 17–19 present the top 10 entities in Aragón in this specialisation area, ranked by funding achieved, number of projects, and coordination actions.

The highest-funded entity in Aragón's Security and Defence sector is INSTALAZA, a local private company (PRC) specializing in defence technologies, with a total funding of EUR 6.3 million. This stresses the role of industry-led innovation in this sector, a trend further reinforced by Equipos Móviles de Campaña ARPA (ARPA) (PRC-SME, EUR 2.45 million), another local specialized company ranked fourth after Fraunhofer (REC, EUR 4.6 million, Germany) and the French public entity Département des Hautes-Pyrénées

(PUB, EUR 3.02 million, France). Among the main Aragonese key players, only UNIZAR is present, occupying the seventh position with EUR 2.14 million.

Table 17. Top 10 entities by funding achievement in Security and Defence within the Aragonese ecosystem.

#	Entity Name	Type	Country	Funding Achieved (EUR)
1	INSTALAZA, S.A.	PRC	ES	6,310,358
2	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	4,607,408
3	Département des Hautes-Pyrénées	PUB	FR	3,020,339
4	EQUIPOS MOVILES DE CAMPAÑA ARPA SA	PRC-SME	ES	2,455,290
5	UNIVERZA V LJUBLJANI	HES	SI	2,215,374
6	STIFTELSEN NORGES GEOTEKNISKE INSTITUTT	REC	NO	2,173,000
7	UNIVERSIDAD DE ZARAGOZA	HES	ES	2,141,064
8	TOTALFORSVARETS FORSKNINGSINSTITUT	REC	SE	2,074,721
9	TDW GESELLSCHAFT FUR VERTEIDIGUNGSTECHNISCHE WIRKSYSTEME MIT BESCHRANKTE RHAFTUNG	PRC	DE	2,000,842
10	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	REC	FR	1,991,516

Table 18. Top 10 entities by number of projects in Security and Defence within the Aragonese ecosystem.

#	Entity Name	Type	Country	Number of Projects
1	INSTALAZA, S.A.	PRC	ES	8
2	UNIVERSIDAD DE ZARAGOZA	HES	ES	6
3	INSTITUTO TECNOLOGICO DE ARAGON	REC	ES	5
4	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	4
5	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON	REC	ES	3
6	Agrupación Europea de Cooperación Territorial Espacio Portalet	OTH	ES	2
7	ASOCIACION AGRARIA DE JOVENES AGRICULTORES ALTO ARAGON	OTH	ES	2
8	ASOCIACION GENERAL DE PRODUCTORES DE MAIZ EN ESPAÑA—INSTITUTO AGRICOLA Y GANADERO	OTH	ES	2
9	ASOCIACION NACIONAL DE MAQUINARIA AGROPECUARIA, FORESTAL Y DE ESPACIOS VERDES	OTH	ES	2
10	CENTRO DE INVESTIGACION ECOLOGICA Y APLICACIONES FORESTALES	REC	ES	2

INSTALAZA also leads in project participation with eight projects, confirming its dominance in the regional ecosystem. UNIZAR (six projects) and ITA (five projects) further emphasize the role of academic and applied research centres.

Interestingly, multiple sectoral organizations (OTH) participate in two projects each, including the Agrupación Europea de Cooperación Territorial Espacio Portalet, ASAJA Alto Aragón, and Asociación Nacional de Maquinaria Agropecuaria, Forestal y de Espacios Verdes. This suggests a diverse range of actors contributing to security-related innovation, including those focused on agriculture, logistics, and environmental risk management.

INSTALAZA also emerges as the leading coordinator, heading six projects, reinforcing its strategic role in leading regional security initiatives (Table 17). Notably, various SMEs

and specialised technology firms also take on leadership roles but with only a low number of projects.

Unlike Advanced Technologies specialisation area, where research institutions played a stronger coordination role, in Security and Defence, industry and public-private collaborations dominate.

Table 19. Top 10 entities by number of coordination actions in Security and Defence within the Aragonese ecosystem.

#	Entity Name	Type	Country	Coordination Actions
1	INSTALAZA, S.A.	PRC	ES	6
2	CONSORCIO PARA LA GESTIÓN, CONSERVACIÓN Y EXPLOTACIÓN DEL TÚNEL DE BIELSA-ARAGNOUET Y SUS ACCESOS	OTH	ES	2
3	FUNDACION PARA EL DESARROLLO DE LAS NUEVAS TECNOLOGIAS DEL HIDROGENO EN ARAGON	REC	ES	2
4	IMPLASER 99 SLL	PRC-SME	ES	2
5	NTT DATA SPAIN, SL	PRC	ES	2
6	RADE TECNOLOGIAS SL	PRC	ES	2
7	TITAN FIRE SYSTEM SL	PRC-SME	ES	2
8	ALISYS DIGITAL SL	PRC-SME	ES	1
9	ASOCIACION ESPANOLA DE FABRICANTES EXPORTADORES DE MAQUINARIA PARA CONSTRUCCION, OBRAS PUBLICAS Y MINERIA	OTH	ES	1
10	Cámara Oficial de Comercio, Industria, Servicios y Navegación de Oviedo	PUB	ES	1

Tables 20–22 present the top 10 entities in the EU Framework program Security and Defence projects based on the same three indicators.

Table 20. Top 10 entities by funding achievement in Security and Defence within the EU Framework Program projects.

#	Entity Name	Type	Country	Funding Achieved (EUR)
1	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	45,187,957
2	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	REC	FR	36,696,308
3	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS	REC	EL	32,897,693
4	KATHOLIEKE UNIVERSITEIT LEUVEN	HES	BE	28,458,117
5	DEUTSCHES ZENTRUM FUR LUFT—UND RAUMFAHRT EV	REC	DE	23,393,434
6	ENGINEERING—INGEGNERIA INFORMATICA SPA	PRC	IT	21,568,866
7	AIT AUSTRIAN INSTITUTE OF TECHNOLOGY GMBH	REC	AT	20,893,723
8	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	REC	FR	20,326,342
9	EREVNITIKO PANEPISTIMIAKO INSTITOUTO SYSTIMATON EPIKOINONION KAI YPOLOGISTON	REC	EL	19,582,945
10	TECHNISCHE UNIVERSITEIT DELFT	HES	NL	18,829,692

At the European level, Fraunhofer (EUR 45.1M) leads security research funding, followed by CEA (EUR 36.7M) and CERTH (EUR 32.9M). The top 10 entities are dominated by research institutions and universities, which collectively secure the majority of EU funding.

By comparison, Aragonese entities receive significantly lower funding. The highest-funded Aragonese actor, INSTALAZA (EUR 6.3M), would not rank among the top 10 at the European level. This suggests regional industry-driven security innovation lacks integration into large-scale EU consortia, potentially limiting funding access and knowledge exchange.

Table 21. Top 10 entities by number of projects in Security and Defence within the EU Framework Program projects.

#	Entity Name	Type	Country	Number of Projects
1	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	91
2	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS	REC	EL	65
3	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES	REC	FR	64
4	KATHOLIEKE UNIVERSITEIT LEUVEN	HES	BE	57
5	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO	REC	NL	46
6	ENGINEERING—INGEGNERIA INFORMATICA SPA	PRC	IT	45
7	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	REC	FR	43
8	ATOS SPAIN SA	PRC	ES	40
9	ATOS IT SOLUTIONS AND SERVICES IBERIA SL	PRC	ES	40
10	TECHNISCHE UNIVERSITEIT DELFT	HES	NL	39

Fraunhofer again leads in project participation (91 projects), followed by CERTH (65 projects) and CEA (64 projects). The Katholieke Universiteit Leuven (KU Leuven, HES, 57 projects, Belgium) and Netherlands Organization for Applied Scientific Research (REC, 46 projects, Netherlands) further highlight the strong role of research and applied science institutions in European security research. It is relevant to mention that two Spanish branches of a French company, ATOS Spain and ATOS IT Solutions and Services Iberia, are in the top 10, with 40 projects.

Table 22. Top 10 entities by number of coordination actions in Security and Defence within the EU Framework Program projects.

#	Entity Name	Type	Country	Coordination Actions
1	ENGINEERING—INGEGNERIA INFORMATICA SPA	PRC	IT	15
2	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS	REC	EL	14
3	KATHOLIEKE UNIVERSITEIT LEUVEN	HES	BE	11
4	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	DE	10
5	EREVNITIKO PANEPISTIMIAKO INSTITOUTO SYSTIMATON EPIKOINONION KAI YPOLOGISTON	REC	EL	10
6	ATOS SPAIN SA	PRC	ES	10
7	CONSIGLIO NAZIONALE DELLE RICERCHE	REC	IT	9
8	IDRYMA TECHNOLOGIAS KAI EREVNAS	REC	EL	9
9	FUNDACION TECNALIA RESEARCH & INNOVATION	REC	ES	8
10	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	REC	FR	7

Again, Aragon's leading entity, INSTALAZA, would rank outside the top 10 at the European level, reinforcing the need for greater integration of regional actors into EU-funded security projects.

Similarly to what happens in the Aragonese ecosystem, a large company, Engineering—Ingegneria Informatica S.p.A. (PRC, Italy, 15 coordination actions), is leading the coordination of projects. It is followed by CERTH (14 actions), KU Leuven (11 actions) and Fraunhofer (10 actions).

As can be seen, the Security and Defence specialisation area in Aragón displays a unique industry-led model, with local specialised companies playing a predominant role in project leadership and coordination. However, the relative lack of engagement with European research institutions and large-scale EU security initiatives suggests untapped potential.

4.2. Cohesion Properties

Table 23 displays the cohesion properties of the project networks classified by specialisation area, allowing for a comparative assessment of structural characteristics, thus providing insights into both the overall network connectivity and the local clustering characteristics that emerge in each area.

Specialisation areas vary widely in network size. Energy and Green Fuels hosts one of the largest networks with 2139 unique entities, followed by Agri-Food and Circular Economy (1820), and Advanced Technologies (1556). At the other end, Aerospace includes just 90 entities, and Security and Defence totals 213. Tie counts also differ sharply. Health and Wellbeing stands out with 43,392 ties among 1322 nodes—indicating a dense web of interactions—while Energy and Green Fuels also shows high connectivity with 27,544 ties. In smaller networks like Aerospace and Security and Defence, the number of ties is lower (682 and 718, respectively), although they may still be tightly knit due to their limited size. Below, the different metrics across specialisation areas are explained.

Table 23. Specialisation area projects' networks cohesion properties.

Specialisation Area	Number of Nodes	Number of Ties	Avg. Degree	H-Index	Density	Connectedness	Closure	Diameter
Advanced Technologies	1556	12,284	7.895	43	0.0051	0.2292	0.6849	8
Aerospace	90	682	7.578	15	0.0851	0.5363	0.7378	6
Agri-Food and Circular Economy	1820	18,112	9.952	53	0.0055	0.3347	0.5966	7
Artificial Intelligence	349	2816	8.069	21	0.0232	0.2707	0.8110	6
Climate Change	239	3488	14.594	42	0.0613	0.2819	0.9032	4
Cultural and Creative Industries and Sectors	525	2346	4.469	17	0.0085	0.0238	0.9029	6
Energy and Green Fuels	2139	27,544	12.877	54	0.0060	0.3825	0.4087	7
Health and Wellbeing	1322	43,392	32.823	153	0.0248	0.3923	0.8459	8
Hydrogen	425	3596	8.461	31	0.0200	0.2877	0.6950	7
Security and Defence	213	718	3.371	15	0.0159	0.0247	0.9537	3
Sustainable Mobility	793	12,876	16.237	45	0.0205	0.3311	0.6406	6
Water	385	3928	10.203	42	0.0266	0.1935	0.8952	6

Average degree—the mean number of connections per node—reflects interaction intensity. Health and Wellbeing leads with 32.82, suggesting highly active collaboration. Sustainable Mobility (16.24) and Climate Change (14.59) also show strong linkages. In contrast, Cultural and Creative Industries (4.47) and Security and Defence (3.37) reflect sparser interactions.

The H-index, measuring both size and connectivity, further confirms these dynamics. Health and Wellbeing tops the list with 153, followed by Energy and Green Fuels (54), and Agri-Food and Circular Economy (53). Aerospace and Security and Defence, with H-indices of 15, show limited cohesion and reach.

Network density—the share of realized vs. possible ties—remains low in large networks like Advanced Technologies (0.0051) and Agri-Food and Circular Economy (0.0055), which is typical for large systems. Aerospace, however, displays the highest density (0.0851), consistent with tighter connections in smaller networks.

Connectedness, or how easily nodes can reach each other, varies widely. Aerospace scores 0.5363, suggesting strong overall linkage. Cultural and Creative Industries (0.0238) and Security and Defence (0.0247) show weak overall integration, hinting at isolated clusters.

Closure, which tracks tightly knit subgroups, is high in several networks. Security and Defence shows near-complete local clustering (0.9537), with similarly strong closure in Climate Change (0.9032) and Cultural and Creative Industries (0.9029). Advanced Technologies (0.6849) and Sustainable Mobility (0.6406) have moderate clustering.

Diameter—the longest shortest path between any two nodes—indicates network reach. Security and Defence (3) and Climate Change (4) offer compact paths for knowledge flow, while larger networks like Advanced Technologies and Health and Wellbeing (both 8) reflect longer communication chains.

Focusing on two priority areas, Advanced Technologies and Security and Defence reveal contrasting cohesion patterns. Advanced Technologies spans 1556 nodes and 12,284 ties, with an average degree of 7.89 and low density (0.0051), typical of large systems. Its moderate closure (0.6849), connectedness (0.2292), and high diameter (8) suggest moderate clustering but a dispersed overall structure.

In contrast, Security and Defence has fewer nodes (213) and ties (718) but much higher density (0.0159) and exceptional closure (0.9537). Its clusters are tightly knit but isolated, as shown by low connectedness (0.0247), lower average degree (3.37), and short diameter (3). While Advanced Technologies supports broader, distributed collaboration, Security and Defence reflects intense but siloed local networks.

Following the global cohesion analysis, Tables 24 and 25 illustrate the average tie strengths between different actor types within the Advanced Technologies and Security and Defence networks. Tie strength is a proxy for the level of collaboration, with higher values indicating stronger financial or strategic connections.

Table 24. Average tie strengths between the different entity types in the Advanced Technologies projects' network.

	PUB	HES	REC	PRC	PRC-SME	OTH
PUB	7.799×10^8	5.599×10^8	9.577×10^8	1.895×10^8	9.996×10^7	2.637×10^8
HES	5.599×10^8	1.297×10^9	2.194×10^9	6.762×10^8	2.841×10^8	5.075×10^8
REC	9.577×10^8	2.194×10^9	5.021×10^9	1.184×10^9	7.170×10^8	8.298×10^8
PRC	1.895×10^8	6.762×10^8	1.184×10^9	1.245×10^9	3.176×10^8	2.836×10^8
PRC-SME	9.996×10^7	2.841×10^8	7.170×10^8	3.176×10^8	1.338×10^8	1.465×10^8
OTH	2.637×10^8	5.075×10^8	8.298×10^8	2.836×10^8	1.465×10^8	4.777×10^8

In the Advanced Technologies network, tie strengths generally fall in the order of 10^8 , with research entities (REC) displaying particularly robust internal collaboration—as evidenced by a REC–REC tie strength of 5.021×10^9 —and strong crossties with both PUB and HES actors. In contrast, collaborations involving companies (PRC and PRC-SME) tend to be weaker, suggesting that their financial or strategic linkages are less pronounced.

Table 25. Average tie strengths between the different entity types in the Security and Defence projects' network.

	PUB	HES	REC	PRC	PRC-SME	OTH
PUB	6.633×10^9	8.853×10^9	1.042×10^{10}	7.371×10^8	5.121×10^8	3.692×10^9
HES	8.853×10^9	8.800×10^9	1.063×10^{10}	1.519×10^9	1.677×10^9	1.360×10^9
REC	1.042×10^{10}	1.063×10^{10}	6.311×10^9	9.230×10^8	1.482×10^9	1.593×10^9
PRC	7.371×10^8	1.519×10^9	9.230×10^8	2.068×10^9	9.297×10^8	9.505×10^7
PRC-SME	5.121×10^8	1.677×10^9	1.482×10^9	9.297×10^8	1.186×10^9	4.926×10^7
OTH	3.692×10^9	1.360×10^9	1.593×10^9	9.505×10^7	4.926×10^7	6.316×10^{-2}

Conversely, the Security and Defence network exhibits markedly higher tie strength values, predominantly in the order of 10^9 to 10^{10} . In this network, the interactions among core actor types—specifically between PUB, HES and REC organizations—are particularly intense (with PUB–REC and HES–REC ties reaching approximately 1.04×10^{10} and 1.06×10^{10} , respectively), indicating a very high level of collaborative integration. However, the OTH category in Security and Defence shows an anomalously low self-tie strength (6.316×10^{-2}), suggesting that actors classified in this group may play a peripheral role in the network's collaborative dynamics.

The integration of the cohesion metrics with the tie strength analyses reveals complementary insights into the collaborative dynamics of both Advanced Technologies and Security and Defence networks.

4.3. Centrality Properties

To deepen the understanding of network influence and structural positioning, this section analyses the centrality metrics of project networks classified by specialisation area. Table 26 presents the average centrality metrics for the different specialisation area networks. These measures quantify the influence and connectivity of entities within each network, providing a way to assess which fields exhibit the most centralised, highly connected, or influential actors.

Table 26. Average centrality properties of the entities' networks by specialisation area.

Specialisation Area	Average Degree	Average Closeness	Average Eigenvector	Average Betweenness
Advanced Technologies	8.864×10^{11}	1.197×10^4	3.655×10^{-3}	414.7
Aerospace	1.664×10^{12}	4.162×10^2	1.284×10^{-2}	39.80
Agri-Food and Circular Economy	4.430×10^{11}	1.164×10^4	5.495×10^{-4}	674.4
Artificial Intelligence	9.923×10^{11}	2.060×10^3	1.370×10^{-2}	94.74
Climate Change	2.005×10^{12}	1.001×10^3	2.363×10^{-2}	39.83
Cultural and Creative Industries and Sectors	1.715×10^{11}	3.608×10^3	1.991×10^{-3}	7.349
Energy and Green Fuels	1.551×10^{12}	1.285×10^4	2.577×10^{-3}	735.2
Health and Wellbeing	7.525×10^{12}	8.656×10^3	2.887×10^{-3}	456.3
Hydrogen	9.975×10^{11}	2.764×10^3	2.981×10^{-3}	113.1
Security and Defence	5.507×10^{11}	8.346×10^2	1.394×10^{-2}	1.127
Sustainable Mobility	1.310×10^{12}	4.343×10^3	1.762×10^{-3}	186.4
Water	3.230×10^{11}	2.377×10^3	1.100×10^{-2}	67.14

The average degree—a measure of direct ties per actor—is highest in the Health and Wellbeing network (7.525×10^{12}), signalling dense interconnections. At the other end, Cultural and Creative Industries and Sectors has the lowest value (1.715×10^{11}), indicating limited direct engagement among actors.

Average closeness centrality, which reflects how quickly actors can reach others in the network, is highest in Energy and Green Fuels (1.285×10^4) and Advanced Technologies (1.197×10^4). In contrast, Aerospace (4.162×10^2) and Security and Defence (8.346×10^2) show significantly lower accessibility.

For eigenvector centrality—indicating influence through connections to important nodes—Climate Change leads (2.363×10^{-2}), while Agri-Food and Circular Economy trails behind (5.495×10^{-4}), suggesting weaker influential linkages.

Average betweenness centrality, which captures how often actors serve as bridges, is highest in Energy and Green Fuels (735.2) and Agri-Food and Circular Economy (674.4). Security and Defence (1.127) and Cultural and Creative Industries (7.349) rank lowest, showing fewer intermediary roles.

These metrics highlight diverse structural dynamics and influence patterns across specialisation areas.

Focusing on the paper's two priority areas, Advanced Technologies shows strong interconnectivity, with high average degree (8.864×10^{11}) and closeness (1.197×10^4), confirming a broad, accessible network. Security and Defence, by comparison, has a lower average degree (5.507×10^{11}) and closeness (8.346×10^2), pointing to a sparser, less accessible structure.

Notably, Security and Defence has a higher eigenvector centrality (1.394×10^{-2} vs. 3.655×10^{-3}), meaning its key actors are linked to other influential nodes. However, its betweenness centrality is much lower (1.127 vs. 414.7), suggesting fewer bridging roles compared to Advanced Technologies.

In short, while Advanced Technologies benefits from distributed collaboration and strategic brokers, Security and Defence depends more on a few influential nodes. These differences offer clear policy insights for strengthening innovation and connectivity in each domain.

5. Discussion

Addressing the first research question, our analysis of participation, cohesion, and centrality metrics reveals key dynamics within Aragón's innovation ecosystem. A few specialisation areas dominate project activity and funding. Energy and Green Fuels leads with over 20% of projects and 21% of funding, followed by Health and Wellbeing at 19%. Along with Agri-Food and Advanced Technologies, these four areas capture two-thirds of the total funding, suggesting that established networks—led by research centres, universities, and major companies—are better aligned with regional, national, and EU funding mechanisms (Foray, 2016). However, this concentration raises concerns about over-specialisation and path dependency, which could hinder adaptation as priorities or technologies shift (Isaksen & Trippl, 2016).

In contrast, emerging areas such as Hydrogen, Artificial Intelligence, Security and Defence, and Water together receive only 10% of total projects and funding. This is surprising given recent strategic emphasis and investment in Hydrogen and Water (Aragón Digital, 2025; Aragón Noticias, 2024). The low uptake points to barriers in funding access, readiness, or collaboration—echoing previously identified misalignments between S3 goals and funding instruments (Esparza-Masana, 2022).

From an RIS3 perspective, this imbalance signals coordination failures (Rossoni et al., 2024), since insufficient alignment among actors leaves many potential partnerships unexplored. Some strategic fields struggle to gain traction due to weak engagement during S3 design or limited actor alignment. These findings support the need for tailored approaches: one-size-fits-all policies fail to address structural disparities across specialisation areas.

Network cohesion metrics deepen this view. Larger networks like Health and Well-being and Energy and Green Fuels show many nodes and ties but low density—many connections remain untapped. Smaller domains like Aerospace show higher density and stronger local ties but risk becoming siloed, as seen in fragmented metropolitan RIS contexts (Tödtling & Trippel, 2005). High closure values across several networks also point to tight internal clusters, although they are not always well integrated externally.

Centrality analysis shows mature areas are driven by multiple influential actors—typically large research centres and businesses—while smaller domains depend on a few key players, which may restrict diversity and the discovery of new opportunities. These insights reinforce the need for specialisation-specific policy tools: some areas need better outreach; others require stronger inter-cluster bridges (Tödtling & Trippel, 2005).

In Advanced Technologies, ITA leads in funding and participation, with UNIZAR playing a central academic role. AITIIP and CIRCE bridge research and industry, while BSH represents strong private engagement. Cluster organisations often coordinate consortia but tend to act as collaborators rather than leaders, highlighting opportunities to strengthen local leadership in major initiatives.

In contrast, the Security and Defence network is industry-led. Firms like INSTALAZA and ARPA drive activity, with limited public research involvement beyond UNIZAR and ITA. Collaboration is sparse and skewed towards public entities, creating a closed network with weak SME integration. As in other regions with organisational thinness (Isaksen & Trippel, 2016), targeted policies—such as public–private consortia and SME support schemes—are needed to open access and strengthen links to larger European networks.

The analysis of the second research question shows that key institutions like UNIZAR, CIRCE, ITA, and AITIIP play central—but uneven—roles in Aragón’s innovation ecosystem. While they mobilize research, drive industrial engagement, and form collaborative networks, direct partnerships between them remain rare. For example, CIRCE and AITIIP collaborated on only five projects over the past decade, and their links to ITA and UNIZAR are even more limited. Funding models that favour public–private ties may discourage broader R&D collaboration, reinforcing silos despite a dense local innovation landscape—an issue observed in other regions (Isaksen et al., 2022). As a result, ITA and CIRCE rarely combine their applied research strengths, missing key opportunities for collaboration. This reflects the weak inter-organisational ties often noted in the literature on quadruple helix actors (Foray, 2014).

Externally, these institutions act as Aragón’s gateways to global networks. UNIZAR partners with top-tier universities and research centres like CNRS and CEA, while CIRCE links local firms to international leaders in energy and digitalisation (e.g., Fraunhofer, CERTH). ITA, although less connected abroad, has joined over 60 projects with global players. AITIIP focuses mainly on regional partnerships in advanced manufacturing and plastics, reinforcing its local anchoring.

This work builds on our earlier research (Rodríguez Ochoa et al., 2025), enriching the theoretical perspective by expanding the focus from social capital to structural dynamics within Aragón’s innovation network. Network metrics reveal strong ties in mature domains like Energy and Green Fuels, but fragmented structures in emerging ones like Security and Defence. These differences confirm that one-size-fits-all strategies fall short and that place-based policies are needed to unlock underused potential (Demblans et al., 2020; Molica et al., 2025; Suedekum, 2025).

Missed opportunities are especially evident in underrepresented areas like Water and Hydrogen, which have seen significant public investment but remain weakly positioned in competitive funding. Targeted policies could bridge these gaps by connecting regional capabilities with market opportunities (Asheim, 2019; McCann, 2023).

At the same time, our analysis highlights the evolving nature of entrepreneurial discovery in Aragón's transition from the 2014–2020 RIS3 to the 2021–2027 framework. We also observe that, while many entities participate in multiple projects, only a few act as consistent bridges between local and European innovation spaces. This raises concerns about the inclusiveness of Aragón's entrepreneurial discovery process (EDP), which requires broad engagement and strong external ties to remain dynamic (Gheorghiu et al., 2016; Laranja et al., 2022; Marinelli & Perianez, 2017; Szerb et al., 2020). Multi-level SNA reveals sector-specific gaps that limit discovery and suggests the need for integrative tools—like inclusive funding calls and consortium-building programs—to diversify participation and sustain learning (Karo et al., 2017; Szerb et al., 2020). Bringing in actors from outside Aragón helps local stakeholders tap frontier expertise and fresh ideas, boosting entrepreneurial discovery and keeping innovation paths adaptive and outward-looking.

These findings support the broader shift toward “S3 2.0,” which emphasizes sustainability, inclusiveness, and resilience (Buyukyazici, 2023; European Committee of the Regions et al., 2023; Foray, 2023). Well-connected areas like Energy and Green Fuels already embed environmental goals, while fragmented sectors lag behind. Metrics like high closure or uneven centrality can guide targeted action to strengthen underperforming areas (Arranz et al., 2022; Arranz & Arroyabe, 2023).

Inclusion also matters. Emerging domains like Security and Defence lack the actor density and bridging entities found in more mature sectors, echoing patterns in other developing regions (Yue et al., 2024). Broadening participation—from SMEs to civil society and local administrations—can enrich innovation processes and build agility (Torre, 2019). Collaborative calls that prioritise underrepresented actors could help bring more diverse knowledge into play.

Finally, resilience is now essential. Regions must anticipate economic or environmental shocks. Our SNA framework supports this by identifying over-dependence on single actors and enabling policy rebalancing. For instance, in Security and Defence, leadership is overly concentrated among a few firms. In contrast, in Advanced Technologies, the challenge lies in reducing central actor dominance and promoting cross-sector partnerships (Barbero et al., 2022; Janošec et al., 2024; McCann, 2023; Moujaes, 2024).

These insights align with the gaps flagged in Aragón's 2021–2027 S3 strategy: fragmented R&D efforts, limited inter-institutional collaboration, and insufficient public support. Despite the influence of major institutions, weak internal ties (as shown in Table 5) suggests that overlapping competencies and dispersed efforts may be diluting their overall collective impact (McPhillips, 2020). This fragmentation—combined with low outreach capacity and uneven access to funding—especially affects SMEs and peripheral areas. The fact that nearly 60% of local organisations report receiving no public R&D support highlights the need for stronger intermediary networks and more accessible innovation instruments (Rossoni et al., 2024).

The third research question expands the focus to both local and cross-border collaborations, exploring how external knowledge flows and transnational ties drive regional growth. By benchmarking Aragón's innovation ecosystem against large EU Framework Program projects without Aragonese partners, the study highlights how external actors—often brokers or gatekeepers—shape high-impact networks. Understanding why Aragonese entities are absent from these consortia can help policymakers connect the region to top-tier European R&D efforts. The analysis unfolds across three fronts: (i) comparing Aragón's ecosystem with major EU R&I projects lacking local involvement; (ii) generating policy recommendations from the structural insights in this study; and (iii) addressing S3 bottlenecks that hinder alignment between Aragón's innovation potential and long-term goals.

Our comparison spans 2464 projects in Aragón and 33,933 EU-funded projects (2014–2023). Despite receiving 12 times less funding (EUR 5.03B vs. EUR 57.36B), Aragón has more unique participants (8233 vs. 5741). This reflects a fragmented ecosystem dominated by small, short-term collaborations, unlike the EU's dense, repeated partnerships—a common issue in regions facing coordination failures (Isaksen et al., 2022). Moreover, Aragón channels more funding to private firms (PRC) and intermediaries (OTH), reinforcing its industrial focus, while EU projects favour academic and research institutions. This imbalance suggests underdeveloped scientific leadership and limited engagement in high-risk R&D (Isaksen & Trippel, 2016).

From policy implications standpoint, findings highlight both risks and opportunities. Aragón's broad but shallow participation structure points to untapped potential: stronger, repeated collaborations with EU consortia could boost both visibility and impact. However, to do so, knowledge-transfer mechanisms need to improve links between universities and large firms. Aligning with S3 2021–2027 goals, such measures would help reinforce strong sectors (e.g., Advanced Technologies) while activating emerging areas like Hydrogen or Water through strategic international engagement.

Benchmarking network metrics like fragmentation or density against centralised EU networks can guide targeted policy interventions. These might include dedicated calls, matchmaking platforms, or incentives to integrate local actors into robust, pan-European partnerships. In doing so, regional funding instruments would better align with EU priorities, addressing a key RIS3 implementation challenge (Esparza-Masana, 2022).

Finally, this section applies those insights to two contrasting S3 areas: Advanced Technologies, a mature sector, and Security and Defence, an emerging one. By tailoring policy actions to each domain's structural features, Aragón can position itself more strategically in European innovation ecosystems and deliver on its S3 2021–2027 ambitions.

The Advanced Technologies network in Aragón features a strong set of actors—ITA, UNIZAR, CIRCE, and AITIIP—closely connected with local firms and intermediary organizations. However, while these local clusters perform well in national calls, large-scale European projects remain led by top research institutions like Fraunhofer, IMEC, and CEA. This gap in project scale and funding highlights the need to increase regional network density and strengthen Aragón's presence in major EU consortia, addressing persistent weak ties among quadruple helix actors (Rossoni et al., 2024).

Anchor institutions such as ITA, UNIZAR, and CIRCE stand out for their extensive regional and international collaborations, including with Fraunhofer, CETH, and RINA. Their high betweenness centrality shows strong potential for coordinating consortia and managing resources. However, limitations remain: industrial actors often engage via cluster-led structures rather than long-term partnerships, and key Aragonese recipients attract less funding than their European counterparts. This dynamic echoes institutional fragmentation in other metropolitan RIS (Tödtling & Trippel, 2005).

To strengthen the ecosystem, several policy measures are recommended. First, strategic calls should target high-value areas (e.g., Industry 4.0, robotics, semiconductors) and prioritise consortia that combine multiple regional R&D centres with international partners. Second, despite a comparatively modest academic base, represented largely by UNIZAR, these actors can achieve more by expanding living labs and collaborative testing spaces with firms. Scaling initiatives like the Aragón European Digital Innovation Hub (AEDIH, 2017) and connecting them with EU leaders (EUA, 2019) offers an immediate opportunity. These measures directly confront the RIS3 challenge of insufficient monitoring and feedback loops by encouraging continuous, practice-oriented experimentation and learning.

Internationalisation is also key. While ITA and CIRCE have global links, many SMEs and tech firms remain disconnected from major European projects. This gap could be

addressed through targeted missions, matchmaking events, or shared proposals with institutions such as Chalmers, TU Eindhoven, or VTT (Ferraro & Iovanello, 2017). Creating an “Advanced Technologies International Office” within the regional government would help local organizations track and engage with emerging EU opportunities—tackling organizational thinness and enhancing absorptive capacity (Isaksen et al., 2022).

Finally, boosting local leadership in consortia would align technical capacity with strategic influence. Although ITA is a leading participant, it rarely coordinates EU projects. Introducing incentives for regional actors who lead international proposals—along with dedicated training in consortium leadership and EU project management—could close this gap (López-Rubio et al., 2020).

Altogether, these actions—enhancing local collaboration, improving academic–industry ties, and deepening international engagement—can elevate Aragón’s role in this area, positioning the region as a competitive, high-impact innovation hub.

Aragón’s Security and Defence network is mainly driven by industry, with companies like INSTALAZA and ARPA leading in both coordination and funding. These firms have capabilities aligned with emerging EU priorities, such as dual-use technologies and border security solutions (European Commission, 2024). However, unlike in Advanced Technologies, public research and academic involvement remains limited. At the European level, major institutions like CEA, Fraunhofer, and KU Leuven dominate consortia, making it hard for new or smaller players to enter. While UNIZAR and ITA act as occasional bridges, only three entities exhibit enough betweenness centrality to support wider network integration.

This configuration presents both opportunities and constraints. On the one hand, firms like INSTALAZA and ARPA already show strong technical capacity and could align with European initiatives if better connected. Stable, high-closure clusters indicate internal cohesion and readiness for collaborative innovation. On the other hand, few bridging nodes and stringent security regulations restrict access—especially for SMEs lacking the credentials or networks to enter the defence domain. These barriers reflect a key S3 implementation gap: limited engagement beyond initial planning phases hampers the growth of emerging sectors (Laranja et al., 2022).

To strengthen this ecosystem, policymakers should consider a targeted “Defence and Dual-Use Innovation” program (Csernaton, 2021), to attract new entrants through dedicated grants and lower entry thresholds. Cross-sector demonstration projects—combining defence needs with AI, hydrogen, or robotics—could foster new collaborations and broaden the sector’s base. Hosting international research chairs or offering secondments for European experts would also raise the profile of local actors. A joint Project Office focused on EU defence calls could ease participation, reduce administrative hurdles, and support local leadership in multinational proposals.

Together, these measures—engaging first-time participants, promoting interdisciplinary pilots, strengthening global ties, and offering practical support—would transform Aragón’s Security and Defence network into a more connected, competitive, and outward-looking ecosystem. They also directly address the RIS3 bottlenecks of fragmentation, limited outreach, and institutional inertia, offering a path toward a more responsive and strategically aligned regional innovation system.

6. Conclusions

This study builds on our previous analysis (Rodríguez Ochoa et al., 2025) of Aragón’s innovation ecosystem under the 2014–2020 RIS3 strategy, expanding it in four key areas: (i) a deeper analysis of cohesion and centrality across regional, national, and EU levels by specialisation area; (ii) examination of collaboration patterns among Aragón’s key institutions (UNIZAR, ITA, CIRCE, and AITIIP); (iii) identification of leading actors in EU

Framework Program projects; and (iv) assessment of how S3 policies can address persistent challenges, including fragmented R&D capacity, limited cooperation, and technology transfer bottlenecks.

Our results show a highly concentrated funding landscape: just four areas—Energy and Green Fuels, Health and Wellbeing, Agri-Food, and Advanced Technologies—capture about two-thirds of all competitive funding. Meanwhile, emerging fields like Hydrogen, AI, Security and Defence, and Water remain marginal, representing only 10% of total project activity. These imbalances stem from both strong legacy networks and persistent barriers in newer domains, such as limited outreach, weak funding alignment, and low technology readiness.

Cohesion metrics reveal a split structure: larger areas host many participants but remain poorly connected, while smaller ones are denser but too limited in scale. Centrality analysis confirms that mature areas benefit from multiple influential hubs, while emerging ones depend on just a few actors, which restricts knowledge diffusion and entrepreneurial discovery.

Focusing on Advanced Technologies and Security and Defence, the analysis identifies ITA and UNIZAR as key intermediaries in the former, supported by CIRCE, AITIIP, and firms like BSH. However, most of these actors tend to collaborate rather than lead large consortia. In contrast, Security and Defence is led by firms like INSTALAZA and ARPA, forming a tightly closed, industry-centric network with minimal academic involvement and limited reach. Across both domains, SMEs show weak integration—underscoring the need for targeted public–private partnerships and support mechanisms. Meanwhile, although institutions like UNIZAR, CIRCE, ITA, and AITIIP act as key “knowledge anchors” locally and internationally, they rarely collaborate directly. This siloing—driven in part by funding schemes favouring business–public pairings—dilutes their collective impact.

Considering the theoretical contributions, this study advances RIS3 theory by showing why place-based, differentiated strategies matter. Our network analysis reveals the pitfalls of “one-size-fits-all” approaches, highlighting the structural contrasts between mature sectors (e.g., Energy) and newer ones (e.g., Defence). Metrics like closure, density, and centrality can guide policy design to better harness local assets and fix domain-specific weaknesses. The findings also question the inclusiveness of the entrepreneurial discovery process, showing that only a few institutions truly bridge local and EU networks, leaving many actors at the periphery. Broader participation—via consortium-building and more inclusive funding calls—is essential. Finally, by applying a sustainability–inclusiveness–resilience lens, this work shows how social network analysis can serve as a continuous diagnostic tool for adaptive, data-driven governance. In doing so, it provides a roadmap for transforming static RIS3 plans into dynamic, evidence-based strategies.

With regard to the policy implications, benchmarking Aragón’s 2464 locally led projects against 33,933 EU initiatives reveals several strategic directions to strengthen its innovation system. To increase network density and reduce fragmentation, future challenge-driven calls should require consortia that connect multiple Aragonese R&D centres, SMEs, and at least one top-tier European partner. This structure would not only diversify partnerships but also stimulate deeper collaboration across the regional ecosystem.

To support emerging fields like Security and Defence and Hydrogen, the region would benefit from launching an Advanced Technologies International Office and a dedicated Defence and Dual Use Innovation program. These initiatives could help smaller firms join EU consortia by offering preparatory grants, targeted matchmaking with international actors, and legal assistance throughout the application process.

Embedding social network analysis into S3 governance would create a much-needed feedback mechanism to adjust funding instruments dynamically, prevent institutional

inertia, and align public support with real network structures and policy goals. At the same time, building local capacity remains critical. Training programs in EU consortium leadership—particularly for key players such as ITA—and the expansion of collaborative “living lab” models would encourage broader participation in underrepresented specialisation areas, especially Hydrogen and Water.

By taking these coordinated steps, Aragón can transition from a fragmented and uneven innovation landscape to a more integrated, resilient, and outward-facing ecosystem, which is better aligned with its smart specialisation strategy and more capable of seizing the opportunities of the European R&D landscape.

While this study offers valuable insights, it also has some limitations that point to future research opportunities. By focusing exclusively on competitive public calls, it overlooks private R&D investments and informal innovation activities—both of which play a key role in shaping collaboration, especially in industry-led sectors. Our social network analysis, based on project-level data, may also miss the influence of actors who contribute through spinouts, advisory roles, or contract research outside formal partnerships.

Aligning projects with the S3 Aragón 2021–2027 specialisation areas offers consistency but may exclude emerging fields—like AI-enabled technologies, biotechnology, or quantum computing—that have yet to gain full policy recognition. Expanding the analysis to include patent data, scientific publications, or foresight studies could better capture these nascent trajectories. Similarly, while the comparison with Horizon 2020 and Horizon Europe strengthens external validity, incorporating other EU funding programs—such as the European Defence Fund or LIFE Programme—could refine the picture and help identify the structural barriers limiting Aragonese participation in pan-European consortia.

Building on this work, future research should track how Aragón’s network metrics evolve over time in response to S3 2021–2027 interventions, helping to clarify causal relationships between specific policy actions and changes in cohesion or centrality. Combining this longitudinal analysis with qualitative interviews—from policymakers to SMEs and civil society—would add depth, revealing the motivations and obstacles behind real-world partnerships. Additionally, exploring unfunded or unsuccessful consortia could uncover untapped collaboration potential and procedural hurdles that block promising initiatives. Together, these mixed methods could offer more practical, evidence-based insights for refining and adapting smart specialisation policies.

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following link: <https://www.ciencia.gob.es/home/Convocatorias> (accessed on 8 May 2025). At the regional level, the information about projects can be found in the Aragón government's official database (<https://www.aragon.es/-/next-generation-eu-convocatorias#anchor1>, accessed on 8 May 2025) and from the database of the Aragón Development Institute (IAF for its initials in Spanish) <https://www.iaf.es/ayudas> (accessed on 8 May 2025).

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Abbreviations

The following abbreviations are used in this manuscript:

AITIIP	AITIIP Foundation
ALIA	Aragonese Logistic Cluster
ARPA	Mobile Field Units ARPA
CAAR	Automotive and Mobility Cluster of Aragón
CDTI	Centre for Industrial Technology Development
CEA	French Alternative Energies and Atomic Energy Commission
CERTH	Centre for Research & Technology, Hellas
CIRCE	CIRCE Foundation
CNR	Italian National Research Council
CNRS	French National Centre for Scientific Research
CORDIS	Community Research and Development Information Service
CSIC	Spanish National Research Council
EC	European Commission
EDP	Entrepreneurial Discovery Process
EU	European Union
FP	Framework Programme
GDP	Gross Domestic Product
GVA	Gross Value Added
H2020	Horizon 2020 Framework Research Programme
HE	Horizon Europe
HES	Higher education establishments entity type
IAF	Aragón Development Institute
IMEC	Interuniversity Microelectronics Centre
ITA	Aragón Technology Institute
KU Leuven	Katholieke Universiteit Leuven
NIF	Tax identification number
OTH	Sector-level organisations entity type
PIC	Participant Identification Codes
PRC	Private companies entity type
PRC-SME	Small and medium enterprises entity type
PUB	Public sector entity type
REC	Research organisations entity type
RIS	Regional Innovation Systems
RIS3	Research and Innovation Strategies for Smart Specialisation
RQ	Research question
R&D	Research and Development
R&I	Research and Innovation
S3	Smart Specialisation Strategy
SME	Small and Medium Enterprises
SNA	Social Network Analysis
UN	United Nations
UNIZAR	University of Zaragoza
URF	Unique Registration Facility

Appendix A

For clarity and ease of reading, supplementary details to the Materials and Methods section have been relocated to this appendix.

The detail of the primary data sources for this study are shown below.

- **Regional Project Databases:** Data on competitive public projects at the regional level were collected from official Aragón government repositories and databases, including those maintained by the Aragón Development Institute (IAF).
- **National Project Databases:** Information regarding national-level projects involving Aragonese entities was obtained from Spain's Ministry of Science and Innovation and other related national funding agencies, such as the Centre for Industrial Technology Development (CDTI).
- **European Project Databases:** Project data at the European level were sourced from databases managed by the European Commission, including those for Horizon Europe, INTERREG, and LIFE programs, among others. The CORDIS database (Community Research and Development Information Service) has been particularly instrumental, providing detailed information on projects, participants, funding, and outcomes.

For the Aragonese innovation ecosystem, we exclusively included projects featuring at least one participant from the Aragón region. Although the majority of these projects are collaborative public initiatives—characterized by multiple independent entities working together on shared research and innovation objectives—a small proportion of competitive projects undertaken by a single entity was also incorporated. For example, projects funded under the H2020 SME Instrument were included to reflect the performance of these entities in specific domains.

For the selection of entities, those from the Aragón region were identified using their tax identification numbers (NIF in Spanish) and associated addresses. Accordingly, any external entities involved in the selected projects were also included, as they contribute directly to the Aragonese research and innovation ecosystem through collaborative efforts.

Regarding the European benchmark, only projects under Horizon 2020 and Horizon Europe were considered, as these two funding schemes represent 78% of the total funding allocated within the Aragonese ecosystem. This focused selection enables a comprehensive comparison of regional performance in the context of broader European initiatives.

To ensure the accuracy and relevance of the data to Aragón's innovation ecosystem, several rigorous processing steps were undertaken:

- **Data Cleaning:** Following the extraction of data from regional, national, and European project databases, a thorough cleaning process was implemented to remove duplicates, resolve inconsistencies, and correct inaccuracies. Entity identifiers were verified, and formatting was standardized across datasets. For Aragón-based entities, confirmation was achieved through their tax identification numbers (NIF) and registered addresses. Additionally, the dataset was cross-referenced with official regional directories and national databases—such as records from the Spanish Ministry of Science and Innovation—and, for European projects, with the European Commission's Participant Identification Codes (PICs) and the Unique Registration Facility (URF) database. This extensive validation ensured that both local entities and their external collaborators were accurately represented.
- **Network Construction:** Using the refined dataset, collaborative networks were constructed wherein entities are depicted as nodes and their joint participation in projects as edges. These networks, covering projects from the regional, national, and European levels (2014–2023), serve as the foundation for subsequent social network analysis aimed at revealing the structural and dynamic characteristics of the ecosystem.

- **Attribute Assignment:** Each node in the network was enriched with relevant attributes to facilitate a nuanced analysis of its role and significance. Attributes included the type of entity (e.g., higher education institutions, large private companies), their project role (coordinator or participant), the participation level (regional, national, or European), the specialisation area and the funding received.
- **Data Validation:** To maintain the integrity of the constructed networks, random samples were cross-checked against the original databases, and any identified discrepancies were promptly addressed. This validation step was critical to ensure that the networks accurately reflect the collaborative activities and relationships within Aragón's innovation ecosystem over the specified period.

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