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From Firm-Level Alignment to Institutional Coordination: European and National Funding in Spanish Aviation [†]

Juan-Francisco Reyes-Sánchez ^{1,*}, Gustavo Alonso ¹ and Gustavo Morales-Alonso ²

¹ School of Aeronautical and Space Engineering, Universidad Politécnica de Madrid. Pl. del Cardenal Cisneros, 3, 28040 Madrid, Spain

² School of Industrial Engineering, Universidad Politécnica de Madrid C. de José Gutiérrez Abascal, 2, 28006 Madrid, Spain

* Correspondence: juanfrancisco.reyes@alumnos.upm.es

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Abstract

This study explores entities' strategy to combine multiple governmental funding sources to complement their research and innovation activities. It focuses on the case of Spanish aeronautics entities and their participation in both European and national research and innovation programs over two successive periods. Using a mixed-methods approach, this study combines qualitative interviews with three representative entities and a quantitative analysis of project-level data. The interviews are first used to identify key variables and analytical categories, such as entity type, Joint Undertaking membership, technological focus, and temporal evolution, which then guide the quantitative analysis. Quantitative data on budgets, funding, participation, and technologies are analyzed across both periods and programs, including pairwise correlation analysis. The findings show that Spanish entities actively seek to align national and European funding at both financial and technological levels, although with uneven success in some cases. Joint Undertaking membership and position within the aeronautical value chain strongly influence the ability to participate in both programs and to accumulate funding. While many entities develop informal alignment strategies, these efforts often exceed their organizational capacity, particularly in the second period. The results highlight the need for formal, government-level coordination mechanisms to support effective alignment between European and national aeronautics funding programs.

Keywords: public investment on research and innovation; firms' management on aviation research and innovation; alignment of funding programs; aviation strategies; coordination of research strategies

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1. Introduction

It is broadly acknowledged that research and innovation are essential determinants of long-term economic growth [1] and the creation of quality employment [2]. In an increasingly globalized world, cooperation between entities for technological developments is crucial to achieve goals that would be impossible individually in many cases, as well as

to coordinate knowledge and increase the effectiveness of investments [3]. However, the role of public policy in research and innovation is somewhat controversial [4], although there is a broad consensus that without government support, certain market niches that entail too much risk could not be addressed [5]. Not in vain, the complexity and adaptive nature of entrepreneurial ecosystems is receiving increased attention [6] due to the challenges imposed by the unprecedented levels of volatility, uncertainty, complexity, and ambiguity (VUCA) which organizations are facing nowadays [7].

Assuming the positive effect of public investment, another question is the effectiveness of the duality of sources of public support for innovation, which has been a matter of discussion in several studies [8]. It is mostly supported in the literature that the lack of success is mainly due to failure in the implementation action [9], and it is emphasized that there is a need for coordination of public investment in research and innovation (R&I). This coordination [10] allows for aligning strategies and using budgets more effectively, avoiding duplications, and addressing challenges in a joint manner [11]. Nevertheless, the definition and synchronization of joint strategies require long and complex processes, as well as the creation of efficient mechanisms [12].

Since the early steps of creating Europe as an economic community, investment in R&I has been a clear priority [13]; however, it has experienced ups and downs. Due to the nature of the European Union (EU), collaboration in policies, as a first step, is essential for economic development, making the introduction of Framework Programs (FPs) fundamental for initiating transnational cooperation in R&I [14]. But in addition to the FPs, each country counts on its own policies and budgets for R&I, and one of the objectives of the European Council [15], through the Lisbon Strategy in 2000, was to attempt to harmonize European, national, and regional funding strategies. Despite several initiatives, the effective synergy between different funding sources has yet to be fully realized [16], owing to the complexities associated with aligning European programs with national or regional ones.

In the 1990s, the European Union considered the aerospace sector a fundamental pillar of its R&I investment policy [17]. It has been heavily included in transnational funding centrally managed by the European Commission through the Framework Programs (FPs) along the years, and specifically through the Joint Technology Initiatives such as Clean Sky 2 Joint Undertaking (CS2JU) in the period 2014–2020 and Clean Aviation (CAJU) in the period 2021–2027. However, it was not as successful in aligning different funding strategies among the Member States [18]. Due to the nature of the aeronautic industry and its products, investment in R&I and cooperation among entities is essential to tackle such complex, costly, and high-risk developments [19]. Additionally, without intense government investment, many projects requiring research to address societal challenges, such as environmental impact, and/or large missions [20] would be very difficult to undertake [21].

CS2JU has spearheaded the first steps for the implementation of aligning European and regional funds for aviation [22], between 2014 and 2020, using European Strategic Investments Funds (ESIFs). It has established a synergy system which could be considered a success [23] due to the novelty approach. Its successor, CAJU has fine-tuned the procedure between 2021 and 2025 with regions, but there is still a need for improvement. However, the real challenge lies in aligning European strategies with national ones, as they could be crucial for ensuring genuine integration between funding sources [24] and alleviating the internal management on entities seeking to participate in multiple programs.

Participating in multiple funding programs simultaneously poses challenges for entities, such as internal decisions' strategies, managing resources, and meeting differing program requirements. To address these challenges, entities must adopt strategic planning and flexible resource management [25]. Additionally, collaboration between national

governments and the European Commission could be essential to harmonize program requirements, streamline processes, and reduce administrative burdens. This joint effort could make it easier for entities to navigate funding schemes, enhancing their success in securing and utilizing resources effectively.

At this stage, it is essential to clearly articulate the purpose of this study by emphasizing the reasons that make this investigation timely and relevant, and by formulating research questions aligned with recent policy developments. The successor of Clean Sky 2 Joint Undertaking in the period 2021–2027 [26], the Clean Aviation Joint Undertaking, has been explicitly encouraged by the European Commission to explore the feasibility and sustainability of aligning European funding with national R&I programs in the aviation sector, particularly during the final years of the European program from 2026 onward [27], to find a suitable procedure to be implemented in the next period, from 2028 to 2034.

This policy context raises a fundamental question as to whether entities participating in both European and national programs actively seek and effectively benefit from complementary funding sources [28] and, if so, how these funding streams are internally managed and translated into technological and competitive advantages. While the combination of funding instruments is increasingly promoted at the policy level, empirical evidence on how firms operationalize such alignment strategies, particularly over time and across successive program frameworks, remains limited when there are no formal procedures.

To address this gap, this study analyzes the behavior of Spanish entities in the aviation sector when engaging with European and national R&I programs across two distinct program periods. The first period corresponds to the Clean Sky 2 funding program (CS2) and covers projects funded between 2014 and 2017, with execution extending until 2020. The second period relates to the Clean Aviation (CA) program and covers participation between 2021 and 2024, with execution extending until 2026. Both periods include the analysis of participation in the Spanish national program [29] managed by “Centro para el Desarrollo Tecnológico y la Innovación” (CDTI). This longitudinal perspective enables this study to examine not only whether entities attempt to align funding and technologies across programs but also how the need and capacity to do so have evolved over time as program architectures and access conditions have changed.

Accordingly, the main research question guiding this study is as follows: *What factors shape entities’ strategic choices to pursue aligned funding and technologies between national and European aviation R&I programs in the absence of formal coordination frameworks?*

When organizations manage to participate in both programs, three complementary sub-questions are addressed:

Are there any relations between the technological and financial support provided by national and European programs?

Is the alignment of national and European programs useful for participating entities in terms of technological development, funding accumulation, and progression across technology maturity levels, and how has this perceived usefulness evolved across program periods?

Is there a need for a formal, government-level coordination procedure between European and national programs to facilitate alignment and avoid placing the burden of program coordination solely on individual entities.

To answer these questions, this study adopts a sequential mixed-methods approach that integrates qualitative and quantitative analyses. First, a qualitative phase based on semi-structured interviews with three representative entities in the Spanish aviation ecosystem is conducted. The interviews are used to explore internal decision-making processes, participation strategies, and perceived barriers to program alignment. Importantly, insights derived from this phase inform the identification of the key variables, categories, and analytical dimensions required to address the research questions.

Building on this qualitative groundwork, a comprehensive quantitative analysis is then performed using a dataset of aviation related projects funded under the European programs managed by CS2JU and CAJU, as well as the national program managed by CDTI. The dataset covers both program periods and allows for a comparative analysis of participation patterns in terms of budget, funding, entity type, technological focus, and maturity. Pairwise correlation analysis between key variables is used to assess the degree of alignment between national and European participation.

Finally, interview evidence is revisited to interpret and contextualize the quantitative results, particularly in cases where anomalies or structural differences emerge. This iterative use of qualitative insights ensures a more robust understanding of observed participation behaviors and alignment strategies.

This paper contributes to the literature by proposing an integrated empirical approach to analyzing cumulative and aligned funding strategies at European and national levels in the aeronautics sector [8]. Beyond documenting firms' behavior, this study highlights a structural policy gap: despite clear bottom-up efforts by entities to align technologies and funding, the absence of formal coordination mechanisms places a significant burden on firms. The findings therefore support the need for formal, government-level agreements between European and national programs to facilitate alignment, reduce uncertainty, and enable more efficient use of parallel funding instruments [9,28].

The remainder of this paper is organized as follows. The next section reviews the literature on public R&I investment in the EU, coordination mechanisms, and the specific challenges of the aeronautics sector, and it develops the analytical framework used in this study. The third section describes the dataset and the mixed-methods research design, including both the qualitative interview analysis and the quantitative modelling. The fourth section presents the results and findings, integrating statistical outcomes with interview evidence. The final section concludes with policy implications and directions for future research.

2. Literature Review and Analytical Framework

2.1. Public Expenditure on Research and Innovation, and Its Impact in the EU

Technological progress is one of the main determinants of long-term economic growth [1], taking always into account the emphasis on the distinctive difficulties in creating knowledge and the essential role of public policy in encouraging the associated research and innovation [30]. It is broadly accepted that these processes are embedded within a network of relationships among various actors and institutions [3], including the supportive role of government policies.

Public investment in R&I addresses market failures that often prevent private sector investment due to high uncertainty [31], long development timelines, and significant spillover effects [5]. It reduces these risks, thereby encouraging private entities to engage in R&I activities [9]. Beyond it, the support of basic research is crucial for future technological developments and innovation but often lacks immediate commercial applications [32].

The impact of public R&I funding is broad and significant [25]. Economically, it stimulates productivity [33] and creates high-quality jobs [2]. Empirical research has shown that countries with higher public R&I investment tend to experience stronger economic performance [4] and greater competitive advantages in the global market. Socially, public R&I funding addresses critical issues such as environmental sustainability or societal challenges.

The foundation for European funding in R&I can be traced to initial efforts to promote scientific investment since the creation of the European Economic Community in 1957. Nevertheless [13], a formalized strategy for R&I funding did not emerge until the early 1980s, with the introduction of the Framework Programs. These programs, born

from the necessity for cross-border cooperation and efficient resource allocation, highlight the continued importance and necessity of R&I funding in Europe [14].

The 1990s marked a tumultuous period for the European Union, as it grappled with a sectoral crisis and economic decline relative to other global economic regions. In response to these challenges, the European Council recognized the imperative of devising a new long-term strategy to rejuvenate growth and enhance competitiveness [15]. Thus, the EU embarked on a transformative journey, pivoting toward the creation of a knowledge-based economy and implementing structural reforms aimed at stimulating employment. This strategic realignment culminated in a seminal moment in March 2000, during the Lisbon session, where the European Council articulated a bold new objective: to establish the world's most competitive and dynamic knowledge-based economy. This vision was encapsulated in the Lisbon Strategy, a comprehensive plan designed to translate ambitious aspirations into tangible outcomes [34].

2.2. The Importance of EU Coordination in R&I Expenditures Stemming from Public Sources

The importance of collaboration between stakeholders [35] in order to overcome the challenges imposed by VUCA environments [7] calls for a better understanding of their dynamics, with a special emphasis on financing activities. By coordinating R&I public investments, resources can be utilized more effectively, preventing redundant efforts and enhancing synergy among various projects and initiatives [9]. The coordination between different governmental funding bodies contributes to a more competitive economy by nurturing environments conducive to high-tech industries and advanced research [36]. This approach not only attracts a higher private investment but also promotes industry–academia and international collaborations, thereby enhancing the overall economic global impact [11].

However, effective alignment of public R&I investment requires strategic planning and policy coherence across different levels of governance [37]. National or regional governments must synchronize their R&I strategies with broader international frameworks to optimize impact and capitalize on additional funding opportunities [12]. Robust governance structures are crucial for the coordination of R&I investments. This involves setting up clear collaboration frameworks, implementing transparent decision-making processes, and creating mechanisms for monitoring and evaluation to ensure alignment with strategic objectives [20].

European Union public expenditure on R&I is crucial for overcoming market failures, supporting foundational research, and driving socio-economic development. The coordinated efforts of the EU with national governments to invest in R&I through comprehensive programs highlight the strategic importance of public funding in cultivating a robust and innovative research landscape [38].

Central to the implementation of the already-introduced Lisbon Strategy in Europe, a fundamental concept aimed at harmonizing R&I policies across Europe was the creation of the European Research Area (ERA) [39]. As part of this endeavor, efforts were made to align European and national/regional funding programs, recognizing the importance of coherence and coordination in maximizing the impact of investments. For that purpose, the EC sought to foster collaboration and innovation through the establishment of sectoral European Technological Platforms [40], which aimed to develop long-term strategies through the creation of the Strategic Research (and later innovation) Agendas [41], ensuring alignment between European and national strategies and funding programs.

2.3. Evolution of Alignment in EU R&I Public Expenditures

The coordination of European and national research funding policies was firstly introduced by the European Commission in 1972, addressing a gradual implementation

through isolated programs till the adoption of the first EU research and development Framework Program for Community research in 1983 [42]. The primary goal of the FP was to establish the objectives, areas, and topics for research cooperation to be funded at the community level through a centralized funding approach. It was primarily managed by the EC through a common pot provided by States, coordinated at policy level and addressing the transnational cooperation of entities [43]. However, it was not a real alignment of national and European funding programs and policies. The coordination with national policies remained insufficiently addressed [44] beyond the EC-managed transnational funding.

The first real implementation of cross-border coordination of national research and development funding programs was the creation of the EUREKA program in 1985 by national governments in Europe [45]. Beyond this, at European level, under the umbrella of the ERA [34], new instruments were created to enhance the coordination of European, national, and regional funding programs through the sixth Framework Program and beyond, such as the ERA-Net initiatives [39].

In recent years, the integration of European and regional funds via Smart Specialization Strategies (S3) has also emerged as a fundamental aspect of the European Union's regional innovation policy [46] to harmonize mechanisms [47]. The alignment of European and national or regional funds coming from ESIF is essential for implementing synergies between programs, enhancing the coherence and impact of investments [48].

Although these initiatives have been introduced, achieving effective synergy between different funding sources remains a challenge [16] due to the complexities involved in aligning European programs with national or regional ones.

2.4. Importance of R&I on the Aeronautic Industry and the Need for EU Cooperation

The aeronautic industry is marked by its significant technological demands and the constant necessity for innovation. R&I efforts [19] in this field are essential for the creation of new aircraft, enhancement of performance, improvement of safety, and reduction of environmental impact [49]. These efforts stimulate economic growth by generating high-value employment, increasing exports, and supporting the development of related industries.

Technological progress in aeronautics not only benefits the industry itself but also has extensive effects on other sectors and plays a vital role in driving economic growth [50]. The aeronautic sector makes a substantial contribution to national economies, especially in countries with well-established aerospace industries.

The aeronautic industry stands as a fundamental pillar of contemporary technological progress, defined by its intricate and deeply interconnected supply chain. Original Equipment Manufacturers (OEMs) and their networks of suppliers' chain (Tier-1, Tier-2, and Tier-3 suppliers) [51] are crucial in propelling technological advancement and fostering innovation within this field. The supply chain cooperation in the aeronautics sector, as well as the resource sharing and the influence as organizational relationship linkage, is crucial for innovation [52].

Given the significant costs and complexities involved in aeronautic R&I, collaboration between companies, research institutions, and governments is prevalent [21]. Large-scale projects that might be beyond the reach of individual entities are often enabled through public–private partnerships.

The aviation sector, facing its own set of challenges during the 1990s, emerged as a critical focus area for policy intervention. Recognizing the sector's significance for economic recovery and innovation, the EC issued a call for supportive policies to enhance the global competitiveness of the aerospace industry [17]. Key stakeholders within the European aeronautic industry underscored the imperative of cooperation for global

competitiveness, emphasizing the importance of aligning efforts at both European and national levels [53].

2.5. Evolution of EU Alignment in R&I Funding for Aviation

In alignment with ERA directives and the strategic objectives outlined in the “European Aeronautics: A vision for 2020” report, the establishment of the first European Technology Platform, called Advisory Council for Aeronautics Research in Europe (ACARE), in 2001 marked a significant milestone in collaborative efforts within the aerospace sector at the strategy level in Europe [54]. It was focused on the collaboration established under the EU R&I FPs, managed as a common pot by the EC. Within this framework, CS2JU [55] dealt with most of the budget for European research and innovation funding aimed at developing cutting-edge technologies to mitigate the environmental impact of aviation [56], including initiatives to reduce emissions, lower noise levels, and enhance fuel efficiency. Between 2014 and 2020, the Clean Sky 2 Joint Undertaking (CS2JU) supported projects through grants covering between 70% and 100% of eligible direct costs and actively encouraged entities to become members of the Joint Undertaking via in-kind and in-cash contributions. In return, JU membership provided substantial strategic benefits, including access to long-term research and innovation activities within the CS2 program and the opportunity to contribute key competences and technical capabilities aligned with the program’s high-level objectives. This membership and governance model was subsequently maintained under the CA program for the 2021–2027 period, reinforcing this role as a central factor shaping participation in European aeronautics R&I programs.

However, realizing the full potential of policy integration and funding alignment remained a complex endeavor when synergies between different funding bodies at European and national level are referring [57].

To try to achieve a real cooperation, the EC and the ACARE Member States Group launched the Air Transport Net ERA-Net (AirTN), based on the achievements of the Group for Aeronautical Research and Technology in Europe (GARTEUR) to facilitate European aeronautics R&T collaboration [58]. The main objective of AirTN was to coordinate national R&I strategies and to serve as a pilot case through the launch of two joint calls, based on EUREKA functioning, among a different number of Member States in 2012 and 2013. The pilot resulted in being a no-go because there was no real success in the implementation to align national funding programs [59]. The discrepancy of financial instruments and national aeronautics R&I programs between members was related in terms of capabilities, national industrial interests, competitiveness, capacity to cooperate, regulations, and timeframes of calls.

Recent initiatives, such as the CS2JU, supported by AirTN and ACARE MSG, represent important strides toward aligning European and regional funding programs in the period 2014–2020 [60]. Although not fully established, CS2JU has managed to set up a synergy system between European and regional strategies, taking advantage of the policy intervention through the ESIF [61]. During this period, CS2JU signed 18 Memorandums of Understanding (MoUs) to coordinate with regional programs, enabling CS2JU members to propose complementary activities, extend project scopes, and fund research facilities [23]. Its successor, CAJU, has continued this tendency with the signature of five MoUs; however, no results of the funded projects have yet to be indicated. These efforts are aimed at enhancing the effectiveness of regional and European funding for research projects.

Building upon the already-mentioned synergy concept [47] with regions in the aviation sector, the next challenge for the EC is to enhance the alignment of the European Aviation R&I funding strategies with the countries that have their own aviation programs.

3. Materials and Methods

3.1. Research Design

This study adopts a sequential exploratory mixed-methods design (qualitative to quantitative) [62] to analyze alignment between European and national R&I funding programs in the aeronautics sector. This design is particularly suitable when existing theory is limited and when qualitative insights are required to identify the most relevant explanatory variables prior to quantitative analysis.

The methodological logic of this study is as follows: qualitative interviews are first used to uncover the factors that firms perceive as shaping participation in funding programs, and these factors are subsequently operationalized and tested quantitatively using project-level data across two time periods. This approach ensures that the quantitative analysis is theoretically and empirically grounded in sector-specific evidence rather than based on arbitrarily selected variables. Finally, interview evidence is revisited to interpret and contextualize the quantitative results.

3.2. Qualitative Phase: Exploratory Interviews

The first phase of the research consists of semi-structured interviews with key representatives of the aeronautical ecosystem whose entities have participated in both the European and the Spanish funding programs. It should be noted that only a limited number of entities have managed to participate in both programs simultaneously; in fact, during the second period analyzed, only nine entities achieved this.

From this population, three entities were selected for the interviews, as they were considered representative for several reasons. First, the selected entities correspond to the three typologies analyzed in this article, namely one OEM, one Tier-1, and one supply chain entity. Second, the entities were chosen to reflect different trajectories of participation in the European program: one of them has been a member since the program's inception, while the other two joined progressively over time in both periods analyzed. Consequently, these latter entities have experience participating both as Joint Undertaking members and as non-members. This enables them to provide informed insights into the advantages and disadvantages of program participation under different institutional conditions and across the different periods considered.

The interviews were designed to capture participants' perceptions of how European and national programs function, how participation conditions have evolved over time, which factors most strongly influence access to projects and funding, and their perception regarding the need to align both programs. Although the questions defined for the interviews are related to the research questions addressed in this article (see Appendix A), they are not the same. The interview questions were designed to bring out relevant information from the interviewees in order to identify the key variables and categories under study and the specific cases that may influence the alignment of national and European programs across two different periods, thus enabling their comparison. In fact, the research questions in this article were defined on the basis of the interviewees' responses.

An inductive thematic analysis [63] was conducted to identify recurring patterns across interviews. This approach is particularly suitable when existing theory is fragmented and when the objective is to identify patterns and generate hypotheses rather than test predefined relationships. The interviews were analyzed to detect repeated themes, with special emphasis on those factors in which interviewees explicitly associated participation difficulties in both programs with obstacles in technological alignment. Particular attention was paid to themes that (i) appeared consistently across different interviewees and (ii) were explicitly linked to differences in participation between European and national programs and the need for financing synergies.

3.3. Transition from Qualitative to Quantitative Analysis

Rather than treating qualitative and quantitative components as independent analyses, this study uses the qualitative findings as a hypothesis-generating mechanism. The themes identified in the interviews were systematically translated into measurable variables for the quantitative analysis.

Specifically:

- JU membership was operationalized distinguishing entities affiliated with the Joint Undertaking from non-members.
- Type of entity was operationalized according to the organization's position in the aeronautical value chain (OEM, Tier-1 supplier, or supply chain actor).
- Temporal change and evolution were operationalized through a comparative analysis of two program periods (2014–2017 and 2021–2024).

This design ensures methodological coherence by directly linking practitioners' perceptions to empirical measurement.

3.4. Quantitative Phase: Project-Level Analysis

The quantitative phase examines the participation of Spanish entities in both European and national aeronautics R&I funding programs, with a focus on participation in terms of budget, public funding, technological specialization, and program alignment. The objective is to understand how Spanish entities engage with each funding instrument and whether their participation patterns and technological choices [64] are aligned across programs and over time.

This analysis starts from the full population of funded projects under the European programs managed by CS2JU for the first period (2014–2017, running until 2020) [65] and the one managed by CAJU [66] for the second period (2021–2024, running until 2026), as well as all projects funded by the Spanish national program managed by CDTI during the same periods [67,68]. From this comprehensive dataset, projects were filtered to identify Spanish participations, enabling the construction of a participation-based dataset centered on entities and projects.

For each Spanish participation, a set of quantitative variables was extracted and aggregated. These variables include total project budget, public funding received, number of funded projects, number of participations in projects, number of participating Spanish entities, and number of demonstrators or technological areas addressed. Together, these variables provide a systemic view of participation intensity, financial commitment, and technological involvement across programs (Table 1).

Table 1. Variables selected for this study.

Variable	Definition
T_Budget	Projects' budget
T_Funding	Projects' funding
N_Projects	Number of funded projects
N_Participations	Number of participations in funded projects
N_Entities	Number of entities participating in the projects

Since complex and lengthy phrases have been used to describe specific situations that are part of our quantitative study, a specific definition coding system was created to simplify comprehension and reduce the wording (Table 2).

Table 2. Coding selected to better interpret complex texts.

Coding	Definition
ALL_CDTI	All CDTI-funded projects related to aviation
ALL_CDTI_CS2TS	All CDTI funded projects related to CS2 technology structure
CDTI_ONLY_CS2TS	CDTI-funded projects related to CS2 technology structure, developed by entities applying only to CDTI program
CDTI+CS2_CS2TS	CDTI-funded projects related to CS2 technology structure, developed by entities applying to both programs
CS2_SPANISH_CS2TS	Spanish participation in CS2 projects, related to CS2 technology structure
CS2+CDTI_CS2TS	Spanish participation in CS2 projects, related to CS2 technology structure, developed by entities applying to both programs
ALL_CDTI_CAVTS	All CDTI-funded projects related to CA technology structure
CDTI_ONLY_CAVTS	CDTI-funded projects related to CA technology structure, developed by entities applying only to CDTI program
CDTI+CA_CAVTS	CDTI-funded projects related to CA technology structure, developed by entities applying to both programs
CA+CDTI_CAVTS	Spanish participation in CA projects, related to CA technology structure, developed by entities applying to both programs
CA_SPANISH_CAVTS	Spanish participation in CA projects, related to CA technology structure

To better understand the selection and preference of funding program and technology by entities and to relate them to selected variables, this analysis identifies [69] four fundamental categories extracted by interviews (Table 3). The first fundamental category is the role of entities in the supplier pyramid. It is very important to understand how it affects participation depending on an entity's relationship with OEMs [52]. Although in theory, Tier-1 suppliers are considered supply chain, we categorized them as a separate type in our study because they are the drivers of the supply chain and are responsible for ensuring the entire operation is being managed within the OEM integration. Tier-1 and Tier-2 were grouped into a single category because, based on this study and the interviews conducted, Tier-2 and Tier-3 are considered to share the same characteristics regarding participation in national and European programs.

The second fundamental category is JU membership, which is very related to the type of entity and its capacity.

Table 3. Categories selected for this study.

Categories	Classification
Role of entity	OEMs
	Tier-1
	Supply chain
JU membership	JU Members
	Non-JU Members
Demonstrators (DEMs)	Large Passenger Aircraft (LPA)
	Regional Aircraft (REG)
	Fast Rotorcraft (FRC)

	Airframe (AIR)
	Engines (ENG)
	Systems (SYS)
Key thrusts (KTHs)	Hybrid electric regional (HER) Small and medium range (SMR) Hydrogen (H2)
JU membership	JU Members Non-JU Members

When cumulating data of all projects, the variables defined in Table 1 were tied together with categories (Table 3) and/or with coding (Table 2), obtaining a first set of information.

3.5. Technology Categorization and Entity-Level Alignment

A core element of the quantitative methodology is the categorization of technologies developed in funded projects using the European programs' technological roadmaps as reference frameworks.

For the first period (2014–2017), all projects, both national (CDTI) and European (CS2JU), were categorized using the Clean Sky 2 Technology Structure (CS2TS) [70], which organizes aeronautical research into large-scale demonstrators (DEMs) [55,71]. This framework provides a common technological language that enables direct comparison between national and European projects despite differences in program governance.

For the second period (2021–2024), the same methodological approach was applied using the Clean Aviation technology roadmap (CAVTS), which is organized in key thrusts (KTHs), reflecting the evolution of European aeronautics priorities and demonstrator structures under the new partnership framework [72].

Beyond project-level classification, the analysis introduces an entity-level technological alignment perspective. For each Spanish entity, the demonstrators/thrusts (Table 3) addressed in national projects were compared with those addressed in European projects within the same period. This enabled the identification of whether entities strategically pursue the same technological domains across both programs, indicating technological alignment, or whether they target different technologies depending on the funding instrument. This entity-level comparison is essential to assess alignment as a result of firms' strategic choices rather than program design alone.

3.6. Correlation Analysis

To complement the categorical analysis, a pairwise correlation analysis is applied to key quantitative variables for each program and period [73]. Pairwise correlation analysis measures the strength and direction of linear relationships between pairs of variables in the dataset. This method is crucial for identifying patterns, assessing collinearity, and informing decision-making, though it does not imply causation. Multiple correlation allows us to measure the strength and direction of the linear relationship between one dependent variable and the rest of variables combined. Pearson correlation coefficients are used to examine relationships between number of participations, project budget, public funding, participation intensity, and technological scope through the participation of different demonstrators in both programs.

Formally, the Pearson correlation coefficient between two variables X and Y is defined as follows:

$$r = \text{Cov}(X, Y) / (\sigma_x \cdot \sigma_y)$$

where $\text{Cov}(X,Y)$ represents the covariance between the two variables, and σ_x and σ_y denote their respective standard deviations.

The coefficient ranges from +1 (perfect positive linear relationship) to -1 (perfect negative linear relationship), while values close to zero indicate the absence of a linear association. In applied organizational and behavioral research, coefficients above 0.5 are generally interpreted as strong associations, whereas values between 0.3 and 0.5 indicate moderate relationships.

The sufficiency of the number of observations was assessed for each period analyzed. For the first period ($n = 19$), correlation coefficients exceeding approximately 0.46 are statistically significant at the 5% level, while for the second period ($n = 13$), the corresponding threshold is approximately 0.55.

In both periods, the main correlations discussed in the manuscript exceed these thresholds by a substantial margin, with many coefficients falling within ranges typically interpreted as strong or very strong associations.

Conducting the analysis separately for the periods 2014–2017 and 2021–2024 allows this study to capture temporal changes in these relationships and to assess their stability across successive program frameworks.

By combining project-level data, entity-level technological alignment, and categories derived from qualitative insights, our quantitative methodology enables us to perform a robust and policy-relevant assessment of alignment between national and European aeronautics R&I programs and how firms' strategy management of synergies has evolved over time.

4. Results and Discussion

4.1. Qualitative Findings: Determinants of Participation and Temporal Dynamics

The thematic analysis of the interviews identifies a set of recurrent and interrelated factors that interviewees perceive as decisive in shaping participation in European and national aeronautics R&I programs and the need for programs' alignment. Three themes emerge as structurally significant: Joint Undertaking (JU) membership; position within the aeronautical value chain, distinguishing between OEMs, Tier-1 suppliers, and supply chain actors; and temporal evolution across successive program periods.

Interviewees consistently described JU membership as a key mechanism facilitating access to European programs, particularly for entities positioned close to system integration and agenda-setting processes. However, respondents emphasized that the role of JU membership has evolved over time, reflecting changes in program governance, access rules, and thematic priorities between periods.

Value chain position was repeatedly reported to interact with these temporal changes. OEMs and Tier-1 suppliers were perceived as better able to adapt to evolving program structures, maintaining or strengthening their participation across periods. The JU members are also in a better position to adapt to the changes, regardless of which role they have in the supply chain. However, interviews reported that the evolution of the program increased difficulties in participating in proposals and growing barriers to entry, even for JU members.

In addition, respondents stressed that alignment between national and European programs has become increasingly critical over time. While national programs were described as effective entry points, several interviewees noted that difficulties in the participation in the European program in the second period have limited the ability of supply chain actors to progress from national projects to European-level demonstrators. These temporal changes were cited as a key reason why longitudinal analysis is necessary to determine whether observed participation asymmetries reflect structural features of the

aeronautics innovation system or the outcome of evolving program design and governance.

These qualitative insights directly informed the quantitative analysis, motivating the focus on JU membership, entity role, and comparisons across two program periods.

4.2. Quantitative Results: First Period (2014–2017)

4.2.1. Participation and Technological Alignment

During the first period, 161 aviation-related R&I projects funded by CDTI were identified, involving 82 entities, with a total budget of €205 million and public funding of €146 million. After consolidating parent–subsidiary relationships, the final dataset comprised 74 entities managing 161 projects. Table 4 shows the result of the analysis by variable (Table 1) and coding (Table 2).

Table 4. Spanish participation in projects funded under CDTI program, by variables, categories, and coding in the first period.

CDTI	ALL_CDTI	ALL_CDTI_CS2TS	CDTI_ONLY_CS 2TS	CDTI+CS2_CS 2TS	CS2JU Mem- bers	CS2JU Non- Members
N_Entities	74	56	18	19	9	10
N_Projects	161	138	47	91	57	34
T_Budget (M€)	205.97	188.65	37.94	150.71	123.98	26.73
T_Funding (M€)	146.10	134.24	25.72	108.52	89.91	18.61

Mapping national projects to the CS2TS shows that 138 projects, representing 92% of the CDTI budget (Table 4), are aligned with CS2 technologies. These projects involve 56 entities, indicating that the national program was widely used to support technologies consistent with the European roadmap [70].

However, only 19 of these entities also participated in the European program. Despite their limited number, these entities concentrate 79% of the CDTI budget associated with CS2TS aligned projects. The remaining 37 entities, although technologically aligned, relied exclusively on national funding.

Spanish participation in CS2 included 80 entities involved in 97 projects, receiving approximately €102 million. Table 5 shows the result of the analysis by variable (Table 1) and coding (Table 2). Among the 19 entities active in both programs, 9 were JU members, capturing 87% of the European budget allocated to dual participants.

Table 5. Spanish participation in projects funded under CS2 program, by variables, categories, and coding in the first period.

CS2	CS2_SPAN- ISH_CS2ST	CS2+CDTI_CS2 TS	CS2JU Members	CS2JU Non- Members
N_Entities	80	19	9	10
N_Projects	97	34	15	22
T_Budget (M€)	132.63	128.46	112.93	14.70
T_Funding (M€)	102.02	95.94	84.64	11.29

A detailed assessment of the involvement of these nine JU members in the CDTI program (Table 4) reveals a similar pattern. These entities also capture the highest share of national funding, receiving 60% of the total CDTI budget and 82% of the budget corresponding to entities that participate in both programs.

The reasons why some entities participated exclusively in one program while others engaged in both national and European funding instruments are heterogeneous and closely linked to institutional, financial, and program-specific factors. Evidence from the interviews indicates that participation outcomes cannot be attributed to a single determinant, but rather to a combination of eligibility constraints, funding conditions, and program maturity.

On the one hand, interviewees highlighted that a significant share of the aeronautics innovation ecosystem consists of technology centers and universities, which are eligible for participation in European programs but not eligible for funding under the national CDTI program. This structural constraint explains why several entities are present exclusively in the European program. In addition, respondents pointed out that the funding intensity of national calls is, in some cases, substantially lower than that of European programs, making European participation more attractive for entities with high R&I investment needs.

On the other hand, interviews revealed that during the first program period, some entities found it comparatively easier to participate in the national program. This was partly due to the low success rate of the initial Clean Sky 2 calls (2014–2015). Interviewees attributed this outcome to the novelty of the program, which introduced new governance rules, proposal formats, and evaluation procedures with which many applicants were initially unfamiliar. Moreover, a significant share of the available European budget during the early calls was channeled through mechanisms targeting entities willing or able to become Joint Undertaking members. Both interview evidence and project-level data confirm that entities with strong links to OEMs and Tier-1 suppliers were more likely to succeed in these early European calls and to secure JU membership. These findings further justify the focus on entity type and JU membership as key analytical categories in the quantitative analysis.

4.2.2. Relation and Frequency at DEM Level

Upon analyzing the selected demonstrators for each entity (considering in this case only the sample of 19 entities applying to both programs), the most predominantly utilized technologies were related to the AIR demonstrator, with a relative frequency of 0.52 in the CDTI program and 0.43 in the CS2 program. It was followed by the LPA, with a relative frequency of 0.21 in the CDTI program and 0.17 in CS2 program.

As depicted in Table 6, the selection of DEMs and the absolute/relative frequencies are similar in both programs for each entity.

Table 6. Frequency of specific demonstrators covered by Spanish entities in both programs in the first period.

DEMs	Absolute Frequency in CDTI Projects	Relative Frequency in CDTI Projects	Absolute Frequency in CS2 Projects	Relative Frequency in CS2 Projects
AIR	15	0.51	13	0.43
LPA	6	0.21	5	0.17
REG	1	0.03	4	0.13
SYS	5	0.17	6	0.2
ENG	1	0.03	1	0.03
FRC	1	0.03	1	0.03

4.2.3. Entity Type, JU Membership, and Budget Distribution

For the 19 entities participating in both programs, CDTI budget distribution initially shows 44% for supply chain entities, 31% for OEMs, and 25% for Tier-1 suppliers (Figure

1). This pattern is distorted by a single large supply chain entity (entity A) submitting an exceptionally high-budget project. Excluding this outlier yields a more representative distribution: 43% for OEMs, 38% for Tier-1 suppliers, and 17% for supply chain entities.

In Clean Sky 2, budget allocation reflects the program's early governance structure. OEMs account for 32% of the budget, Tier-1 suppliers for 59%, and supply chain entities for 9%, consistent with the focus on core partner selection in early calls.

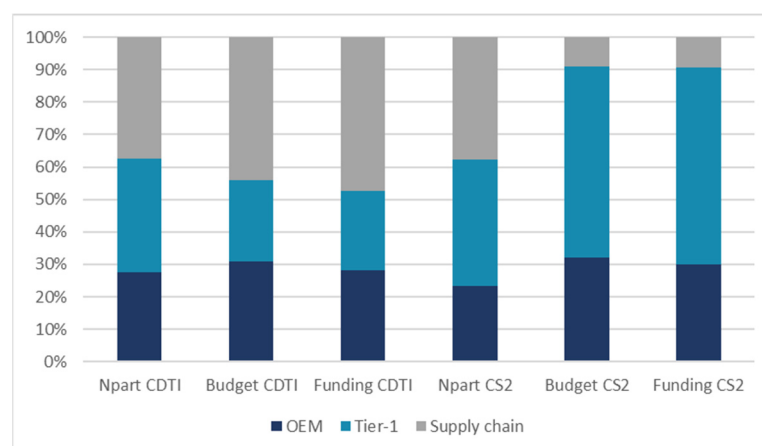


Figure 1. Spanish participation in the national and European programs, by type of entity in the first period.

Turning now to the role of JU membership, the analysis of the Spanish participation of the nine JU members in CS2 shows that 33% of the budget corresponds to OEMs, 61% to Tier-1 suppliers, and 4% to supply chain entities (Figure 2). Although this distribution does not reflect the intended balance of the program, it is consistent with the fact that the early CS2 calls were primarily structured around core partner selection processes, favoring OEMs and especially Tier-1 organizations.

A different pattern emerges when examining CDTI project budgets (Figure 2). The largest share of CDTI funding, 45%, was allocated to supply chain entities (five organizations), followed by OEMs with 37% (one entity), and Tier-1 suppliers with 17% (three entities). As in the previous analysis, this outcome is driven by the presence of the same large supply chain company (entity A), which is also a JU member and submitted an exceptionally high budget proposal to CDTI, thereby distorting the distribution. Excluding this outlier, the budget shares shift to 61% for OEMs, 28% for Tier-1 suppliers, and 9% for supply chain entities, values more consistent with typical participation patterns.

Overall, JU members exhibit considerably higher returns in CS2 than non-members. As shown in Table 2, 90% of the budget obtained by supply chain entities in CS2 corresponds to JU members, and similar or higher proportions are observed for OEMs and Tier-1 suppliers. Returning to Table 4, this tendency is also reflected in the national program when analyzing budget distribution by entity type.

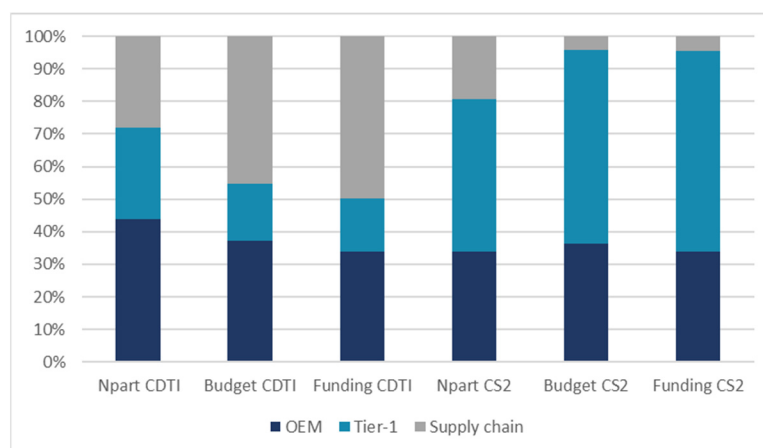


Figure 2. Spanish JU members participation in the national and European programs, by type of entity in the first period.

JU membership reinforces the observed participation patterns, with JU members capturing the majority of the European budget across entity types, particularly among OEMs and Tier-1 suppliers, but it usually applies also to national budget. This confirms the strong association between membership embeddedness and participation success identified in the interviews and reflects the higher technological and organizational capabilities of these entities, consistent with their dominant position in national funding allocation.

Interview evidence further indicates that JU membership, especially when combined with proximity to OEMs and Tier-1 suppliers, enables certain entities to participate more easily in both national and European programs, accumulate funding, and pursue coherent technological strategies across funding levels. For these actors, program alignment translates to effective operational synergies.

By contrast, entities with weaker ties with OEMs, Tier-1 or JU members, are often limited to participation in a single program despite developing technologies aligned with European roadmaps. Universities and research centers, due to eligibility constraints, tend to concentrate on their participation at the European level. Overall, the interaction between entity type and JU membership helps explain why some entities can access both programs and leverage cumulative funding, while others face structural limitations. These findings highlight that, although technological alignment exists, access to aligned participation remains uneven and strongly shaped by institutional and governance mechanisms.

4.2.4. Correlation Analysis

The correlation analysis (Table 7) provides quantitative support for the qualitative evidence indicating that Spanish entities actively seek to participate in both national and European R&I programs. Strong positive pairwise correlations between the pair of variables number of participations ($r = 0.65$) and the number of DEMs addressed ($r = 0.52$) indicate that entities tend to engage in comparable technological domains across funding levels, reflecting deliberate efforts to align their participation strategies at the entity level. We assume that values of $r > 0.5$ mean that the strength and direction of the linear relationship between one dependent variable and the rest of variables combined are strong.

Lower values of correlations initially observed for funding received ($r = 0.39$) and project budget ($r = 0.49$) are explained by the presence of a single entity (entity A) with an exceptionally high level of participation in the national program, which distorts the aggregate results. When this anomaly is excluded from the analysis, values of correlations increase substantially, reaching $r = 0.79$ for funding and $r = 0.76$ for budget. These results confirm that, once structural outliers are accounted for, entities participating in both programs exhibit highly consistent behavior in terms of resource allocation, reinforcing the

conclusion that firms systematically attempt to coordinate their participation across national and European funding schemes despite existing institutional constraints.

Table 7. Correlation matrix in the first period.

	N_Participations CDTI	T_Budget CDTI	T_Funding CDTI	N_DEMS CDTI	N_Participations CS2	T_Budget CS2	T_Funding CS2	N_DEMS CS2
N_Participations CDTI	1							
T_Budget CDTI	0.71730378	1						
T_Funding CDTI	0.645909	0.99354959	1					
N_DEMS CDTI	0.77914853	0.37694315	0.30045179	1				
N_Participations CS	0.65321796	0.35732704	0.29510921	0.56315635	1			
T_Budget CS2	0.63676552	0.48958982	0.42565621	0.47404202	0.68130599	1		
T_Funding CS2	0.61211037	0.45920293	0.39799828	0.46428015	0.74076131	0.99231757	1	
N_DEMS CS2	0.67428241	0.329207	0.25513461	0.52819038	0.63811171	0.44173975	0.43318154	1

4.3. Quantitative Results: Second Period (2021–2024)

4.3.1. Participation and Technological Alignment

In the second period, 159 entities participated in the national program through 59 projects, with a combined budget exceeding €308 million. Table 8 shows the result of the analysis by variable (Table 1) and coding (Table 2). Most of this budget corresponds to technologies aligned with the Clean Aviation technology structure, involving 93 entities. These results suggest that a substantial share of the Spanish aviation R&I ecosystem is predominantly oriented toward CA-aligned technologies, and that most entities leverage the national funding program to support projects that are partially or fully aligned with CAVTS. Among these, only 13 also participated in the European program.

Table 8. Spanish participation in projects funded under CDTI program, by variables, categories, and coding in the second period.

CDTI	ALL_CDTI	ALL_CDTI_CAVT	CDTI_ONLY_CA	CDTI+CA_CA	CAJU Mem- bers	CAJU Non- Members
		S	VTS	VTS		
N_Entities	159	93	66	13	5	8
N_Projects	59	33	26	23	22	1
T_Budget (M€)	308.64	219.19	89.45	128.29	106.57	21.72
T_Funding (M€)	186.58	130.11	56.47	70.82	58.75	12.07

Spanish participation in Clean Aviation comprised 36 entities involved in 19 projects, with a total budget of €98 million. Table 9 shows the result of the analysis by variable (Table 1) and coding (Table 2). Only 13 entities participated in both national and European programs. Despite their small number, these entities capture the vast majority of funding in both programs in the Clean Aviation program. The five entities that are members of the JU account for 89% of the budget allocated to the entities participating in both programs.

Examining the role of JU membership within the national CDTI program (Table 8) reveals a similar pattern: these same JU members concentrate 83% of the budget allocated to the 13 dual-program-participating entities.

Table 9. Spanish participation in projects funded under CA program, by variables, categories, and coding in the second period.

CA	CA_SPAN- ISH_CAVTS	CA+CDTI_CAV TS	CAJU Members	CAJU Non- Members
N_Entities	36	13	5	14
N_Projects	19	19	19	7
T_Budget (M€)	98.19	67.26	59.92	7.34
T_Funding (M€)	69.86	47.08	41.95	5.14

4.3.2. Relation and Frequency at Key Thrusts Level

Upon analyzing the selected technological key thrusts for each entity in the second period (considering only the sample of 13 entities participating in both programs), a markedly different pattern emerges compared to the first period. In the national CDTI program, the most frequently addressed technological key thrust corresponds to SMR, with a relative frequency of 0.64, whereas in the European Clean Aviation program the predominant focus is on HER, reaching a relative frequency of 0.72 (Table 10).

Unlike the first period, the technological focus chosen by entities does not coincide across programs. This divergence is primarily explained by the increased difficulty of participating in certain European key thrusts during the second period, particularly SMR, where the limited number of topics and their high level of competition significantly restrict access for Spanish entities. As a consequence, entities tend to allocate SMR-related developments to the national program, where participation conditions are perceived as more accessible.

Faced with these constraints, entities strategically redirect their European participation toward HER-related technologies, not necessarily as a first best option but as a feasible alternative within the available Clean Aviation calls. This adaptive behavior results in the use of national and European programs to support different technological key thrusts, making full technological alignment across programs more difficult in the second period. Nevertheless, the findings confirm that entities continue to seek complementarities across funding instruments, even when alignment is achieved through differentiated rather than parallel technological strategies.

Table 10. Frequency of specific demonstrators covered by Spanish entities in both programs in the second period.

KTHs	Absolute Fre- quency in CDTI Projects	Relative Fre- quency in CDTI Projects	Absolute Fre- quency in CA Pro- jects	Relative Fre- quency in CA Pro- jects
SMR	9	0.64	2	0.11
HER	4	0.29	13	0.72
HPA	1	0.07	3	0.17

4.3.3. Entity Type, JU Membership, and Budget Distribution

Analysis of the national program shows that OEMs account for 59% of the total CDTI budget (Figure 3), followed by Tier-1 suppliers with 23% and supply chain entities with 17%. This distribution reflects the existence of a dedicated aeronautics program with a substantial budget and a structure favoring OEM participation.

For the 13 entities active in both programs (Figure 3), the Clean Aviation budget is distributed as 53% for OEMs, 36% for Tier-1 suppliers, and 9% for supply chain entities, broadly mirroring national program results. Although Clean Aviation does not include explicit core partner calls as in the first period, the scale and scope of its topics naturally favor OEMs and their Tier-1 suppliers.

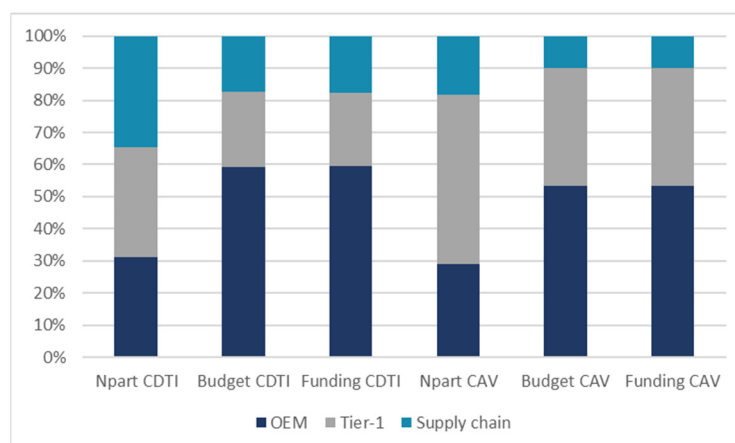


Figure 3. Spanish participation in the national and European programs, by type of entity in the second period.

JU membership (Figure 4) plays an even more decisive role than in the first period. JU members account for 95–100% of the Clean Aviation budget allocated to Spanish OEMs and Tier-1 suppliers participating in both programs. In contrast, only 10% of the supply chain budget corresponds to JU members. This asymmetry reflects program structure constraints: at the start of Clean Aviation, supply chain entities had no access to JU membership, and only a single membership call in 2023 allowed limited inclusion.

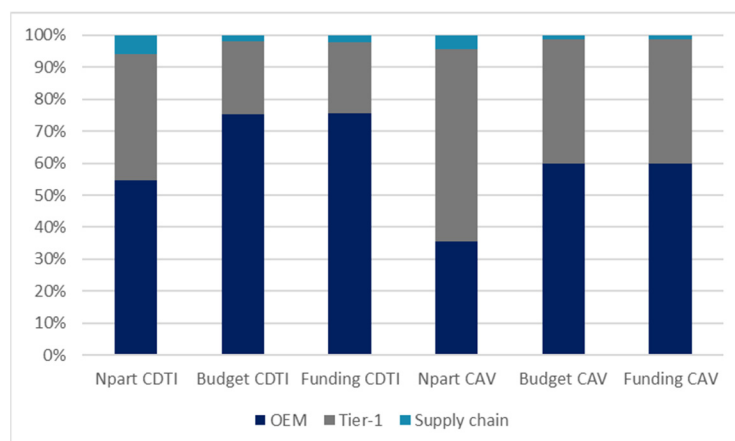


Figure 4. Spanish JU members' participation in the national and European programs, by type of entity in the second period.

4.3.4. Correlation Analysis

The pairwise correlation analysis (Table 11) for the second period reveals a very strong alignment between national and European participation patterns. We assume that values of $r > 0.5$ mean that the strength and direction of the linear relationship between one dependent variable and the rest of variables combined are strong. Correlation coefficients reach $r = 0.96$ for funding received and $r = 0.97$ for project budget in both programs for the pairs of variables, indicating a high degree of consistency in how entities allocate resources across programs.

These results suggest that, in the second period, entities participating in both programs display a more consolidated and coherent participation behavior than in the earlier phase. The consistently high correlations across key variables provide strong quantitative support for this study's hypothesis, confirming that entities systematically coordinate their engagement at national and European levels to maximize funding continuity.

Table 11. Correlation matrix in the second period.

	N_Participations CDTI	T_Budget CDTI	T_Funding CDTI	N_DEMs CDTI	N_Participations CA	T_Budget CA	T_Funding CA	N_DEMs CA
N_Participations CDTI	1							
T_Budget CDTI	0.970804	1						
T_Funding CDTI	0.96973942	0.99968143	1					
N_DEMs CDTI	0.59228484	0.54004974	0.53904258	1				
N_Participations CA	0.74288907	0.76151748	0.75295952	0.27721422	1			
T_Budget CA	0.9466147	0.9714867	0.96880782	0.48108855	0.87864509	1		
T_Funding CA	0.9466147	0.9714867	0.96880782	0.48108853	0.8786451	1	1	
N_DEMs CA	0.57188059	0.61474346	0.60162434	0.1678604	0.90956296	0.738951	0.738951	1

However, the results show a weak correlation between the technological key thrusts addressed in the national and European programs during the second period. This divergence reflects the increasing difficulty faced by Spanish entities in accessing the European program in the second period, which is characterized by fewer and larger topics led mainly by OEMs and major Tier-1 suppliers. In response, entities broaden their participation at the national level, addressing a wider range of technologies and key thrusts where entry barriers are lower.

Interview evidence indicates that this outcome does not reflect entities' preferred strategies. Respondents emphasized that they would favor the parallel use of national and European funding on related technologies at different Technology-Readiness Levels (TRLs), as was more feasible in the first period. The lack of correlation between technological KTHs therefore highlights structural constraints in the European program rather than a lack of intent by entities to align funding strategies.

4.4. Synthesis of Results and Findings

Across both periods, the integrated results demonstrate that participation in aeronautics R&I programs is shaped by a combination of JU membership, value chain position, and program evolution over time. While technological alignment between national and European programs remains high, access to cumulative participation increasingly concentrates among a limited set of entities.

The longitudinal comparison confirms interview findings that program alignment is not only a matter of technological consistency but also of governance accessibility. The results highlight the importance of aligning national and European programs not only in technological terms but also in participation mechanisms, particularly to ensure meaningful access for supply chain actors.

5. Conclusions, Implications, Limitations, and Suggestions for Further Research

This study contributes to the growing body of research on multi-level R&I funding by examining the alignment between European and national aeronautics programs through a combined qualitative and quantitative approach. In line with current European Commission policy, which actively promotes the combination of European, national, and regional funding instruments, the Clean Aviation Joint Undertaking is identified as a key institutional framework to operationalize such synergies and to clarify the processes required for their effective implementation in the period 2028 onward.

Methodologically, this study adopts a mixed-method and longitudinal-research design. A qualitative phase based on semi-structured interviews was first conducted to explore the determinants of participation in European and national aeronautics programs

and to identify recurring themes related to program structure embeddedness, entity type, technological positioning, and temporal evolution. These qualitative insights functioned as a hypothesis-generating stage and directly informed the selection of variables and analytical categories used in the subsequent quantitative phase. The quantitative analysis then examined project-level participation of Spanish entities across two program periods, combining categorical comparisons with pairwise correlation and frequency analysis to assess technological and financial alignment between programs over time. This sequential approach ensures coherence between qualitative interpretation and quantitative evidence, strengthening the robustness of the findings.

By analyzing the participation strategies of Spanish entities in the European programs (Clean Sky 2 and Clean Aviation) and the national program managed by CDTI, this research provides empirical evidence on how firms combine funding sources at both financial and technological levels. The results show that, despite the absence of predefined technological priorities in the national program during the first period, Spanish entities systematically proposed national projects aligned with the technological structure of the European program, confirming the existence of bottom-up strategies aimed at technological coherence across funding levels.

The findings reveal, however, that the feasibility and effectiveness of such alignment strategies evolve significantly across program periods. During the first period, although early European calls were initially oriented toward JU members, interview evidence indicates that entities were generally satisfied with their participation over the course of the program. This stability enabled entities to participate in both national and European programs and to exploit synergies through parallel or complementary funding of related technologies.

In contrast, the second period reflects a structural shift in the European program design. Clean Aviation is characterized by a reduced number of large-scale topics, typically led by OEMs or major Tier-1 suppliers, and centered on extensive consortia that tend to attract their established supply chains. This evolution significantly limits the participation of Spanish entities in the European program. Although participation in the national program becomes broader and more favorable in this period, the reduced presence of Spanish entities at the European level constrains the practical opportunities for aligning both programs. Nevertheless, the few entities that do participate in both programs continue to apply alignment strategies, confirming the persistence of this behavior where conditions allow it.

Across both periods, success in European participation remains strongly associated with entity type and membership embeddedness. OEMs, Tier-1 suppliers, and entities closely connected to them exhibit higher participation rates, reflecting their central role in large-scale aeronautical programs. In this context, JU membership emerges as a critical enabling factor, providing access to governance structures, strategic decision-making processes, and European networks, while also reinforcing participation at the national level.

The analysis further highlights the reciprocal nature of participation in national and European programs. JU membership not only facilitates access to European funding but also strengthens national participation through in-kind contributions and increased R&I capacity. This mutual reinforcement is supported by the strong correlations observed between national and European variables, except at the technological level in the second period that reflects difficulties in participation due to the new program structure and calls.

Interview evidence also shows that entities strategically differentiate the use of funding instruments according to technological maturity and risk profile, allocating European funding to lower TRL, higher-risk product innovations in most of the cases, and national funding to higher TRL, process-oriented developments. While these informal alignment

models demonstrate clear strategic intent, they frequently exceed the organizational capacity of individual entities, particularly for supply chain actors.

Taken together, these findings reveal a clear policy gap in the coordination between national and European aviation research and innovation programs. Despite significant bottom-up alignment efforts by individual entities, effective coordination at the program level remains limited and largely dependent on the capabilities and strategies of participating organizations. To address this limitation, formal and institutionalized alignment mechanisms at the governmental and program level are required.

In this context, the establishment of a government-level cooperation framework, such as a Memorandum of Cooperation (MoC) between CDTI and the Clean Aviation Joint Undertaking, would be instrumental. Such an agreement would enable the definition of coordinated technological and financial roadmaps at both national and European levels, thereby preventing overlaps and gaps in funding and research priorities. Moreover, the MoC could provide an “umbrella” strategic cooperation framework through the joint development of a Common Technical Roadmap identifying national investment programs, priority areas, technical domains, and related R&I topics to be supported under the respective programs of each party.

To ensure effective implementation, this cooperation framework should include the establishment of a dedicated working group composed of representatives from both parties, responsible for the development, monitoring, and continuous updating of the common roadmap, as well as for providing the necessary strategic, administrative, and operational support to co-design and implement synergy mechanisms. By shifting the burden of alignment from individual entities to program governance structures, such an institutionalized approach would contribute to reducing structural participation barriers and fostering a more coherent and efficient integration of national and European aviation research programs. This study is subject to limitations related to data availability across program periods. For the second period, only data corresponding to the first four years of implementation are currently available. To ensure methodological consistency and allow for a robust comparative analysis, this study therefore restricts the analysis of the first period to its corresponding initial four-year window, despite the availability of additional data for later years. In addition, although the first period covers a longer overall timeframe with available data, it is also affected by constraints related to incomplete publication of project outcomes in the last years.

This deliberate alignment of time frames not only enables a balanced comparison of participation patterns, funding behavior, and technological alignment across periods; it also implies that the results capture early-stage program dynamics rather than the full evolution of each initiative. Future research should extend this analysis once complete data for the full duration of the second period become available, allowing for a comprehensive longitudinal assessment of how alignment strategies and participation conditions evolve over the entire lifecycle of European and national aeronautics programs. In conclusion, aligning national programs with the evolving objectives and governance of Clean Aviation is essential to ensure technological continuity, investment efficiency, and inclusive participation in European aeronautics R&I. Enhanced coordination between national governments and the European Commission would enable entities to engage more effectively across funding levels and maximize the impact of public investment toward sustainable aviation goals.

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Abbreviations

The following abbreviations are used in this manuscript:

ACARE	Advisory Council for Aeronautics Research
AIR	Airframe
AirTN	Air Transport Net ERA-Net
CAJU	Clean Aviation Joint Undertaking
CAJU	Clean Aviation
CAVTS	Clean Aviation Technology Structure
CDTI	Centro para el Desarrollo Tecnológico y la Innovación
CS2	Clean Sky 2
CS2JU	Clean Sky 2 Joint Undertaking
CS2TS	Clean Sky 2 Technology Structure
DEMs	Demonstrators
EC	European Commission
ERA	European Research Area
ESIFs	European Strategic Investments Funds
EU	European Union
FP	Framework Program
GARTEUR	Group for Aeronautical Research and Technology in Europe
HER	Hybrid electric regional
JU	Joint Undertaking
KTHs	Key thrusts
LPA	Large Passenger Aircraft
MoUs	Memorandums of Understanding
OEMs	Original Equipment Manufacturers
R&I	Research and innovation
S3	Smart Specialization Strategies
TRLs	Technology-Readiness Levels
VUCA	Volatility, uncertainty, complexity, and ambiguity

Appendix A

The purpose of this interview is to understand how Spanish entities use European and national funding to build capabilities, seeking different sources of funding in order to align their technologies. Therefore, we will focus on the topic of synergies; however, to do so, we will also explore the characteristics of and participation in each program.

The European program Clean Sky 2 and the national program CDTI are analyzed for the period 2014–2017, and compared with the European program Clean Aviation and the national program CDTI for the period 2021–2023.

On the one hand, we aim to identify the variables that influence the decision-making strategy regarding participation in the programs—such as the type of entity, the type of membership in the European program, and the functioning of the programs themselves—as well as the decision whether or not to seek synergies between them. On the other hand, by comparing different periods, we will observe the evolution of the programs in line with political priorities and the changes in the entities' strategies.

The interview is designed to last no more than one hour and consists of 10 questions, with answers limited to a maximum of five minutes each.

Questions:

Calls—Period 2014–2017

Clean Sky 2

- Why did you decide to participate in the Clean Sky 2 program, and what was the process to try to succeed? How do the type of participating entity, the type of call selected, and the JU membership influence participation?
- What were your expectations, and what is your current opinion regarding what you aimed to achieve? Advantages and disadvantages/barriers.

CDTI

- What has been your experience participating in the national program? Advantages and disadvantages.
- Intention to align technologies through funding from both programs
- How do you manage participation in both programs in terms of deciding which type of technology or project to fund under each one? Advantages and barriers.

Calls—Period 2021–2024*Clean Aviation*

- Why did you decide to participate in the Clean Aviation program, and what was the process to try to succeed? How do the type of participating entity, the type of call selected, and CAJU membership influence participation?
- What were your expectations, and what is your current opinion regarding what you aimed to achieve? Advantages and barriers.

CDTI

- What has been your experience participating in the national PTA program? Advantages and disadvantages.
- Intention to align technologies through funding from both programs
- In this new period, how do you manage participation in both programs, if applicable, in terms of deciding which type of technology or project to fund under each one? Advantages, barriers, and recommendations for the future.

Comparison between both periods

- How do you think the programs have evolved in line with European policies, both in terms of program operation and the selection of technological blocks to be funded?
- Regarding the alignment of European and national programs, how has this evolved up to the second period, if at all? What are your recommendations to improve this alignment in the future?

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