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Executive Summary

ITINERIS (Italian Integrated Environmental Research Infrastructures System) was established within the framework of the Italian National Recovery and Resilience Plan (NRRP) to strengthen, upgrade and integrate the national ecosystem of environmental Research Infrastructures (RIs). Bringing together the national nodes of 22 leading Research Infrastructures operating across four major scientific domains—Atmosphere, Marine, Terrestrial Biosphere, and Geosphere/ Land Surface, and involving CNR together with six major national research organisations, the project was designed to address a longstanding challenge in environmental research: overcoming fragmentation among Research Infrastructures, disciplines and data systems in order to provide a coordinated national framework supporting scientific excellence, innovation, environmental monitoring and evidence-based decision making.

This report is organised in six parts. Part I provides an overview of the project, its strategic rationale and its implementation architecture. Part II presents the governance, monitoring and management model adopted to ensure effective execution, compliance and accountability throughout the project lifecycle. Part III illustrates the main cross-domain results, including the ITINERIS HUB, the National Access Framework, FAIR implementation, Virtual Research Environments and training activities. Part IV reports the domain-specific results achieved by the vertical Work Packages in the Atmosphere, Marine, Terrestrial Biosphere, and Geosphere/Land Surface domains. Part V summarises the project's scientific and technological impact, collaborations and synergies. Part VI draws the main conclusions and outlines the legacy and future outlook of ITINERIS.

Over the course of its implementation, ITINERIS achieved substantial progress in both physical and digital infrastructure development. More than €109 million were invested in scientific instrumentation, facilities, laboratories, observational systems and digital infrastructures. These investments significantly enhanced the operational capabilities of participating infrastructures, enabling the deployment of new technologies, the upgrade of existing facilities and the expansion of scientific services available to researchers, public institutions and other stakeholders. At the same time, the project generated a large body of scientific outputs, including hundreds of scientific publications, new datasets and digital resources that contribute to the long-term value of the national environmental research ecosystem.

One of the most significant achievements of the project has been the development of a common framework for data management, interoperability and access to services. Through the implementation of shared policies, FAIR data principles and interoperable metadata standards, ITINERIS established the foundations of an integrated ecosystem capable of connecting distributed infrastructures and facilitating data discovery, access and reuse. Central to this effort was the development of the ITINERIS HUB, conceived as a unified gateway to environmental research resources, services, facilities and expertise. The HUB, together with a portfolio of Virtual Research Environments and domain-specific digital services, represents a major step towards the creation of an interconnected and user-oriented infrastructure aligned with European initiatives such as EOSC and ENVRI.

Capacity building and human capital development constituted another key pillar of the project. Through the establishment of the ITINERIS Training Centre, the organisation of specialised courses, schools and training initiatives, and the development of innovative digital learning resources, the project strengthened competences across the environmental research community. Hundreds of researchers, students and technical personnel benefited from training activities, while dedicated actions supported doctoral education, interdisciplinary skills development, and the adoption of FAIR and Open Science practices. These efforts contributed not only to the dissemination of knowledge but also to the creation of a stronger and more interconnected national research community.

The infrastructures, digital services, datasets, training resources and collaborative networks established through ITINERIS constitute a significant legacy for the Italian research system and provide a solid foundation for future developments at national and European level. As environmental challenges become increasingly complex and interconnected, the integrated approach promoted by ITINERIS offers a model for advancing environmental research, supporting innovation and strengthening the role of science in addressing societal needs.

Beyond the delivery of infrastructure upgrades and digital services, ITINERIS contributed to the maturation of the Italian environmental RI ecosystem, increasing interoperability, visibility, scientific coordination and participation in European initiatives. By strengthening the position of Italian nodes within

major European Research Infrastructures and creating a shared national framework for access, data and services, the project laid the foundations for the long-term evolution of ITINERIS HUB towards a national environmental Research Infrastructure.

1. PART I — PROJECT OVERVIEW

ITINERIS (Italian Integrated Environmental Research Infrastructures System) was established within the framework of the Italian National Recovery and Resilience Plan (NRRP), Mission 4 “Education and Research”, Component 2 “From Research to Business”.

With a total budget exceeding 155 Mln €, ITINERIS represented the most significant national investments devoted by the Ministry of University and Research (MUR) to research infrastructures under NRRP Notice No. 3264 of 28 December 2021¹.

The project started on 1 November 2022 and ended on 30 June 2026.

ITINERIS was conceived to strengthen, upgrade and integrate the Italian ecosystem of environmental Research Infrastructures, creating a national network of facilities, services, data resources and expertise capable of supporting research, monitoring and evidence-based decision-making across the relevant scientific domain: atmosphere, marine domain, terrestrial biosphere and geosphere and land-surface.

The project responded directly to a long-standing structural challenge in Italian environmental research. Italy hosts a large number of internationally recognised Research Infrastructures and observation networks, including the national nodes of major European ESFRI infrastructures, and several European Research Infrastructure Consortia (ERICs), European RIs, and national RIs. However, these resources had historically developed within separate scientific domains and organisational frameworks, generating a fragmented landscape in which technical standards, data practices, access models, and governance approaches varied considerably across institutions and communities. ITINERIS was designed to address this fragmentation by creating a common national framework capable of linking infrastructures, disciplines and institutions within a coherent, interoperable and user-oriented system.

The strategic rationale underpinning the project was shaped by the recognition that complex environmental challenges — climate change, biodiversity loss, ecosystem degradation, pollution and natural hazards — require integrated, multidisciplinary responses that no single infrastructure or scientific community can provide in isolation. Addressing these challenges demands coordinated observations, interoperable data systems, and analytical capabilities that connect processes occurring across different components of the Earth system. ITINERIS was therefore conceived not merely as an investment in individual infrastructure upgrades, but as a systemic intervention aimed at transforming a distributed set of facilities into an integrated and collaborative national ecosystem.

ITINERIS coordinates the national nodes of 22 Research Infrastructures distributed across the four environmental domains, linking major ESFRI landmarks, European RI initiatives and selected national infrastructures into a common framework: the Italian nodes of the ESFRI Landmarks ACTRIS, EMSO, Euro-Argo, ICOS and LIFEWATCH, from the ENV domain and ANAEE from the H&F domain and closely linked to the ENV domain; the Italian nodes of the ESFRI projects DANUBIUS, DISSCO, e-LTER, from the ENV domain, and EMPHASIS and EU-IBISBA from the H&F domain and also relevant for ENV; the EU RIs ECORD, EUFAR, Eurofleets, JERICO and SIOS, all from the ENV domain; and the national RIs ATLAS, CeTRA, Laura Bassi, and SMINO, from the ENV domain, and Geosciences and LNS, both from the PSE domain, that in ITINERIS support services in the marine domain.

These infrastructures include observation systems, monitoring networks, experimental facilities, laboratories, repositories, analytical platforms and digital services that collectively support a broad spectrum of environmental research activities.

The seven implementing institutions involved in the project are: CNR (Consiglio Nazionale delle Ricerche), acting as coordinating institution and proponent implementing entity, together with INFN (Istituto Nazionale di Fisica Nucleare), INGV (Istituto Nazionale di Geofisica e Vulcanologia), ISPRA

¹ <https://www.mur.gov.it/atti-e-normativa/avviso-n-3264-del-28-12-2021>

(Istituto Superiore per la Protezione e la Ricerca Ambientale), OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale-OGS), UNIFI (University of Florence) and UNIVE (Ca' Foscari University of Venice). These institutions collectively mobilised a large and highly interdisciplinary community distributed across 39 operational units located throughout the national territory.

The project was articulated in eight Work Packages (WPs), each structured into multiple activities aimed at achieving specific intermediate objectives and delivering planned outcomes.

Four vertical WPs focus on the key environmental subdomains: atmosphere (WP4), marine domain (WP5), terrestrial biosphere (WP6), and geosphere and landsurface (WP7). Within these WPs, the participating Research Infrastructures (RIs) collaborate to harmonize development, ensure interoperability, and standardize methods. WP8 serves as a horizontal, cross-sectorial WP, leveraging capacities developed in WP4-WP7 to foster a cross-disciplinary approach via Virtual Research Environments. WP2 establishes the ITINERIS HUB, serving as a singular access point to comprehensive resources provided by participating RIs, while WP3 develops the ITINERIS Training Programme, coordinating training plans and producing training materials. Finally, WP1 is dedicated to overseeing overall project coordination and management, ensuring alignment with objectives and efficient execution across all activities.

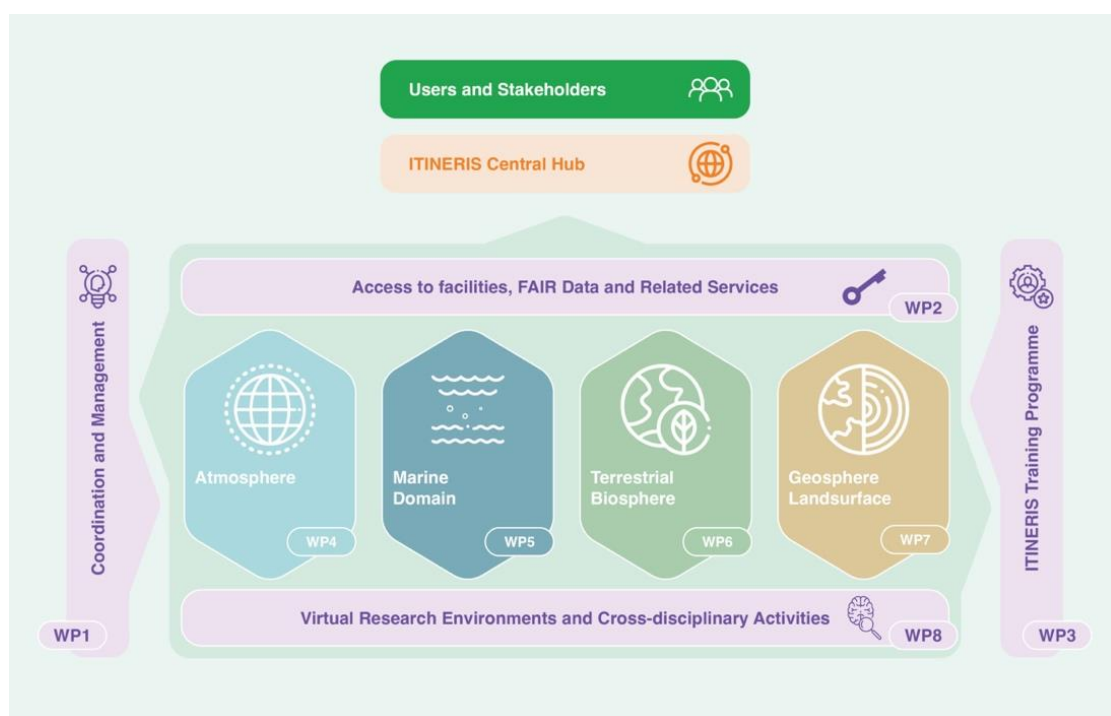


Figure 1- Architecture and interaction scheme of the ITINERIS Work Packages

Beyond the enhancement of individual infrastructures, ITINERIS pursued a broader transformative vision: the creation of a national network of environmental research infrastructures in which facilities, services, data resources and scientific expertise operate in a coordinated and interoperable manner. Through shared standards, common governance mechanisms and integrated digital services, the project sought to maximise the scientific and societal value of environmental RIs, improve access to resources and services, and strengthen Italy's contribution to the European and international research landscape. The results presented in this report demonstrate how ITINERIS has contributed to transforming a distributed set of infrastructures into a more integrated, collaborative and strategically positioned national system.

2. PART II - GOVERNANCE, IMPLEMENTATION AND MANAGEMENT

The implementation of ITINERIS required a robust governance and management framework capable of coordinating one of the largest investments in environmental Research Infrastructures ever undertaken in Italy. The project brought together 22 Research Infrastructures, seven implementing institutions and a large network of 39 Operating Units (OU) distributed across the national territory, operating in different scientific domains and organisational contexts. The scale of the initiative, combined with the ambitious objectives established under the National Recovery and Resilience Plan (NRRP), required the adoption of effective coordination mechanisms to ensure the timely and coherent execution of scientific, technical, administrative and financial activities throughout the project lifecycle.

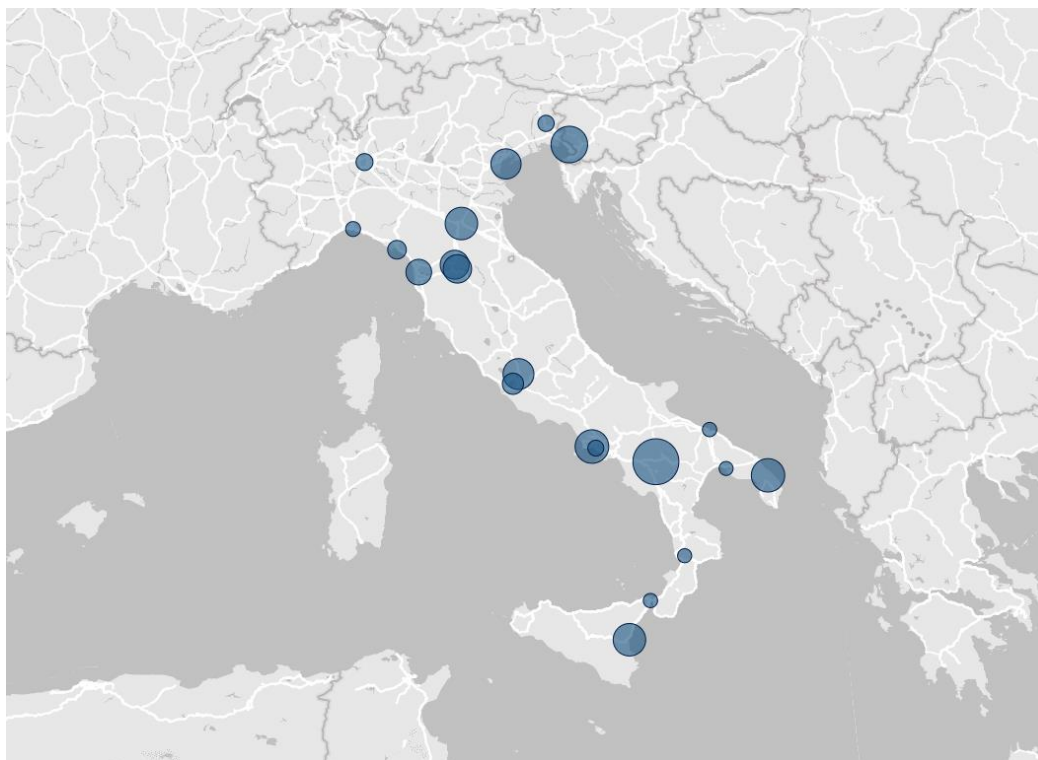


Figure 2 - Distribution in Italy of the 39 Operating Units of the Project

CNR, acting as coordinating institution and proponent implementing entity, was responsible for the overall management of the project and for ensuring alignment with the objectives and requirements established by the Ministry of University and Research (MUR). The governance structure was designed to combine strategic oversight with distributed operational responsibility, allowing participating organisations to implement the work packages' specific activities while maintaining strong coordination at project level.

In this regard, Work Package 1 – Coordination and Management served as the operational, administrative and strategic backbone of ITINERIS, providing the robust governance framework required to manage large-scale resources and diverse institutional interactions. Structured around two complementary pillars — centralized coordination, monitoring and administrative-financial management on the one hand, and communication, dissemination and stakeholder engagement on the other — WP1 successfully guided the complex consortium. Acting as the primary interface with MUR, Invitalia, and the participating institutions, it ensured the regular operation of decision-making and advisory bodies. Through continuous oversight, WP1 guaranteed total alignment between scientific objectives, financial execution and strict NRRP and NextGenerationEU regulatory obligations, effectively turning a complex plan into an executable reality.

A distinctive feature of project implementation was the collaborative governance model established among the participating institutions. Beyond coordinating project execution, this model created the organisational framework that enabled continuous collaboration among Research Infrastructures with different levels of scientific, digital and organisational maturity. Through the coordinated activities carried out across the various Work Packages, this collaboration promoted the exchange of expertise, methodologies and operational practices in areas such as FAIR data implementation, interoperability, digital services,

metadata harmonisation, access procedures and the integration of resources within the ITINERIS HUB, progressively strengthening the overall maturity and coherence of the national environmental RI ecosystem.

A key achievement of WP1 was the development of an integrated digital project management and monitoring system. Moving far beyond basic document storage, this platform functioned as an integrated data environment connecting structured repositories, advanced metadata and granular permissions across a multi-layered framework. It supported the collection, validation and consolidation of technical, financial and procedural information, providing real-time monitoring of deliverables, milestones, intermediate targets and budget execution. It significantly reduced data fragmentation risks, strengthened traceability and auditability, and facilitated compliance verification throughout the project lifecycle.

Communication and dissemination

ITINERIS implemented a communication and dissemination strategy aimed at increasing visibility and maximizing the scientific and societal impact of its results at national and international level.

An inclusive and collaborative approach was adopted: the Coordination Office defined the overall framework and ensured coherence, while partners actively contributed to dissemination and outreach activities.

Communication was carried out through multiple channels, including the project website (<https://itineris.cnr.it/>), the social media (*X* (Twitter) and *Bluesky*), as well as dedicated newsletters, mailing campaigns, outreach materials and public engagement events.

Flagship initiatives strengthened visibility and international positioning. ITINERIS participated in the GEO Global Forum 2025 with an exhibition stand showcasing environmental RIs, and the ITINERIS EYES oceanographic campaign (July 2025) combined scientific activity with broad communication actions (videos, media coverage, podcasts and social media), bringing marine science to the public.

The collected figures (although they may not fully capture the entirety of outputs produced across the consortium) confirm that dissemination activities were particularly intense and highly diversified. Dissemination actions included participation in major national and international scientific events through more than 227 oral presentations, 187 posters and 35 conference proceedings, significantly enhancing the visibility of ITINERIS across multiple environmental research domains, including Earth system science, atmospheric sciences, marine science, biodiversity and geosciences. Key international events included the EGU General Assembly (2023–2026), the ESA Living Planet Symposium 2025, IGARSS. These dissemination activities were supported by a substantial scientific production generated by the project, including 461 peer-reviewed publications, 280 datasets and 227 public deliverables, which further contributed to the visibility, accessibility and long-term impact of ITINERIS results.

2.1. Work Breakdown Structure and technical reporting

The project implementation was guided by an extensive Work Breakdown Structure (WBS) that translated the overall design of ITINERIS into 8 Work Packages, 89 activities, 228 deliverables and 75 intermediate objectives. This structure made it possible to assign responsibilities clearly, monitor implementation at multiple levels and ensure that scientific, technical and administrative components progressed in a coordinated way across the consortium. The WBS was particularly important because the project had to integrate a very large number of actions, some of which were highly technical or infrastructure-specific, while others were transversal and concerned access, training, interoperability and coordination. In practice, the WBS functioned as the bridge between the strategic architecture of the project and the day-to-day implementation of activities across the 39 operational units.

At the end of the project, all planned activities were successfully completed, marking the full execution of all activities, alongside the release of all deliverables and the successful attainment of all intermediate objectives.

Work Package	# Activities	# Intermediate Objectives	# Deliverables
WP1	2	15	49
WP2	4	5	22
WP3	8	11	20
WP4	16	8	51
WP5	21	9	31
WP6	20	8	24
WP7	9	8	9
WP8	9	11	22
Total	89	75	228

Table 1 - Breakdown and final completion status of activities, Intermediate Objectives and deliverables per Work Package

Progress towards the Intermediate Objectives (IOs) was continuously monitored through the set of Key Performance Indicators (KPIs) defined by each Work Package in the project proposal. These indicators covered not only procedural and financial aspects, such as procurement and recruitment progress, but also the delivery of planned outputs, including deliverables, services, infrastructures, datasets, and scientific outcomes. This monitoring framework provided a structured basis for assessing project advancement and verifying the achievement of the expected results throughout the project lifecycle. To accommodate actual operational dynamics, 32 of the 75 Intermediate Objectives were flexibly realigned with respect to the original schedule, without any impact on the final project targets and deliverables. In many cases, this adjustment did not imply a delay in the scientific-technical work itself, but merely a postponement in the formal verification of administrative indicators, particularly those related to procurement and financial procedures. The completion of these processes naturally shifted some dependent scientific tasks and the formal sign-off of the affected deliverables and Intermediate Objectives.

WORK PACKAGES	BIM	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
WP1		IO 1.1	IO 1.2	IO 1.2	IO 1.4	IO 1.5	IO 1.6	IO 1.7	IO 1.8	IO 1.9	IO 1.10	IO 1.11	IO 1.12	IO 1.13	IO 1.14							IO 1.15
WP2				IO 2.1			IO 2.2				IO 2.3						IO 2.4					IO 2.5
WP3				IO 3.1	IO 3.2			IO 3.4								IO 3.5	IO 3.6 IO 3.7 IO 3.3				IO 3.8 IO 3.9 IO 3.10	IO 3.11
WP4			IO 4.1	IO 4.2				IO 4.3	IO 4.4		IO 4.5						IO 4.6		IO 4.7			IO 4.8
WP5		IO 5.1		IO 5.2	IO 5.3	IO 5.4		IO 5.5									IO 5.6				IO 5.7 IO 5.8	IO 5.9
WP6			IO 6.1				IO 6.2					IO 6.3	IO 6.4			IO 6.6	IO 6.7				IO 6.5	IO 6.8
WP7			IO 7.1				IO 7.2			IO 7.3			IO 7.5				IO 7.6	IO 7.7	IO 7.4			IO 7.8
WP8				IO 8.1		IO 8.2	IO 8.3	IO 8.4	IO 8.5	IO 8.6	IO 8.7		IO 8.8							IO 8.9 IO 8.10		IO 8.11

Table 2 - Intermediate Objectives against reporting periods, with green cells indicating full achievement

The project management and monitoring system supported the collection, validation and consolidation of technical, financial, and procedural information, providing real-time monitoring of deliverables, milestones, intermediate targets and budget execution across all Work Packages and operational units. It also incorporated specific data collection workflows designed to track NRRP compliance criteria in a structured and auditable manner. These included dedicated modules for the Do No Significant Harm (DNSH) principle, climate tagging requirements, gender balance indicators, procurement traceability and financial eligibility checks. By compiling the necessary declarations, checklists and supporting documentation within a single integrated environment, the system significantly reduced the risk of data fragmentation, strengthened traceability and auditability, and facilitated compliance verification throughout the project lifecycle.

Business intelligence dashboards provided governance bodies with real-time visibility of project status, enabling the immediate identification of risks and the rapid adoption of corrective measures whenever required.

The monitoring system was therefore not only a reporting instrument, but a genuine management tool that made it possible to coordinate a highly differentiated portfolio of scientific, technical and administrative actions under a common implementation logic. The digital monitoring platform developed by ITINERIS therefore constitutes not only an operational legacy for the project itself, but also a replicable model for the management of complex multi-partner infrastructure initiatives within the NRRP framework.

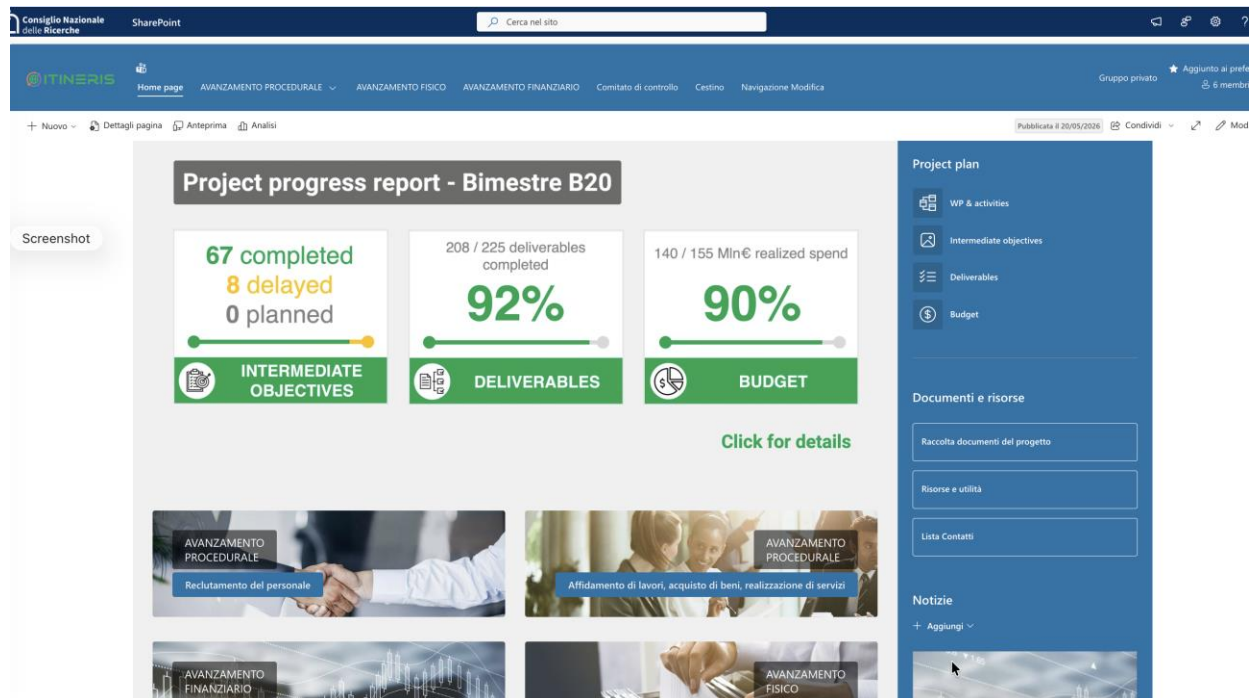


Figure 1 - Homepage of the ITINERIS project management and monitoring system

2.2. Procurement and financial management

A major management effort throughout the project was devoted to the implementation of procurement activities associated with the upgrading of infrastructures, the acquisition of scientific instrumentation and the development of digital services. The project involved more than 820 procurement procedures, ranging from highly specialised scientific equipment to advanced computing resources and digital platforms. This number is particularly significant because it reflects not only the scale of the investment, but also the operational complexity of converting an ambitious infrastructure plan into a concrete and regulated execution process. The management of these activities required close and continuous interaction among scientific, technical, administrative and financial personnel across all participating institutions, ensuring compliance with national regulations and NRRP requirements while preserving the scientific objectives and timelines of the project.

Financial management represented another key component of project implementation. The consortium was responsible for managing an overall initial budget of €155,208,808, representing a massive national investment dedicated to scientific instrumentation, facilities enhancement, digital infrastructures, personnel recruitment, and training activities.

The financial implementation was carefully monitored throughout the project lifecycle. Five ordinary amendments were approved and implemented to reallocate budget surpluses resulting from procurement efficiencies, savings and alternative technical optimisations identified during implementation, ensuring that available resources were directed towards activities of greatest scientific and operational value. Far from indicating a weakness, these adjustments show that the project was governed through a genuine

implementation logic, in which resource allocation was continuously adapted to operational realities while preserving the overall strategic design.

At the conclusion of the project lifecycle, the consortium successfully achieved an overall expenditure rate of 97.5%, reflecting a highly effective absorption capacity.

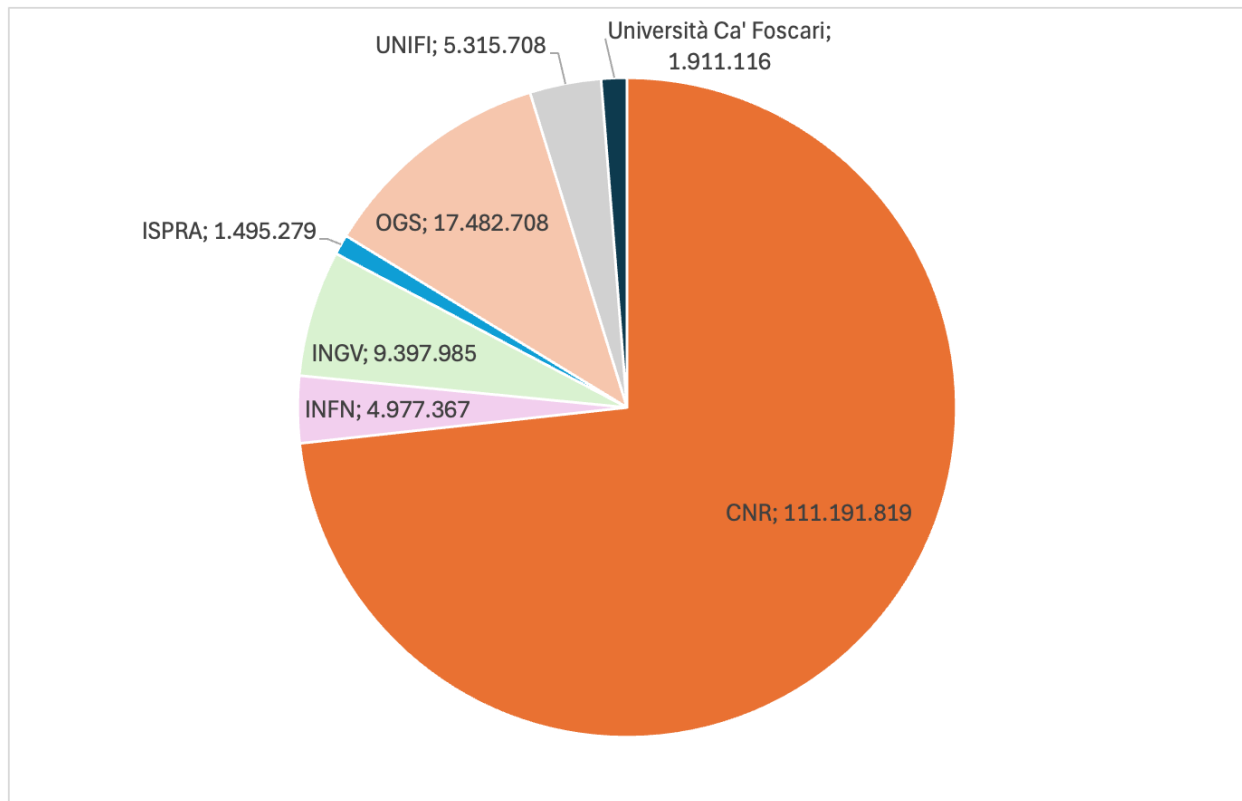


Figure 3 - Expenditures by Implementing Entity in Euro

The minor overall variance of 2.5% is entirely physiological for an initiative of the scale and structural complexity of ITINERIS. All scientific, technical, operational and administrative objectives were fully achieved in accordance with the approved work plan, demonstrating that the residual budget had no impact on the scope, quality or completeness of the project results. The limited financial variance reflects a combination of external administrative factors and efficiencies generated during project implementation. These include the inherent complexity and timing of public procurement procedures for infrastructure investments, the administrative constraints associated with the late activation of university agreements and fellowships for long-term training programmes, and savings generated through competitive procurement procedures and lower-than-expected costs for certain training activities.

Furthermore, had the extension of the project until 30 June 2026 been confirmed at an earlier stage, the final expenditure rate would reasonably have been even higher. In the absence of timely confirmation, several beneficiary institutions had already reallocated personnel costs or secured alternative funding sources to cover the final months of PhD fellowships and other long-term training activities that were originally expected to fall outside the project eligibility period. Consequently, part of these eligible costs could no longer be charged to the project. At the same time, although the savings generated through procurement procedures represented an efficient use of public resources, the timing of the final extension, together with the administrative constraints governing budget reallocations and financial plan updates, did not provide sufficient time to activate additional procurement procedures or fully reinvest the remaining resources

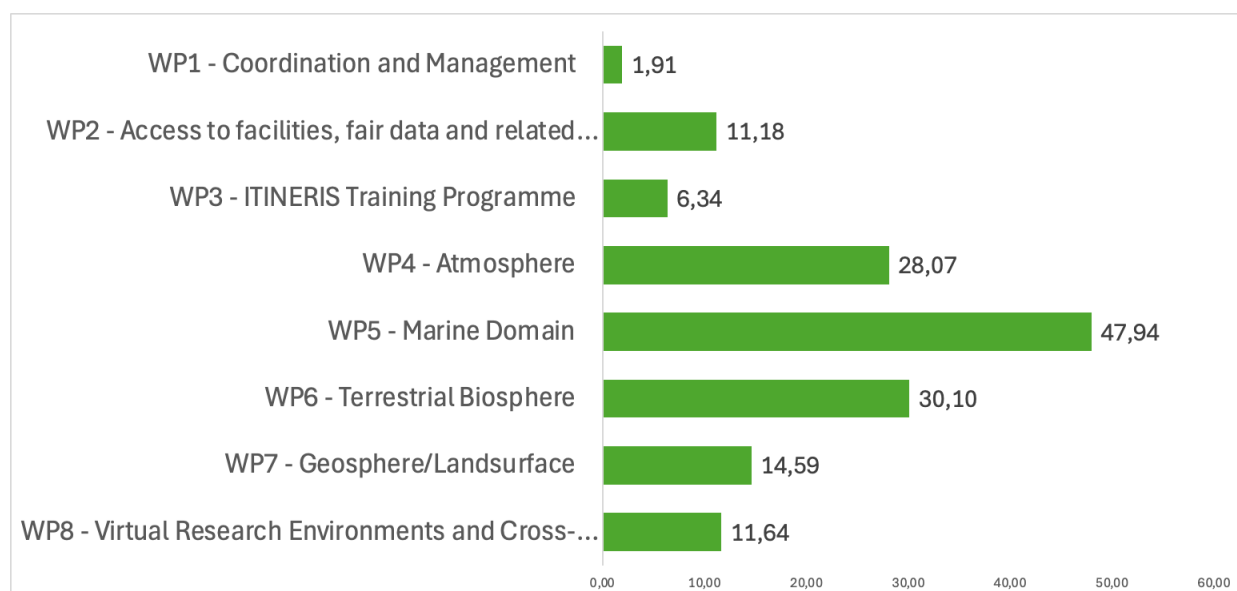


Figure 4 - Expenditures by Work Package in Million Euro

Ultimately, more than €109 million of the spent budget were successfully dedicated to direct procurement activities, resulting in the acquisition and upgrade of advanced scientific equipment, monitoring systems, analytical platforms, and computational resources distributed across the participating infrastructures. These investments significantly enhanced the operational capacity and technological readiness of the national environmental research ecosystem, particularly in domains where advanced instrumentation and interoperable digital services are decisive for scientific performance and long-term usability.

The remaining share of the executed budget was allocated in line with the call guidelines to support the project's core enabling activities: personnel costs covered dedicated staff engaged in the infrastructure's implementation and operation, including researchers and technical staff recruited to strengthen project delivery and ensure continuity of specialized activities; Open/Transnational Access financed virtual and physical access actions, user support, and the development of FAIR-compliant data management methodologies for research infrastructure services; general expenses and other indirect costs necessary to ensure the effective functioning of the project; and training and in-house research activities funded the development of specialized human capital through doctoral grants, advanced apprenticeship, executive education, and other capacity-building initiatives that reinforced the long-term sustainability of the infrastructure.

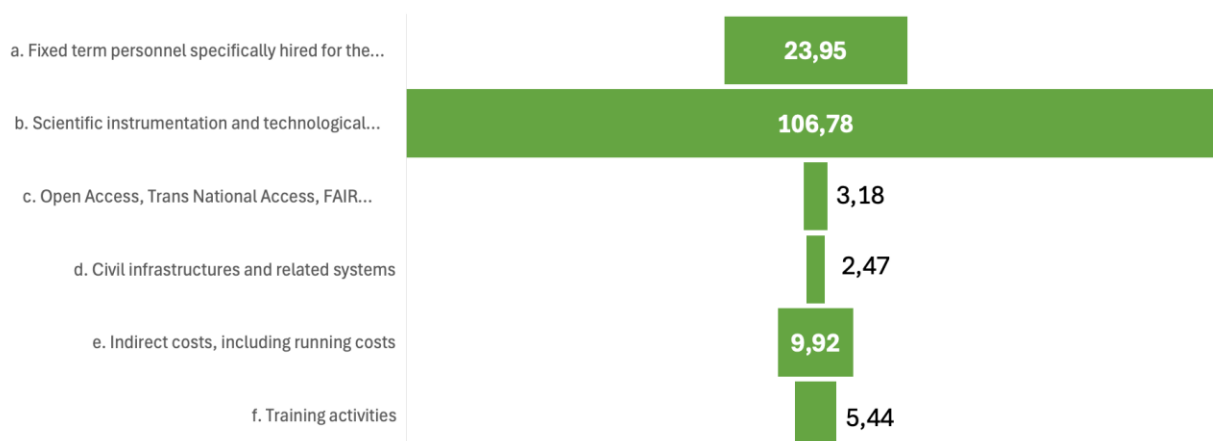


Figure 5 - Expenditures by cost category in Million Euro

Investments were distributed across the national territory, ensuring compliance with the NRRP territorial allocation targets. In particular, over 46% of the total project budget was invested in the Southern Italy

regions, supporting the enhancement of scientific infrastructures, technological capacities, and research services in areas identified as strategic for territorial cohesion.

The distribution in the figure below demonstrates how ITINERIS combined scientific excellence with the broader objective of strengthening the national environmental Research Infrastructure ecosystem in a balanced and inclusive manner: heatmap shows the distribution and concentration of expenditures (Mln €) across Italian regions, highlighting higher values in darker shades; doughnut chart illustrating the proportional breakdown of total reported amounts between the Centro-Nord (54%) and Sud (46%) macro-areas.

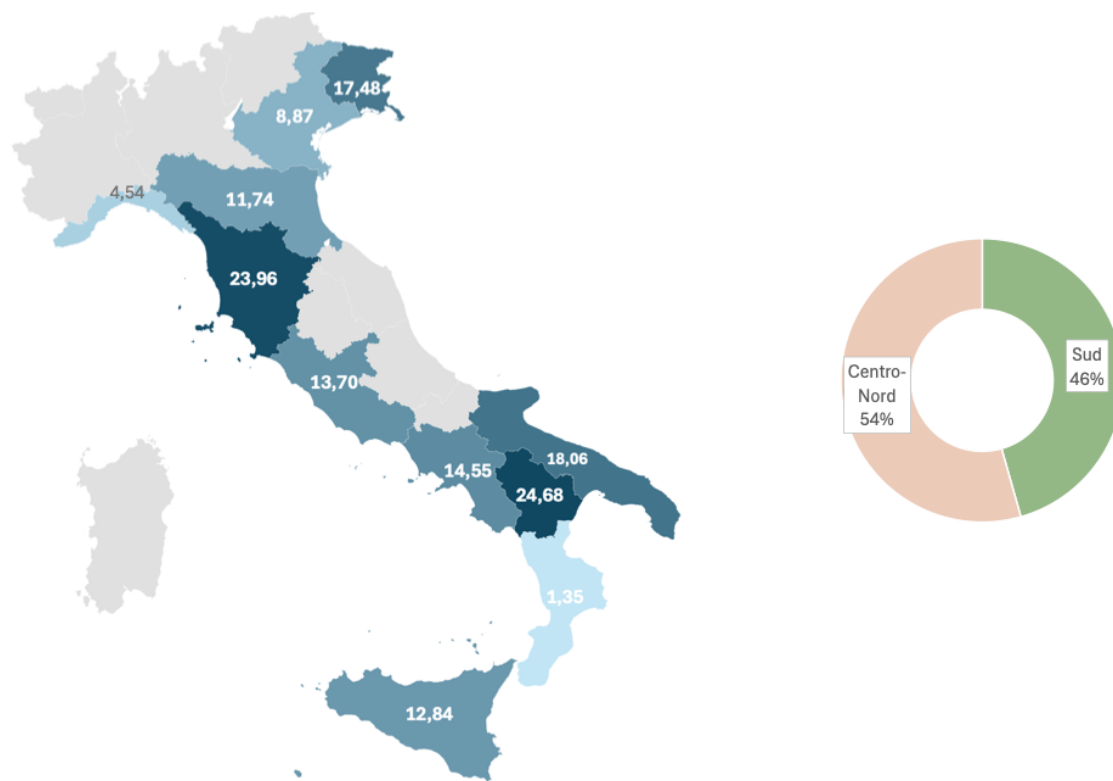


Figure 6 Geographical distribution of expenditures in Milion Euros and regional share

2.3. Personnel and human capital

In addition to physical and digital infrastructure, the project invested significantly in human capital. ITINERIS recruited 190 professionals through 165 selection procedures, strengthening the scientific and operational capacity of the participating infrastructures and contributing to the development of a new generation of environmental research professionals. Recruitment was therefore not an ancillary component of the project, but a central implementation lever that allowed the consortium to translate planned investments into functioning scientific and technical capabilities.

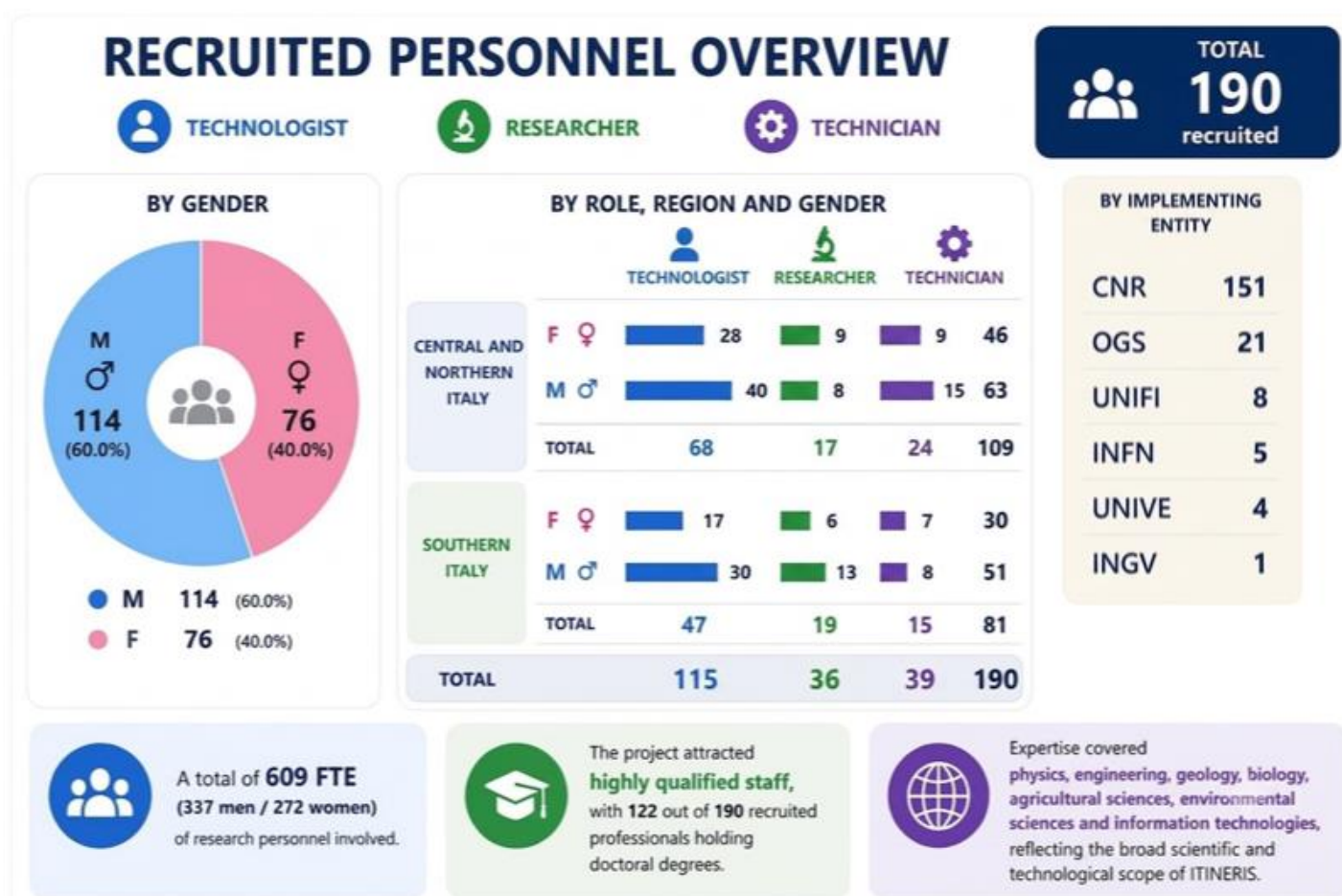


Figure 7 - Overview of recruited personnel

The recruited personnel reflected the multidisciplinary nature of the project and included researchers, technologists, technicians, data managers, software developers, and administrative staff, supporting activities across all Work Packages and scientific domains. Their expertise covered physics, engineering, geology, biology, agricultural sciences, environmental sciences and information technologies, reflecting the broad scientific and technological scope of ITINERIS. The project attracted highly qualified staff, with 122 out of 190 recruited professionals holding doctoral degrees, while the recruitment programme also contributed to national territorial cohesion objectives, with 81 positions located in Southern Italy. Gender balance was actively promoted, with women representing approximately 40% of the recruited personnel.

ITINERIS also supported doctoral education by funding 44 PhD positions across 15 Italian universities, creating a nationwide network of early-career scientists connected to the Research Infrastructures and fostering closer integration with academic research.



Figure 8 - Geographical distribution of funded PhD positions across Italian universities

The broader human capital dimension of the project extended well beyond direct recruitment. According to indicator RRFIC08, the number of research personnel involved in the supported research centres reached 609 Full-Time Equivalents (337 men / 272 women), excluding additional administrative support staff. This figure shows that ITINERIS mobilised a wide community of expertise across the national research system, combining newly hired staff with the existing scientific, technical and administrative resources of the participating institutions. The project therefore strengthened not only the implementation capacity of the consortium, but also the longer-term human base needed to operate, maintain and develop the infrastructures after the end of NRRP funding.

A particularly important contribution was provided by the Infrastructure Manager, a role that served throughout the project and led the Coordination Office, ensuring continuity in strategic, operational and administrative management. The manager oversaw project monitoring and reporting activities, institutional relations with MUR, support to governance bodies, and strategic actions related to the development of the ITINERIS HUB and access framework. He also contributed to follow-up initiatives and sustainability actions aimed at consolidating the project legacy beyond the PNRR timeframe, while coordinating the Working Group of the Environmental RIs funded under the PNRR and promoting collaboration with private-sector stakeholders and institutional representation of ITINERIS at national and international level. This role is worth mentioning because it shows that the project's human capital was not limited to hired personnel but included stable coordination leadership capable of ensuring continuity and institutional memory.

2.4. Compliance, NRRP conditionalities and horizontal principles

ITINERIS was implemented in full compliance with the regulatory framework established for NRRP projects under Notice No. 3264 of 28 December 2021, including all applicable requirements concerning financial eligibility, procurement regularity, anti-fraud and anti-corruption measures, conflict of interest prevention, double-funding avoidance and data reporting obligations. Compliance was managed as a continuous and structured process, embedded in the project's governance and monitoring architecture rather than treated as a purely ex-post verification activity.

The implementing entities ensured compliance through a combination of administrative, financial and procedural controls, supported by self-assessment checklists, internal verification procedures and systematic archiving of supporting documentation. All expenses submitted for reimbursement were verified for eligibility, consistency with project objectives and budget, payment traceability and correct accounting allocation. Verification controls included the presence of legally binding commitments, the project CUP code on all financial documents, proof of payment, compliance with the eligibility period and the availability of complete audit trails. The digital monitoring platform developed within WP1 played a central role in integrating these compliance functions into a single, structured and auditable ecosystem, providing real-time visibility of compliance status across all Work Packages and operational units.

Dedicated measures were adopted throughout the project to prevent, detect and address serious irregularities including fraud, conflict of interest, and double funding. Declarations on the absence of conflicts of interest were collected from all relevant personnel where required by applicable regulations, and internal procedures ensured that any potential conflict was identified, documented, and managed in accordance with NRRP guidelines. Checks on double funding were systematically integrated into the expenditure verification process, ensuring that costs claimed under ITINERIS had not been financed by other national or EU funding sources.

Beneficial owner information was collected and verified in accordance with national and EU anti-money laundering rules, and the required documentation was maintained and made available for audit purposes.

The field of intervention declared for the project — code 055 under Regulation (EU) 2021/241 Annexes VI and VII — was consistently respected throughout implementation. All activities carried out by the implementing entities were confirmed as relevant to this field, and no deviations requiring justification were identified.

The Do No Significant Harm principle was systematically integrated into planning, procurement and operational activities throughout the project. In accordance with NRRP requirements and the provisions of the Environmental Code, activities incompatible with the DNSH principle were excluded from the outset, and DNSH declarations were collected and verified at all stages of implementation. The monitoring system developed within WP1 incorporated dedicated modules for tracking DNSH compliance across all procurement procedures and financial commitments, ensuring that compliance verification was consistent, documented and auditable. The scientific nature of ITINERIS — focused on environmental observation, monitoring and research — is inherently aligned with the DNSH principle, as the project's activities contribute directly to improving understanding of environmental processes and supporting evidence-based approaches to environmental management and protection. No activities posing significant risks to environmental objectives were identified or implemented during the project lifecycle.

Open Science and FAIR Data principles were not treated as external compliance requirements in ITINERIS: they were embedded in the project's design, architecture and daily operations from the outset. The project was conceived to support a trusted, federated and multidisciplinary environment in which data, metadata, services, software and analytical workflows could be discovered, accessed, reused, and combined across domains in full alignment with FAIR, and EOSC principles. Scientific outputs and datasets were progressively made available through the ITINERIS HUB, described using standardised metadata schemas and managed according to FAIR principles, while respecting privacy, security and intellectual property requirements where applicable. The development of 16 FAIR Implementation Profiles, the publication of a machine-readable and human-readable Data Management Plan, and the establishment of the ITINERIS Terminology Service collectively demonstrate the structured and systematic nature of the project's commitment to FAIR implementation. Persistent identifiers (DOIs) were assigned to all new datasets produced within ITINERIS, ensuring traceability and FAIR-compliant reuse.

The ITINERIS HUB was integrated from the outset within the Italian EOSC Node, ensuring alignment with EOSC principles and interoperability with the broader European Open Science Cloud ecosystem. Project outputs including guidelines, best practices and technical reports were published under open licences (CC-BY 4.0), and all communication materials, publications and dissemination outputs complied with the open access obligations established under the NRRP framework.

The project contributed substantially to the Digital Tagging objectives established under the NRRP framework through the deployment of advanced digital infrastructures, interoperable platforms, data management systems, and digital services supporting environmental research activities. Key contributions include the development of the ITINERIS HUB and its component platforms (Catalogue of Data and

Services, metaDATA HUB, Access Platform, Terminology Service, Training Platform, VRE gateway), the implementation of network infrastructure based on an IP Fabric architecture using EVPN/VxLAN, the deployment of high-availability security and monitoring systems, and the enhancement of storage infrastructure through full-flash Storage Area Networks and Scale-Out Network Attached Storage systems. These investments collectively enhanced data accessibility, computational capabilities and digital collaboration across the environmental research community, strengthening the digital transformation of the national research ecosystem in line with NRRP digital tagging requirements.

The project contributed to horizontal principles on equal opportunities and gender equality through dedicated actions integrated into recruitment, training and community-building activities. Among the 190 personnel recruited during the project, women represented approximately 40% of the total, demonstrating consistent attention to gender balance in selection processes. The project also promoted the professional development of early-career scientists and supported intergenerational knowledge transfer through advanced training activities, the PhD programme and the ITINERIS Training Centre.

All implementing entities applied the approved communication guidelines and ensured full compliance with EU and MUR publicity and visibility obligations throughout the project. Dissemination materials, websites, publications, events and communication outputs consistently displayed the required EU and NextGenerationEU visibility elements in accordance with applicable guidelines. The project developed and maintained the ITINERIS web portal, managed social media channels, produced newsletters and communication materials, and participated in major scientific and institutional events at national and international level, including the GEO Week and major European scientific conferences. These activities contributed to the visibility of NRRP investments in environmental research and to the dissemination of project results to scientific, institutional and broader public audiences.

ITINERIS contributed to the Common Indicator RRF-CI-08 by strengthening and integrating national Research Infrastructures and by providing researchers with access to advanced facilities, services, data and digital platforms. The number of research personnel involved in the supported research centres reached a peak of 609 Full-Time Equivalents (FTEs), including 337 men and 272 women, reflecting the broad and interdisciplinary community engaged by the project. These figures do not include the additional administrative and managerial personnel who contributed to project coordination, governance and implementation, nor the large number of external users who accessed project services, training resources and data through the ITINERIS HUB and related platforms.

2.5. Risk management and adaptive implementation

Operating in a multi-partner, high-budget and time-sensitive NRRP framework, WP1 served as the primary instrument for risk mitigation and adaptive management. The work package proactively identified and addressed critical operational bottlenecks related to personnel recruitment, international procurement, and reporting schedules, preventing administrative or technical delays from impacting the overarching scientific milestones. The project achieved full implementation, completing 100% of the approved work plan and ensuring the delivery of all expected activities and results foreseen under the proposal and its subsequently approved updates, with no major deviations from the approved plans.

As expected for a project of this scale and duration, implementation required adaptation to evolving operational conditions, procurement timelines and technical requirements. The consortium demonstrated considerable flexibility in addressing emerging challenges, managing project amendments and adjusting implementation strategies whenever necessary while preserving the overall objectives and expected outcomes of the initiative. The governance framework established within ITINERIS proved effective in supporting decision-making processes, facilitating coordination among institutions and maintaining the overall coherence of the project. WP1 further coordinated the preparation of project amendments, supervised implementation timelines and ensured the proper justification and processing of budget reallocations through the relevant institutional procedures.

During its lifecycle, the project benefited from 3 time-extensions formally approved by MUR. These extensions successively moved the project end date from 30 April 2025 to 31 October 2025, then to 30 April 2026 and finally to 30 June 2026. The requests were submitted and approved in accordance with the applicable ministerial provisions and were supported by detailed technical and administrative

justifications. The extensions ensured the full completion of all planned activities while addressing external and operational factors that had affected the initial implementation schedule, particularly delays in recruitment and procurement, the impact of changing market conditions and supply chains, and the introduction of the new Italian Public Procurement Code.

The extraordinary project amendment approved in September 2025 also allowed the formal realignment of the project implementation plan, including intermediate objectives and their financial allocation, with the actual implementation dynamics. Furthermore, five ordinary amendments were approved and implemented to reallocate budget surpluses resulting from procurement efficiencies, savings and alternative technical optimisations identified during implementation. All modifications complied strictly with applicable guidelines, keeping the project's objectives and structural coherence intact. Far from indicating weakness, these adjustments show that the project was governed through a genuine implementation logic, in which resource allocation was continuously adapted to operational realities while preserving the overall strategic design.

Beyond the successful delivery of planned activities, the experience gained through the management of ITINERIS has contributed to strengthening collaboration among institutions and infrastructures operating within the Italian environmental research landscape. The governance mechanisms, coordination practices and monitoring tools developed during the project constitute an important organisational legacy that may support future initiatives aimed at further integrating national Research Infrastructures and enhancing Italy's participation in the European research ecosystem.

3. PART III — CROSS-DOMAIN RESULTS

ITINERIS did not simply upgrade a set of environmental Research Infrastructures (RIs) operating in parallel. It created the conditions for these RIs to function as an integrated national system, connected through shared digital components, common access and data policies, interoperable metadata and semantic resources, coordinated training actions, and cross-domain analytical environments. This section presents the project-level results that cannot be fully understood when read only through the lens of the individual Work Packages, because they emerged from the interaction between domains, services and communities across the whole ITINERIS architecture.

The following results are selected as the most representative examples of the project's integrated legacy. They illustrate the broader transformation achieved by ITINERIS, while the detailed technical and disciplinary evidence remains available in the individual WP reports under section II.

3.1. The ITINERIS HUB

The ITINERIS HUB (<https://hub.itineris.cnr.it>) is the main infrastructural legacy of ITINERIS as it is the enabling layer through which the project federated 22 Research Infrastructures, exposed large and heterogeneous collections of resources through common metadata and APIs, embedded shared access workflows, and made cross-domain interoperability a practical capability rather than a stated ambition.

Welcome to the ITINERIS HUB

The single gateway to the wide range of data, cutting-edge facilities, analytical tools, and services provided by the Italian environmental Research Infrastructures

What are you looking for?

Q Insert keywords here

[Dataset](#) 1000
 [Service](#) 40
 [Research Infrastructure](#) 22
 [Research Product](#) 30
 [Provider](#) 23
 [VRE](#) 9
 [Training Resource](#) 9

Select a resource type or [view all resources](#)

Features and applications of the ITINERIS HUB



Figure 9 - ITINERIS HUB homepage

The ITINERIS HUB was conceived and implemented not as a simple project website or catalogue, but as the common digital infrastructure enabling discovery, access, interoperability and reuse across the national network of environmental RIs. Besides serving as a simple aggregator or visibility tool, the ITINERIS HUB is a fully integrated digital ecosystem that offers advanced functionalities to enhance research impact. It directly addresses the project's core-mission by providing unified access to the resources of Italian environmental RIs, overcoming the fragmentation that characterised the pre-ITINERIS scenario. Such fragmentation was not only technical but also strategic, resulting from heterogeneous levels of maturity, different approaches to FAIR principles, and diverse access and data management practices across RIs.

This integrated digital ecosystem is built upon shared standards, common metadata schemas, and interoperability protocols, ensuring semantic alignment and enabling both human and machine-to-machine interactions. It also reflects a broader methodological approach that combines the adoption of best practices, capacity building across RIs, and a strong user-oriented design, addressing key user needs and challenges in accessing research resources.

The Catalogue of Data and Services (<https://catalogue.itineris.cnr.it>) is the core component of the ITINERIS HUB and one of its most tangible achievements. It serves as the main single-entry point for virtual, remote and physical access to environmental RI resources, transforming highly distributed and heterogeneous assets into a unified discovery space while allowing them to remain managed at source by the participating RIs.

In this sense, the Catalogue and the connected metaDATA HUB provide the metadata backbone of the platform and the central discovery of resources provided by the environmental RIs. At the same time, the HUB is a broader digital ecosystem built around this core layer. It integrates additional platforms and services — including the Access Platform, the Terminology Service, the VRE component and the Training Platform — through shared standards, common workflows and interoperable interfaces. This architecture allows the HUB not only to support resource discovery, but also to enable access, semantic interoperability, analytical reuse, collaborative research through dedicated VREs, and capacity building within a single user-facing environment.

A comprehensive mapping of the catalogues maintained by the 22 participating RIs was carried out to define the methodological and technical choices underpinning the development of the unified ITINERIS catalogue. On this basis, standardised metadata schemas were established for the different resource types, with the aim of promoting interoperability, improving comparability across domains and supporting interdisciplinary research. This exercise also made it possible to assess consistency across RIs, identify overlaps and gaps, and define opportunities for harmonisation, standardisation and further integration.

The interoperability framework was further formalised through a FAIR Implementation Profile documenting the standards, policies and FAIR-enabling resources adopted within the infrastructure.

The Catalogue now provides a centralised metadata registry that enables users to discover, access, and evaluate resources made available by the participating RIs. It currently offers access to a large and continuously growing collection of resources, demonstrating both the scale and heterogeneity of the integrated resource base:

- Datasets: Over 500,000 metadata records describing environmental datasets harvested and published in the metaDATA HUB²
 - Services: more than 60 services published on the ITINERIS catalogue by different RIs
 - Research products: more than 300 research products published
 - Training resources: more than 600 training resources made available through the Training Platform³
 - Research infrastructures: metadata of the 22 RIs participating in ITINERIS
 - Providers: metadata records describing more than 35 providers of data, services and resources from the participating RIs
 - VRE: 9 Virtual Research Environments developed to support specific environmental research domains and communities and delivered mainly through the D4Science gateway⁴, providing dedicated collaborative environments for users and research communities.
- Terminology Service: the semantic interoperability service providing access to controlled vocabularies, ontologies and other semantic artefact⁵

The screenshot displays the ITINERIS Catalogue interface. At the top, the logo features a stylized globe icon next to the text 'ITINERIS CATALOGUE'. Below the logo is a search bar with the placeholder text 'Insert keywords here'. A horizontal navigation bar contains several categories with their respective counts: Dataset (39120), Research Product (319), Service (66), Research Infrastructure (22), Provider (21), VRE (9), and Training Resource (1). To the right of these counts, specific statistics are shown: 9 Metadata Sources, 39.5k Items, 23 Research Infrastructures, and 7 Types. On the left side, there is a 'Refine your search' section with a 'Filter by location' map and a 'Metadata Sources' dropdown menu currently set to 'ITINERIS Catalogue' (39165). Below this is a 'Types' section with a list of categories and their counts: Dataset (38730), Research Product (319), Service (63), Research Infrastructure (22), Provider (21), and a 'See all Types' link. Further down is a 'Research Infrastructures' section with a list: ACTRIS (26) and DISSCO (12). The main content area on the right shows '39,165 items found' and a list of items. The first item is 'Training on Lidar data analysis, SCC and on technical aspects of Lidar systems', published on April 4, 2026, by Catalogue Manager ITINERIS. The second item is 'Digitisation and metadating of natural scientific collections', published on April 4, 2026, by Armelli Minicante Simona. The third item is 'Biomass Pretreatment', published on April 4, 2026, by Di Fenza Mauro. The fourth item is 'In-situ intercomparison for near-surface gas and aerosol analyzers', published on April 4, 2026.

Figure 10 - The Catalogue of Data and Services listing page

² <https://geonetwork.itineris.cnr.it/geonetwork/srv/ita/catalog.search#/home>

³ <https://training.itineris.cnr.it/en/>

⁴ <https://hub.itineris.cnr.it/virtual-research-environment-vre/>

⁵ <https://terminologyservice.itineris.cnr.it/>

Technical architecture and interoperability framework of ITINERIS HUB

The ITINERIS HUB is the central digital platform supporting data discovery, access, interoperability, and reuse. It has been designed as a modular, standards-based, and interoperable system to manage heterogeneous scientific data and services, fully aligned with European Open Science policies and FAIR principles.

The architecture combines specialised components for metadata management, resource publication, semantic interoperability and collaborative research environments. In particular, the D4Science infrastructure provides the operational framework supporting catalogue services, Virtual Research Environments, user management and collaborative workflows, contributing to the integration of heterogeneous resources and communities within a common federated ecosystem.

The catalogue was developed using open-source CKAN technology, chosen for its capabilities in managing large collections of datasets, providing access via web interface and APIs, and enabling harvesting of metadata from remote catalogues. Datasets are described according to the DCAT-AP standard for datasets, ISO 19139 for geospatial metadata, and EOSC/OpenAIRE-oriented profiles for other resource types. Persistent identifiers (DOIs) have been assigned to all new datasets created within ITINERIS, ensuring traceability and FAIR-compliant reuse. This design supports both human navigation and machine-to-machine interaction, making the HUB usable not only as a browsing portal but also as a programmable infrastructure layer.

Besides its technical role, the Catalogue establishes a common governance framework for the description, publication and maintenance of resources across the participating infrastructures. Resource publication in the catalogue is governed through a moderated onboarding and validation process that ensures metadata quality, semantic consistency and interoperability across participating infrastructures.

Metadata management and discovery are handled by the metaDATA HUB, based on GeoNetwork 4.x, which supports international and European standards such as ISO 19139 and INSPIRE and enables metadata harvesting through standard protocols — OGC CSW 2.0.2 and OAI-PMH — ensuring semantic interoperability and federated discovery with external catalogues and RIs. Technically, CKAN connects to GeoNetwork through the OGC CSW 2.0.2 interface, issuing GetCapabilities, GetRecords, and GetRecordById requests to retrieve ISO 19139-compliant metadata records. CKAN does not access the GeoNetwork database directly; it strictly uses the published catalogue APIs. This approach combines automated harvesting with manual onboarding, allowing the inclusion of resources at different levels of maturity while maintaining high data quality and consistency.

The metaDATA HUB also includes a dedicated monitoring layer: automated harvesting workflows validate metadata records against INSPIRE- and OGC-compliant schemas and perform continuous checks on dataset availability across distributed data providers. The system periodically verifies the status of remote endpoints, detects missing or outdated records, and logs potential inconsistencies in harvesting operations. Alerts and diagnostic reports support operators in maintaining reliability and interoperability across the ITINERIS data landscape, ensuring the long-term integrity, FAIR compliance, and operational continuity of dataset discovery services within the national RI.

Data access and dissemination are supported through domain-specific services. ERDDAP enables standardised, programmatic, and machine-readable access to multidimensional scientific datasets, allowing subsetting, filtering, and retrieval in multiple formats and through different protocols. GeoServer complements this functionality by providing geospatial data publication and visualisation services compliant with OGC standards (such as WMS, WFS and WCS), facilitating interactive map-based exploration and integration with external GIS tools and platforms. Together with the catalogue, metaDATA HUB and Access Platform, these services show that the ITINERIS HUB was designed as a modular but coherent ecosystem capable of serving multiple scientific communities and use cases without flattening disciplinary diversity.

A crucial aspect of the architecture is that resource integration does not depend on centralising all content in one repository. Instead, ITINERIS adopted a federated model in which resources remain distributed across the original RI systems while their metadata are harmonised and exposed through shared standards, harvesting workflows and common onboarding procedures. Rather than requiring all participating RIs to abandon their existing systems, the project created a framework in which RIs with

different levels of digital maturity can progressively align with the HUB while preserving their operational autonomy.

By the end of the project, the ITINERIS HUB had operationally integrated and automatically harvested metadata from 12 Research Infrastructures, providing a federated discovery layer across environmental domains. This figure refers specifically to the onboarding of metadata catalogues and interoperability services within the HUB and should not be interpreted as the full integration of all resources, facilities and services available within each participating Research Infrastructure. The progressive expansion of metadata harvesting and resource integration remains one of the key objectives of the post-project phase.

3.2. The National Access Framework

A further integrated result of ITINERIS lies in the fact that access was progressively transformed from a set of infrastructure-specific procedures into a coherent national framework supporting coordinated, transparent and user-oriented access across the environmental RI system. Rather than remaining confined to the governance logic of individual infrastructures, access became a project-level function designed to enable interoperability among facilities, support multidisciplinary research needs and lay the foundations for a sustainable national access programme.

In this perspective, WP2 helped establish the conceptual and operational basis for a common access architecture, through user strategy and pilot actions converging into the development of policies, procedures and digital platforms in a single systemic vision.

In line with the European Charter for Access to Research Infrastructures, and the evolving European and national policy landscape, the Access Policy establishes a common framework ensuring open, equal and transparent access to facilities, resources and data of environmental RIs in the network. It is designed to meet the needs of the wide range of users, offering the opportunity to conduct scientific experiments, use state-of-the-art research tools and equipment, and benefit from technical services, expert support and training, and educational activities. The policy enables coordinated and concurrent access to multiple RIs, supporting complex and multidisciplinary projects that span different facilities and scientific domains.

The ITINERIS HUB Data Policy defines the governance principles applicable to data and metadata made available through the ITINERIS HUB. It distinguishes resources produced within the ITINERIS related projects from those harvested from federated Research Infrastructures, clarifies the corresponding licensing regime, and establishes expectations concerning attribution, access conditions, accountability, and long-term policy maintenance. These principles are intended to be progressively extended to additional domains and use cases where the ITINERIS HUB serves as a common access point for data, metadata, and services, ensuring a consistent governance framework aligned with the same foundational principles outlined in the policy.

Access and service provision are aligned with the ITINERIS user strategy which is constantly updated to involve users and ensure that service development/improvement efforts meet their expectations and needs and will continue to do so over the long term.

The Access Platform is another core HUB component with project-wide relevance. Developed as a customised management system to manage national access programs, and enhanced from ACTRIS SAMU to meet the ITINERIS requirements, it supports the entire workflow for access requests, from submission and eligibility checks to scientific and technical evaluation, allocation, monitoring and final reporting, as described in the ITINERIS Access Management Plan. This means that the HUB is not limited to resource discovery; it also operationalises coordinated access — one of the main strategic objectives of ITINERIS from the original proposal stage onward.

Access pilot actions

A further and particularly important integrated result of ITINERIS lies in the way the access was progressively shaped into a cross-cutting operational function, rather than remaining a set of isolated

procedures belonging to individual infrastructures. Across the project, access was not limited to formal transnational access calls, or to the physical opening of facilities; it also included access to federated environmental data and digital services through the ITINERIS HUB, the use of shared digital platforms, the activation of Virtual Research Environments, the deployment of new observation and analysis tools, and the strengthening of collaboration among infrastructures operating in different domains. In this sense, ITINERIS it changed the way access itself was conceived, organised and experienced within the Italian environmental RI landscape, while increasing the volume of available access opportunities. Access is no longer conceived as an isolated service provided by individual infrastructures, but as an integrated ecosystem combining physical facilities, distributed observatories, digital services, federated metadata, Virtual Research Environments and coordinated governance through a common national framework.

This section focuses on the major physical, remote and hybrid access actions implemented during the project, which most clearly illustrate the ITINERIS' contribution to the development of a coordinated national access framework. While virtual access to data and digital services is enabled through the ITINERIS HUB and the associated digital ecosystem described in the previous chapter, the initiatives presented here concern access to distributed research facilities, observational platforms, laboratories, specialised services and research infrastructures through physical, remote or combined access modalities. These experiences helped validate common governance models, harmonise procedures, expand user participation and strengthen the visibility of ITINERIS facilities at both national and international level.

The evidence collected from the Work Packages shows that access actions were distributed across the project in multiple forms.

In WP4, access to atmospheric research infrastructure facilities represented a major component of the work and was closely linked to the integration of advanced instrumentation into the operational activities of the participating units. Some of the instrumentation enabled by ITINERIS was deployed in different locations to extend the geographical and temporal coverage of atmospheric observations at national level, and this was achieved either through access activities or through research collaborations. Most significantly, WP4 implemented the ITINERIS-ACTRIS Access Programme in coordination with WP2, resulting in 58 successful national and international access projects (see dedicated box below).

A similar logic is visible in the marine domain. WP5 developed IT-IOOS by incorporating and scaling up existing ocean-observing capabilities already operated by the participating RIs, thereby creating the core of the Italian national ocean observing system. Although the IT-IOOS portal was opened to external users only recently, because the project was primarily devoted to system development, the access dimension is already central to its design. The platform was conceived to provide unified access to marine data and services, and its strategic relevance lies precisely in the fact that it connects the operational capacities of different marine RIs within a single access framework. The project also generated direct interactions with national and international stakeholders, and this makes it reasonable to expect that the impact of IT-IOOS will continue to grow in the coming years. The key point for the access chapter is that ITINERIS prepared the conditions for a durable and user-oriented marine access ecosystem, even where the full quantitative impact will only become visible over time.

WP6 further broadens the picture by showing that access in ITINERIS was inherently multi-modal. The access services developed in the terrestrial biosphere domain include ecosystem experimentation platforms, long-term monitoring sites, biodiversity collections and digitisation facilities, phenotyping infrastructures, biotechnology laboratories, and digital services and VREs. Several of these facilities were integrated into national and transnational access programmes and into European RI service catalogues, while digital services enabled the discovery and exploitation of interoperable datasets, workflows, and analytical tools according to FAIR principles. What matters here is not only that users could access a larger number of resources, but that the project created a layered access environment in which physical facilities, observational sites, digital services and analytical tools became part of the same service logic. The user base also became broader and more diverse, including researchers, students, public institutions and other stakeholders interested in environmental monitoring, biodiversity conservation, agriculture, biotechnology and ecosystem management.

WP7 worked to provide open-access geophysical and geological datasets, with a strong focus on interoperability and FAIR compliance. The integration of these datasets into the ITINERIS HUB is itself an access result, because it improves the discoverability, usability and reusability of resources that were previously fragmented or difficult to access in a coordinated way. Access to the ECORD infrastructure also led to a clear increase in the participation of Italian researchers in ECORD-ICDP campaigns and

international projects, with 15 participants in total, including 10 berth placements and 5 shore-based participations. This is a strong indication that access is not just a matter of availability, but also of scientific opportunity and community building. In addition, the ATLaS digital platform now enables the management of complex 3D datasets and the real-time application of forecasting models, providing direct support to civil protection authorities. In the same vein, the new instrumentation associated with PiTOP enabled 3 TNA activities, during which the performance of different DAS fibre types and interrogators was evaluated, with outcome not limited to technical testing: PiTOP gained visibility, OGS strengthened international collaborations, and a large amount of data was generated and shared on a FAIR basis with the scientific community. Finally, the inclusion of SNAP in the ITINERIS HUB and the development of the new SMINO portal show how access was also improved through better digital presentation, more transparent navigation and more effective linkage among access points.

Although pilot access actions are primarily centred on physical/remote/hybrid access, WP8 provided a crucial complementary digital layer through the development of the Virtual Research Environments (VREs) of the ITINERIS HUB. These environments enable users to discover, access and analyse distributed environmental resources through integrated computational workspaces without requiring direct interaction with the heterogeneous underlying infrastructures. VREs substantially lowered technical barriers to interdisciplinary research and transformed access from the simple availability of individual resources into integrated digital research environments, demonstrating how distributed environmental resources can be made available to users through integrated digital workspaces rather than through isolated infrastructure-specific interfaces. Their development therefore represents a key enabling factors of the national access framework established by ITINERIS.

A survey from the Research Infrastructures participating in ITINERIS confirm this broader picture and help interpret it at an aggregated level. Across the responses, the project clearly appears to have expanded access opportunities through a combination of direct access, shared campaigns, digital platforms and collaborative use of data and services. Three aggregate patterns are especially important.

- the project broadened the user base, with recurring references to national researchers, international researchers, doctoral candidates and young scientists, and in some cases to public authorities, policy makers and private actors.
- several infrastructures explicitly stated that the participation in ITINERIS had significantly expanded their visibility and that demand for access to their data or services is expected to grow after the end of the project.
- the responses suggest that access generated not only immediate usage but also a stronger institutional positioning for the participating RIs, because it placed them more firmly within national and European networks of services, campaigns and scientific collaboration.

Taken together, these results suggest that the most relevant contribution of ITINERIS in the access domain is not reducible to a list of access events or user numbers. The project created a new access culture based on integration, interoperability and shared governance. In practical terms, this meant that users could have access to the environmental RI resources — facilities, datasets, platforms, campaigns, VREs and service catalogues — through a single entry point, ITINERIS HUB. In strategic terms, ITINERIS established the foundations of a national access ecosystem that is more coordinated, more open to cross-domain research and more capable of supporting both immediate scientific exploitation and longer-term expansion of the user community.

The ITINERIS–ACTRIS Pilot Access Programme

The ITINERIS–ACTRIS Pilot Access Programme, launched in July 2024 and managed through the ACTRIS-PASS platform, attracted strong interest from the European research community.

The ITINERIS–ACTRIS Pilot Access Call was launched to test and validate a nationally co-funded access model, while expanding user access to ACTRIS facilities, services, and data and strengthening the integration of the Italian environmental research infrastructure landscape. Researchers from different disciplines were encouraged to apply and use ACTRIS services and data as well as to prove synergy with other Italian environmental RIs.

A total of 63 proposals were submitted from across Europe and beyond, resulting in 58 successfully implemented access projects, with additional 3 projects not carried out due to technical issues. The programme engaged 113 users from 10 countries, providing access to 62 ACTRIS facilities across three modalities — physical, remote, and hybrid — reflecting the diversity of user needs and the broad service portfolio. Approximately 30% of Italian facilities offered access for the first time within the ITINERIS framework, significantly expanding the national access portfolio.



The total budget allocated to the Pilot Access Call amounted to €903,000 — an amount initially set at €500,000 and later increased due to the exceptional level of interest generated by the call. Financial support was provided to both users and providers: each user could receive up to €5,000 for travel and subsistence costs, and each access provider up to €20,000 per single access project. The actual total expenditure reached €635,153.88, broken down as follows: €447,588 reimbursed to providers, €140,517 disbursed as user grants, and €47,048 allocated to ACTRIS ERIC for financial management contributions. User grants averaged €1,615 overall and €2,007 for transnational users, with physical access averaging 6.4 days (9.2 days for transnational access).

A key innovation was the introduction of a centralized national co-funding scheme enabling both international access to Italian ACTRIS facilities and Italian researchers' participation in ACTRIS facilities across Europe, supporting at the same time Italian providers and users. Financial management was centrally handled by ACTRIS ERIC, with grants calculated according to EU Commission Decision C(2021)35 unit costs, ensuring alignment with European TNA practices and reducing administrative burden. A dedicated legal framework — including a Collaboration Agreement, Service Agreements, and a GDPR-compliant Data Processing Agreement between CNR-IMAA and ACTRIS ERIC — governed the entire process with full transparency and traceability.

User feedback confirmed the programme's success, with an overall satisfaction score of 4.4/5 and facility service scores averaging 4.8/5. Nearly all respondents confirmed that access would not have been possible without the financial support provided. Feedback also provided actionable insights for future calls, particularly on simplifying procedures, improving communication clarity, and streamlining reimbursement timelines.

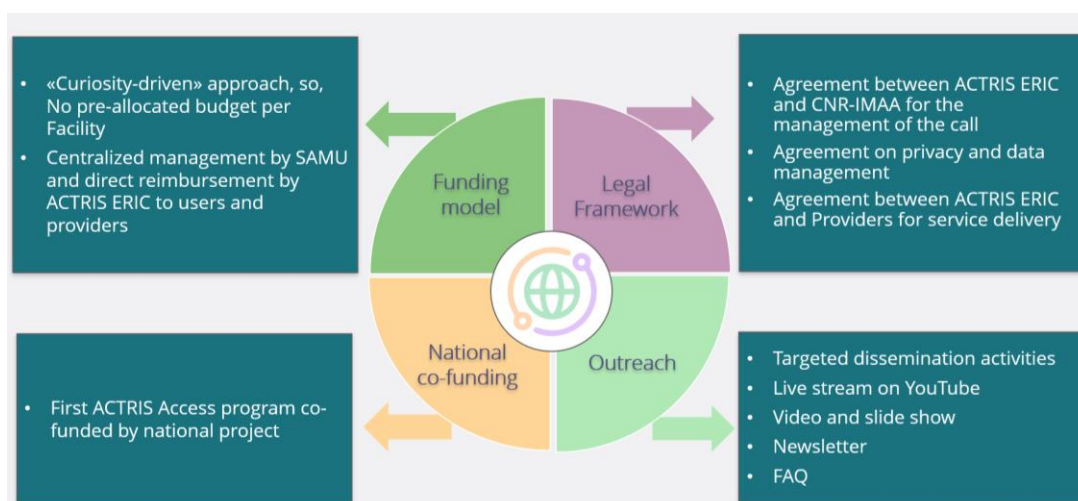


Figure 11 - Innovative aspects of the ITINERIS-ACTRIS Pilot Access Call

The ITINERIS–ACTRIS Pilot Access Call successfully achieved its objectives in terms of participation, community engagement, and transparency. It provides valuable operational experience for refining future access mechanisms. The lessons learned and the proposed adjustments provide valuable insights and recommendations to design future national access programme and are currently introduced in the management of a big EU funded project ATMO-SERV (2026-2030) that unites all Europe’s atmospheric Research Infrastructures to provide integrated, FAIR and open access to over 90 facilities and 12 digital services.

Beyond its immediate operational results, the ITINERIS–ACTRIS Pilot Access Programme generated strategic benefits at multiple levels (Figure X). For ITINERIS, it demonstrated the feasibility of a nationally co-funded access model and increased the visibility and attractiveness of the national environmental RI ecosystem. For ACTRIS ERIC, it provided a validated operational framework for centrally managed access, financial management and governance, generating practical experience that is already being transferred to future European initiatives such as ATMO-SERV. For ACTRIS Italy, the programme expanded the national access portfolio, strengthened coordination among facilities, increased user participation and reinforced the integration of the Italian node within both the national and European research infrastructure landscape.

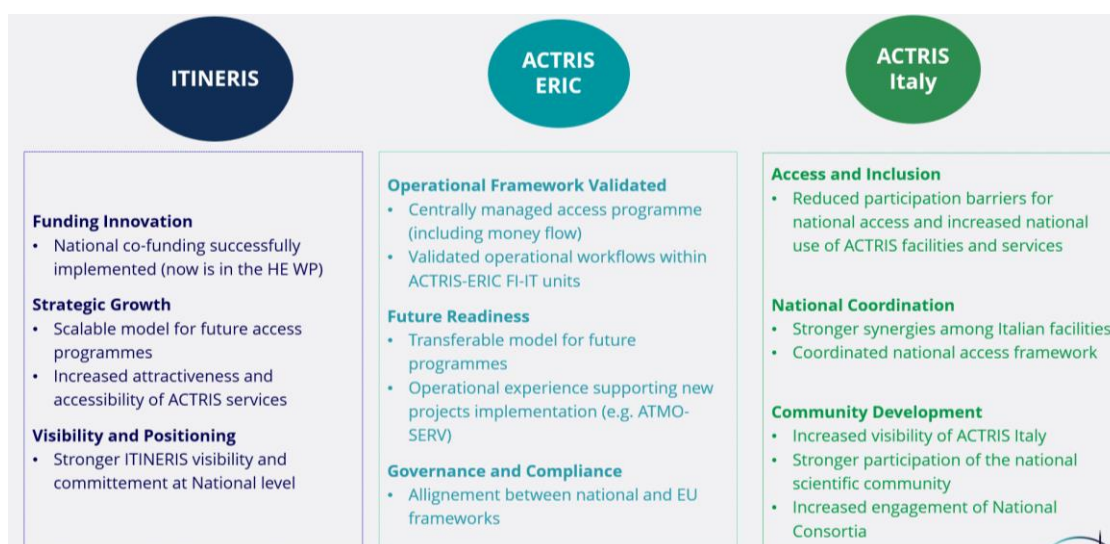


Figure 12 - Key operational and strategic benefits of the ITINERIS–ACTRIS Pilot Access Call

ITINERIS contribution to ECORD Access Programme

ITINERIS sustained a very different access programme, based on a membership fee. ECORD, a distributed RI in the geosphere domain, operates as an independent consortium of 14 members with a centralized management structure and as a member of the International Ocean Drilling Programme (IODP3). Its access model reflects this dual nature:

- drilling and legacy assets proposal submission is not subject to membership;
- access to expeditions is merit-based and weighted against the annual quota of the national member;
- access to training services is excellence-driven and subject to the membership fee;
- access to research grants and scholarships is an excellence-driven initiative for ECORD-based early-career scientists;
- upon request, access to samples/data after the expiration of the moratorium period is wide, unrelated to membership, and free of charge.

ITINERIS has enabled a remarkable increase in access for Italian scientists and students to the ECORD infrastructure in 2024 and 2025, elevating Italy to a prominent position among ECORD's medium contributors and promoting the scientific value of the Italian participation as a major achievement.

The following graphics show the peak of the Italian participation (quotas) in 2024 and 2025 across the transition from the IODP - International Ocean Discovery Program (2013-2024) to IODP3 - International Ocean Drilling Programme (2025-2029), owing to the ITINERIS contribution towards the access to the ECORD infrastructure:

- 883.000 € (1M USD) in 2024, of which 602.298 € represented the ITINERIS contribution
- 900.000 € in 2025, of which 700.000 € represented the ITINERIS contribution.



Figure 13 – Italian participation in ECORD and benefits coming from ITINERIS

In particular, in 2025, the ITINERIS contribution was provided by IMAA. The following list reports the outstanding participation (in numbers) of Italian scientists and representatives in 2024 and 2025: 22 Expeditions, 14 Summer Schools, 3 Scholarships, 4 Research Grants, 16 Panels.

Figure 14 - FAIR connectivity network of the ITINERIS ecosystem before and after ITINERIS

The work resulted in the publication of a peer-reviewed article in *Patterns* presenting the first systematic assessment of FAIR adoption across Italian environmental RIs⁶ as well as in the production of 16 new FAIR Implementation Profiles and an updated Data Management Plan in both human-readable and machine-readable formats⁷.

Semantic interoperability is another area where ITINERIS generated a project-level result with significance beyond the participating communities. The collection and FAIR assessment of semantic artefacts and catalogues used in environmental sciences was published in *Scientific Data*⁸, and this work laid the basis for the development of the ITINERIS Terminology Service. The Terminology Service promotes the reuse of semantic artefacts from multiple environmental domains and enables their exploitation for semantic annotation, providing a suite of services to support interoperability and reusability of cross-disciplinary digital objects. It streamlines access to semantic artefacts distributed across different sources, facilitates the discovery of existing semantic entities, and supports the generation of novel semantic mappings that strengthen interoperability between existing resources.

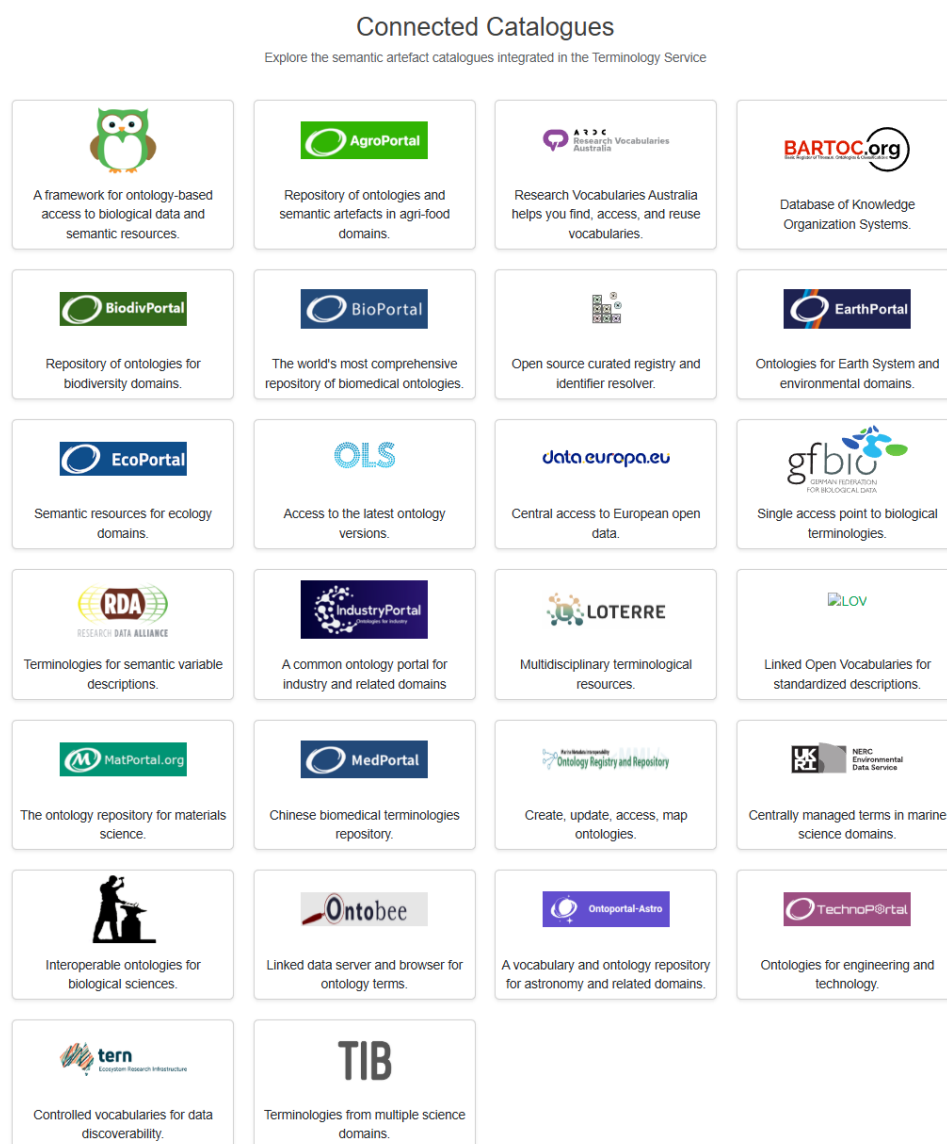


Figure 15 - Catalogues of Semantic Artefacts integrated in the Terminology Service

⁶ <https://doi.org/10.1016/j.patter.2025.101420>

⁷ <https://argos.openaire.eu/explore-plans/overview/public/f2f78a52-3ed1-4872-8a40-80df2fc98fed>

⁸ <https://doi.org/10.1038/s41597-024-03669-3>

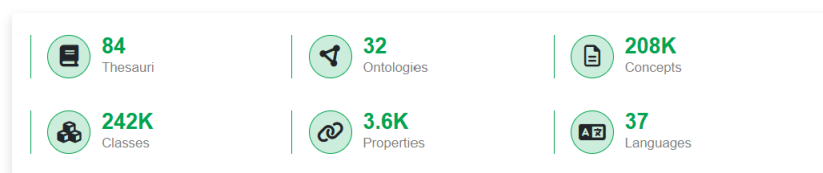


Figure 16 – Key statistics about the resources available in the Terminology Service

The FAIRness level of existing semantic artefacts used and/or managed by ITINERIS RIs was improved through enhanced metadata description and publication in EcoPortal⁹. In addition, the Environmental Research Infrastructures Thesaurus¹⁰ (ERITHES) was co-created within the project to provide concepts describing actors, ESFRI domains, facilities, services, research products and project management activities performed by environmental RIs. These integrations demonstrate that interoperability barriers often arise not from the absence of data, but from the lack of shared and machine-actionable vocabularies. Through the Terminology Service, semantic mappings, the improvement of existing semantic artefacts and the publication of new one through EcoPortal, ITINERIS provided a practical and reusable solution that can support both internal project interoperability and wider reuse beyond the environmental domain.

A key innovation is the release and integration of semantic search and annotation widgets¹¹. These portable components can be embedded into external (meta)data management systems to support semantic search and annotation of digital objects directly at the point of use. Their integration was demonstrated through three operational use cases within ITINERIS: the ITINERIS metaDATA HUB, the LifeWatch Italy Data Portal, and the LifeWatch Italy Metadata Catalogue.

All these relevant integrations because interoperability barriers often arise not from the absence of data, but from the lack of shared and machine-actionable vocabularies that would allow those data to be connected. Through the Terminology Service, semantic mappings, EcoPortal publication workflows and the co-creation of ERITHES, ITINERIS provided a practical and reusable solution to this problem, one that can support both internal project interoperability and wider reuse beyond the environmental domain.

Open Science by Design

Open Science was not an add-on to ITINERIS; it was a design principle embedded in the architecture, governance and daily operation of the project. From the outset, the project was conceived to support a trusted, federated and multi-disciplinary environment in which data, metadata, software, services and analytical workflows could be discovered, accessed, reused and combined across domains, in line with FAIR and EOSC principles.

The ITINERIS HUB is one of the clearest expressions of this strategy. Its value does not lie only in the fact that it integrates resources from 22 environmental Research Infrastructures, but in the way it turns openness into an operational feature of the system itself. Through its modular architecture, the HUB combines a central metadata catalogue, federated discovery, access services, Virtual Research Environments and training components into a single environment that supports both human use and machine-actionable workflows.

The HUB fully adheres to the FAIR principles: data and metadata are Findable through rich, standardised metadata and searchable catalogues; Accessible via open, well-documented protocols; Interoperable through community standards and shared schemas; and Reusable thanks to clear licensing, provenance information and alignment with international best practices. This approach ensures that openness is not limited to publication, but extends to the entire research lifecycle, from discovery and access to reuse and reproducibility.

This orientation is reflected in the technological choices made by the project. Open-source components such as CKAN, GeoNetwork, ERDDAP and GeoServer were adopted as the backbone of the platform, avoiding dependence on proprietary systems for core functions and ensuring that the infrastructure remains extensible, standards-based and sustainable beyond the project lifetime. Their integration within a modular

⁹ <https://ecoportal.lifewatch.eu/projects/ITINERIS>

¹⁰ <https://doi.org/10.48373/fae2-r561>

¹¹ <https://terminologyservice.itineris.cnr.it/widgets/playground.html>

and federated architecture is important because it makes openness a property of the system design, not just of the content it hosts.

The project also combined open data discovery, open metadata, persistent identifiers, clear licensing and distributed access within a coherent governance framework. Metadata on data and services were synchronised to the ITINERIS HUB catalogue through recommended access and harvesting protocols, while project outputs such as guidelines, best practices and technical reports were intended for open publication under CC-BY 4.0 licences. A DOI assignment service was developed to further strengthen FAIR-compliant reuse by providing persistent, citable identifiers for new datasets, while still allowing embargoes or restricted access where required by policy or data sensitivity.

Thanks to these choices, the ITINERIS HUB was integrated from the outset within the Italian EOSC Node, ensuring alignment with EOSC principles and interoperability with the broader European Open Science Cloud ecosystem. In practical terms, this places ITINERIS not only as a national repository of environmental resources, but as a building block of a wider European infrastructure for open, reproducible and machine-actionable science.

Taken together, the FAIR convergence work, the FAIR Implementation Profiles, the Data Management Plan, the Terminology Service and the associated semantic artefacts form a coherent Open Science ecosystem within ITINERIS. Their combined effect was to strengthen data stewardship, improve interoperability across environmental domains and make research outputs more discoverable, reusable and machine-actionable. In this sense, Open Science in ITINERIS was not only a matter of access to data and tools, but a systemic approach to designing a national infrastructure that is open by construction, sustainable over time and fully aligned with the EOSC vision.

3.4. Integration and cross-domain science

The most distinctive scientific legacy of ITINERIS lies in the fact that the project created conditions for the Italian environmental RI system to operate as an integrated observational and analytical ecosystem rather than as a set of adjacent disciplinary domains. This integration was not only organisational; it was made concrete through shared digital RIs, common semantic resources, coordinated access models, interoperable services and pilot scientific activities that combined expertise, data and facilities from different environmental domains.

Integration within ITINERIS occurred at multiple and complementary levels. It involved the combination of observations and expertise across different environmental domains, the coordination of infrastructures operating within the same domain, and the integration of heterogeneous datasets, services and analytical tools through shared digital environments. Together, these dimensions transformed previously fragmented resources into a more coherent environmental research ecosystem capable of addressing complex Earth-system challenges.

The examples below are illustrative of the project's broader integration capacity; more detailed disciplinary and technical evidence is provided in the individual WP final reports.

One of the most representative examples of cross-domain integration developed within ITINERIS is the combination of atmospheric and marine observation capacities through the deployment, for the first time, of an ACTRIS-compliant aerosol lidar on board the Gaia Blu research vessel. This configuration enabled the investigation of atmosphere–ocean exchange processes in the Mediterranean by combining marine observing platforms with advanced atmospheric instrumentation, demonstrating the scientific value of coordinated observations across traditionally separate environmental domains. Activities carried out in WP4 also strengthened integration through the development of innovative airborne aerosol sampling systems, providing Italy with a new observational capability accessible through EUFAR and related RI collaborations. These systems support the collection of samples for chemical, isotopic and biological analyses, including aerosol composition, pollen transport and carbon isotope measurements, substantially expanding the range of environmental processes that can be investigated through a common observational framework. By enabling the simultaneous characterisation of atmospheric particles from multiple perspectives, the project created new opportunities to connect atmospheric observations with ecosystem dynamics, carbon-cycle studies and broader environmental assessments. Integration was further reinforced through activities linking in situ observations with satellite-based Earth Observation systems. High-quality

atmospheric measurements and advanced aerosol products contributed to calibration and validation activities supporting Copernicus services and European Space Agency missions. By connecting ground-based, airborne and satellite observations within coherent observational frameworks, ITINERIS strengthened the role of national environmental infrastructures within European Earth Observation systems and improved the reliability and scientific value of environmental products used for research, operational services and policy applications.

The marine domain offers a further example of integration at system level. WP5 worked to establish the foundations of an Italian Integrated Ocean Observing System (IT-IOOS), connecting fixed, autonomous and shipborne observing platforms operated by different national RIs within a shared framework aligned with GOOS and EOOS observing principles.

The ITINERIS-EYES cruise, carried out on board the CNR research vessel Gaia Blu between 8 and 30 July 2025 across the Western Mediterranean, Tyrrhenian Sea, Sardinia Channel, Algero-Provençal Basin and Ligurian Sea, stands as the most concrete and emblematic cross-domain initiative of the project. The campaign was designed as an inter-disciplinary research cruise leveraging the combined technological and scientific contribution of 11 European and national Research Infrastructures operating in the marine, atmospheric and biodiversity domains: EURO-ARGO, EMSO, ICOS, ACTRIS, DANUBIUS, EUROFLEETS, JERICO, eLTER, DiSSCo, SIOS and LNS. It involved 31 units of scientific and technical personnel, 61% of whom were ITINERIS-recruited personnel and early-career scientists and deployed approximately 80 autonomous Argo floats and Lagrangian drifters to extend observational coverage beyond the ship track. Its scientific mission was to advance the understanding of Mediterranean marine planktonic ecosystems, their biodiversity, functioning and adaptation to climate change, by addressing gaps in the collection of ocean, climate and biodiversity Essential Variables (EVs) across four dimensions. The campaign also deployed the innovative 3D scanning atmospheric-marine LIDAR instrument, a Raman depolarisation fluorescence system capable of combining atmospheric and oceanic measurements, which was used in conjunction with the automatic photometer installed on the vessel's observation deck. This is one of the clearest examples of how ITINERIS made possible observational configurations that required simultaneous expertise and infrastructure from the atmospheric, marine and biodiversity domains — a result that no single RI could have produced independently.

Within the biosphere domain, integration was advanced through activities focused on Essential Variables and long-term ecosystem observations. By harmonising Essential Biodiversity Variables and Essential Climate Variables and linking observations generated through infrastructures such as eLTER, LifeWatch and ICOS, the project developed common approaches for analysing biodiversity dynamics, ecosystem functioning and climate-related processes. These activities demonstrated how datasets produced by different environmental communities can be combined to support integrated environmental assessments. A practical demonstration of this integrated approach was provided in the initiative that used long-term ecological observations, biodiversity monitoring and environmental data collected within the Presidential Estate of Castelporziano to support integrated ecosystem assessment and management. By combining scientific observations with the needs of land managers and decision makers, the case illustrated how environmental Research Infrastructures can contribute to adaptive governance, biodiversity conservation and evidence-based management of complex socio-ecological systems. A further example of cross-RI data integration is the coordinated provision of UAV multi-platform hyperspectral data and site-level measurements across ecosystem sites belonging to eLTER, ICOS and ANAEE, combined with satellite product comparisons, demonstrating that coordinated multi-RI data collection can produce spatially and temporally richer observational records than any domain-specific campaign could achieve independently.

A particularly relevant integration outcome concerns the connection between geosphere monitoring activities and the Downstream VRE developed within WP8. Geospatial products, environmental time series and monitoring data generated within WP7 were made available through a shared analytical environment, where they can be combined with information from other environmental domains. This transformed geosphere observations into interoperable resources supporting integrated assessments of natural hazards and environmental change. Integration within the geosphere domain was also strengthened through the deployment of multi-sensor monitoring systems combining geodetic, geophysical, geochemical and remote-sensing observations. These integrated approaches enhanced the characterisation of geological processes and natural hazards while generating datasets and services that can be related with broader environmental analyses and risk-assessment workflows. The Passo della Morte case study provided a practical demonstration of this approach. By combining advanced monitoring technologies, multi-sensor observations and hazard-assessment tools, the initiative showed how research infrastructures

can support risk management and civil protection activities, translating complex geosphere observations into information directly relevant for territorial planning and operational decision-making.

Cross-domain integration was also strengthened through semantic resources jointly created within WP2 but serving the whole project. A particularly important example is ERITHES, the Environmental Research Infrastructures Thesaurus, co-created to provide shared concepts for actors, ESFRI domains, facilities, services, research products and project management activities performed by environmental RIs. By creating a controlled and reusable vocabulary that spans the whole environmental RI landscape, the project provided a common semantic layer that supports consistent annotation and more effective discovery and linking of heterogeneous resources. This semantic layer is not a purely technical by-product; it is part of the scientific integration capacity of the project. Environmental science increasingly depends on the ability to bring together observations, models and contextual information originating from infrastructures with different histories, methods and metadata cultures. Through semantic mappings, FAIR terminology and the Terminology Service, ITINERIS reduced the difficulty of making resources understandable and interoperable beyond the boundaries of the community that produced them, a key bottleneck in cross-domain science.

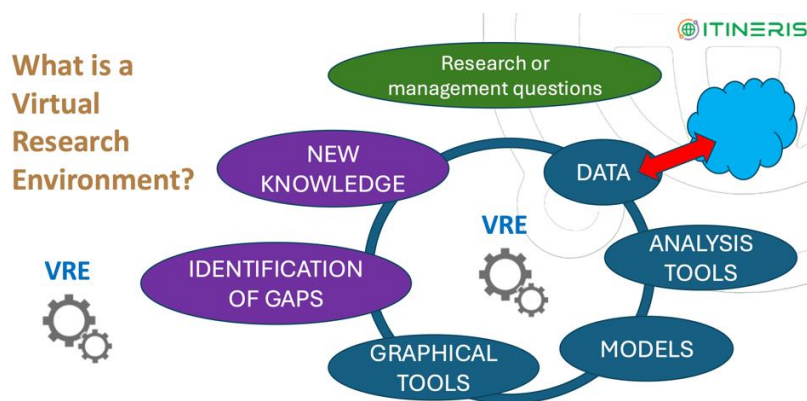
ITINERIS also generated integration through the coordinated strengthening of observing and analytical capabilities across domains. It significantly expanded national observation capacities through the deployment of advanced instrumentation, upgraded laboratory networks, innovative field systems and shared digital services that were progressively consolidated into the HUB. When considered together, these investments did more than modernise individual components: they increased the responsiveness of the Italian environmental RI system to complex research questions involving climate change, biodiversity loss, pollution, natural hazards, carbon cycling and ecosystem resilience.

Another project-level integration result concerns alignment with European and international research infrastructures and scientific frameworks. Beyond strengthening the role of Italian nodes within the relevant European Research Infrastructures and Consortia (ERICs), ITINERIS built on and reinforced the Italian contribution to relevant European and global initiatives. In cross-domain terms, this was significant not because ITINERIS simply consolidated national infrastructures in isolation, but because it made their integration visible, coherent and operational within wider European and global observational and Open Science ecosystems.

Taken together, all these activities demonstrate that ITINERIS did not simply strengthen individual Research Infrastructures. Rather, it created the scientific, observational and digital conditions required for environmental infrastructures to operate as an integrated system, enabling new forms of interdisciplinary research and providing a foundation for future Earth-system science in Italy and beyond.

3.5. ITINERIS Virtual Research Environments

A tangible outcome of ITINERIS integration is represented by the nine Virtual Research Environments (VREs) developed within WP8 and accessible through the HUB. While the HUB provides discovery and access to distributed resources, the VREs translate interoperability into operational scientific practice by enabling datasets, services, analytical tools and computational resources originating from multiple Research Infrastructures to be combined within shared research environments. Covering a broad range of environmental topics, they allow researchers and stakeholders to analyse heterogeneous resources through integrated workflows and collaborative analytical spaces.



Together, the VREs provide concrete examples of how ITINERIS transformed organisational, semantic and technical integration into new scientific capabilities, supporting cross-domain investigation, knowledge generation and innovative forms of environmental research and forming a fully operational system openly available to researchers, environmental managers, planners, decision makers and policy makers.

The environments were designed to support both expert users, who can contribute new resources and workflows, and non-specialist users interested in accessing existing data, tools and services.

The VRE system was conceived as a cross-sectorial layer building on the observational, analytical and digital capacities developed across the atmospheric, marine, terrestrial biosphere and geosphere domains. By integrating data, information and knowledge generated by the different Research Infrastructures, it created operational environments where resources originating from multiple domains could be combined to address complex scientific and societal challenges.

The **Critical Zone VRE (CZ VRE)**, referencing LifeWatch, eLTER, ICOS and SIOS, integrates heterogeneous datasets from Italian and Arctic environments to study complex interactions between atmosphere, biosphere, hydrosphere and geosphere within the thin surface layer spanning from the top of the vegetation to the groundwater. By integrating datasets collected across Arctic, mountain, semi-arid and wetland environments and combining observational resources with ecological and environmental modelling tools, the CZ VRE enables the investigation of Earth surface processes across disciplinary boundaries. The resulting framework provides an operational environment where physical, biological and climatic processes can be analysed jointly, supporting both environmental research and interactions with broader national initiatives such as the National Biodiversity Future Centre.

The **Essential Variables VRE (EV VRE)**, developed in the context of the eLTER Research Infrastructure, provides a dedicated digital environment that establishes a common observational language across domains. Rather than focusing on a single environmental compartment, the VRE harmonizes Essential Climate Variables (ECVs) and Essential Biodiversity Variables (EBVs) to bridge atmospheric, biosphere, marine, and geosphere observations. By integrating heterogeneous datasets from different observatories, field campaigns, and RIs into a single analytical workspace, it enables the production of integrated indicators and cross-domain assessments. A notable demonstration of this capability was a case study analysing the Net Ecosystem Exchange in the Mediterranean beech forest at the Collelongo–Selva Piana eLTER-IT site, illustrating how the EV VRE successfully translates fragmented cross-domain observational data into actionable scientific knowledge.

The **Biomass VRE**, developed within the LifeWatch Italy digital infrastructure in close synergy with LifeWatch ERIC, supports the management, analysis, and modelling of aquatic, marine, and terrestrial biomass data. The platform achieves cross-domain integration by combining remote sensing observations, field data, laboratory measurements, and climate-related information. By leveraging shared semantic resources and controlled vocabularies, the VRE harmonizes heterogeneous biodiversity and ecosystem datasets into common analytical workflows, demonstrating how ITINERIS transformed isolated disciplinary datasets into interoperable resources. Ultimately, these workflows address critical research themes for climate change mitigation and biodiversity conservation—including changes in net primary productivity, biotic-abiotic interactions, and the effects of warming on biodiversity—directly supporting robust ecosystem assessment and environmental management.

The **AERO VRE**, associated with ACTRIS, offers a dedicated digital environment for the analysis, integration and interpretation of atmospheric aerosol observations. It brings together measurements, analytical workflows and domain-specific tools within a single workspace, supporting the study of aerosol properties, sources and transformations across observational platforms and enabling a more coherent use of distributed atmospheric resources. AERO-VRE is a virtual environment that provides users with software and tools capable of processing scientific data and observations on two main topics: i) the presence of desert dust, with tools dedicated to the characterization of dust through observations and models, useful for characterizing the spatial and temporal evolution of phenomena, optical thicknesses and other information, and ii) the analysis of aerosol typing, with tools dedicated to lidar observations and aerosol models. The VRE supports environmental and climate studies.

The **ISOTOPE VRE**, associated with ICOS and geosphere-related expertise, provides an integrated environment for the management and analysis of isotopic data and modelling workflows. By connecting heterogeneous datasets, analytical tools and shared semantic resources, it supports the interpretation of isotope signals and strengthens the use of isotopic information for investigating environmental processes. The VRE addresses the lack of a harmonised national database on environmental isotopes by creating a coordinated environment where researchers and environmental managers can access interoperable databases, analytical services and modelling capabilities. This VRE also supports the integration of new laboratory capabilities introduced through ITINERIS to strengthen national capacities for isotopic analyses across different environmental matrices.

The **CARBON VRE**, associated with ICOS and LifeWatch, provides a strong example of integration across environmental domains. It represents the first digital research environment specifically devoted to quantifying the Italian carbon balance and carbon cycle. It brings together carbon-cycle observations, ecosystem flux measurements, local environmental datasets and modelling tools within a single digital environment, linking ecosystem functioning with atmospheric composition and climate processes. By integrating resources collected through different Research Infrastructures and environmental compartments, the platform supports the analysis of carbon sources and sinks across diverse ecosystems and spatial scales. The VRE enables researchers to combine observations, derived products and modelling workflows in a common framework, facilitating the assessment of carbon dynamics and contributing to the scientific basis for climate-change mitigation strategies and evidence-based environmental policies.

The **CLIMA VRE**, associated with JERICO and broader multi-domain datasets, extends this integration approach to the analysis of climatic indicators and environmental change. It aggregates climatic, atmospheric, marine and environmental variables within a common analytical framework, enabling the generation, comparison and interpretation of indicators across different domains and observation systems. By combining heterogeneous datasets, analytical workflows and visualization tools, the VRE supports the investigation of climate variability and long-term environmental trends at regional and national scales. The marine climate-indicator activities developed for the Ligurian Sea provide a concrete demonstration of this approach, showing how atmospheric and marine observations can be jointly analysed to support integrated climate assessments and the development of indicators relevant for both research and policy applications.

The **Crop, Plants and Pests VRE (CPP VRE)**, developed in connection with ANAEE, provides an integrated modelling environment for agroecological research, combining biophysical simulation models, cloud computing facilities, data transformation tools and FAIR data management approaches. The platform supports the analysis of crop production, plant phenology, pest and disease dynamics, and cropping system management, addressing challenges at the interface between environmental science, agriculture and ecosystem management. By bringing together datasets, modelling solutions and computational resources within a common framework, the CPP VRE facilitates interdisciplinary analyses relevant to climate adaptation, sustainable agriculture and food-system resilience.

The **DOWNSTREAM VRE** was explicitly designed to analyse the cascading effects of climate and environmental change across marine, terrestrial, and geosphere compartments. The marine domain toolbox focalizes in carbon cycling and acidification data available in the North Adriatic Sea: mainly pH, pCO₂, fCO₂, temperature and salinity from the different RI of the marine domain. Actively receiving data, outputs, and geospatial time series from the WP7 Geosphere and Land Surface domain, the geosphere platform enables users to explore, visualize, and download data generated by monitoring systems deployed at pilot sites in the Friuli Venezia Giulia and Basilicata regions. By combining multi-risk analysis capabilities—including landslide dynamics and their related environmental impacts—the VRE serves as

an operational bridge between geophysical observation, scientific research, and practical downstream applications for stakeholders and civil protection agencies.

Besides the individual use cases, the VRE system functions as a bridge between disciplinary Research Infrastructures, including LifeWatch ERIC, ICOS ERIC, ACTRIS ERIC, eLTER RI and other environmental infrastructures. By combining data, tools, models and knowledge originating from different domains within common operational environments, the VREs demonstrate how environmental challenges can be addressed through genuinely cross-disciplinary approaches. In this sense, they represent a prototype of the integrated digital services required to support environmental research and management in increasingly complex socio-environmental contexts.

The long-term sustainability of the VRE system is reinforced by its close integration with the parent European Research Infrastructures and with operational frameworks such as D4Science and Copernicus. Beyond the project, the approach developed within ITINERIS has already been presented in European initiatives including GEO and EuroGEO as a potential model for the development of broader cross-disciplinary Virtual Research Environments supporting environmental research and decision making.

3.6. Human capital and training

Among the enabling components developed within ITINERIS, the activities carried out under WP3 played a fundamental role in strengthening the human, organizational, and knowledge dimensions required to operate a distributed ecosystem of environmental Research Infrastructures (RIs). While the project invested significantly in developing advanced services and technological capabilities, equal priority was devoted to ensuring that these assets could be effectively adopted, managed, and further advanced by skilled communities of users, operators, and researchers.

The primary cross-domain legacy of this effort is the ITINERIS Training Centre. Conceived as a distributed, web-based structure fully integrated within the ITINERIS HUB, the Centre serves as a national reference point for advanced training in environmental sciences. It directly addresses the needs of diverse scientific domains by targeting a wide audience—including researchers, technologists, technicians, PhD students, and infrastructure users—thereby promoting interdisciplinary scientific collaboration and knowledge exchange.

Beyond the delivery of standard training activities, the Centre provides a stable organizational framework to coordinate long-term educational programs. Key operations include the creation of Digital Training Objects (DTOs) aligned with FAIR principles, the curation of educational materials produced by participating infrastructures, and the long-term preservation of open educational resources. By supporting continuous competency development and knowledge transfer, the Training Centre represents a structural contribution to the future operability, accessibility, and overall sustainability of the national RI ecosystem.

A significant contribution of the project has been the concrete strengthening of human capital across the participating Research Infrastructures. Training activities were organised around three complementary lines of action addressing infrastructure personnel (activity 3.6), early-career researchers enrolled in PhD programmes (activity 3.7), and staff interested in strengthening science communication skills (activity 3.8). Overall, 70 advanced courses were organised and delivered over approximately fourteen months through in-person, online, blended and hybrid formats. These activities involved 950 participants and 290 lecturers and covered both highly specialised scientific and technical competencies and transversal skills of increasing relevance within the international research landscape, including data management, digital interoperability, interdisciplinary collaboration and science communication.

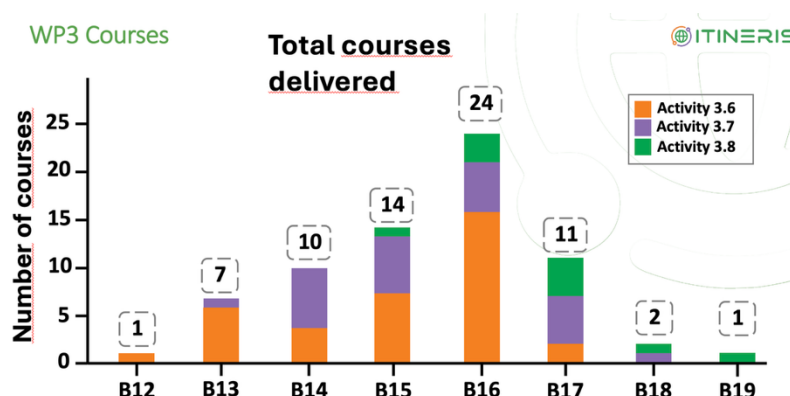


Figure 17 - Temporal distribution of training course delivery per line of activity

The effectiveness of the training programme was evaluated through final examinations and participant assessments. Almost all trainees successfully completed the courses and obtained certification, while overall evaluations of course quality were consistently positive.

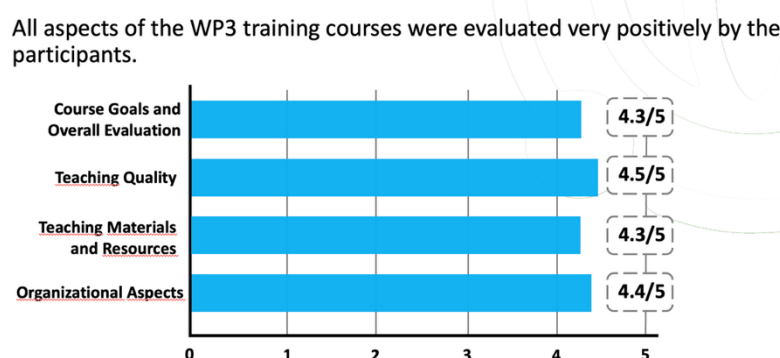


Figure 18 - Overall evaluation of the training programme by trainees

The training programme dedicated to Research Infrastructure personnel represented a major component of this effort. A total of 36 advanced courses were delivered, involving 643 participants and 184 lecturers. These activities covered all environmental domains represented within ITINERIS, including the Atmosphere, Terrestrial Biosphere, Geosphere/Land Surface and Marine domains, while also addressing cross-domain topics related to access and management, eScience and Virtual Research Environments. By bringing together personnel from different infrastructures and scientific areas, the programme contributed to the dissemination of competencies required for the effective operation and integration of services across the ITINERIS ecosystem.

A particular attention was devoted to the involvement of early-career researchers through a dedicated PhD training programme developed in collaboration with the University of Naples Federico II, the University of Naples Parthenope, the University of Pisa, the University of Salento and the University of Tuscia. The programme was activated for the XXXVIII and XXXIX PhD cycles and supported the research projects of 20 PhD fellows. In addition, 24 specialised courses were organised for doctoral students, involving 219 early-career researchers and 78 lecturers. The programme combined domain-specific training with interdisciplinary educational opportunities and included six immersive summer schools organised at the Universities of Salento and Pisa, with participation costs fully covered by project resources. Through these activities, the project established a direct connection between higher education and Research Infrastructures, supporting the development of future users and potential future employees of the environmental research infrastructure community.

The strengthening of communication and dissemination capacities constituted another important dimension of the training framework. Ten intensive science communication courses were organised to support personnel from participating infrastructures in developing more effective communication

strategies and greater familiarity with different communication media and tools. These activities involved 88 participants and 28 lecturers and addressed topics such as storytelling techniques, presentation design, production of audio and video scientific content, use of social media, scientific journalism and strategic communication planning. By reinforcing these competencies, the project enhanced the capacity of Research Infrastructures to communicate scientific knowledge and engage with a broader range of audiences and stakeholders.

Alongside training delivery, the project established a digital ecosystem designed to support the organisation, accessibility and long-term reuse of educational resources. The ITINERIS Training Platform became the central access point for training materials and learning opportunities, serving as the core component of the Training Centre and operating as an integral part of the ITINERIS HUB ecosystem. The platform currently hosts approximately 800 users and 1,224 digital resources, including 603 Digital Training Objects described through FAIR-compliant metadata and made accessible through dedicated sections of both the LifeWatch Italy and ITINERIS HUB Metadata Catalogues. By providing structured access to educational resources for Research Infrastructure personnel, PhD students and stakeholders, the platform extends the principles of interoperability and openness to the training domain and contributes to the broader integration of services and resources within ITINERIS.

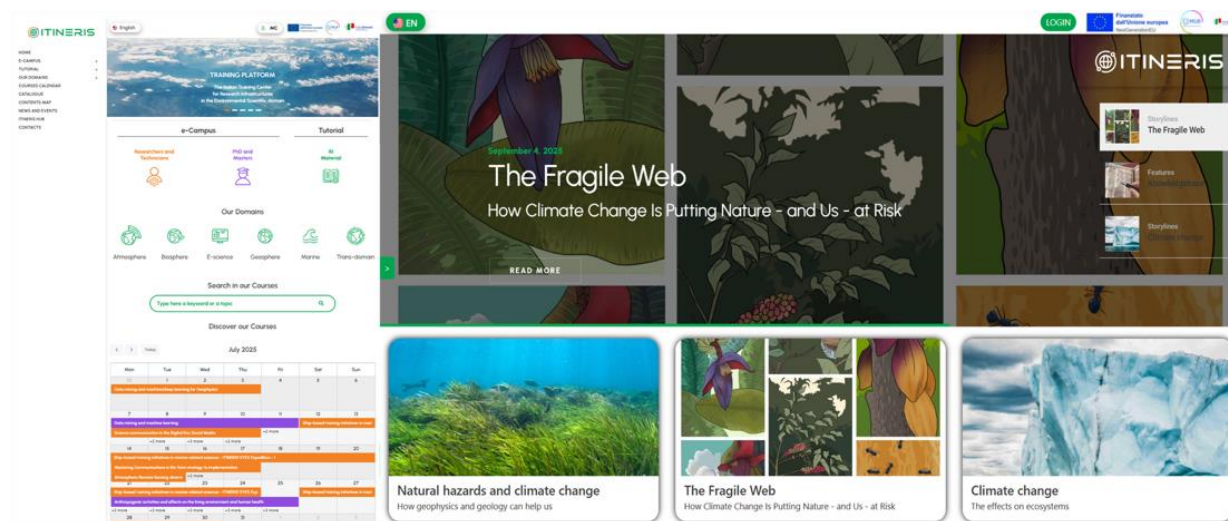


Figure 19 - ITINERIS training platform

The creation of FAIR Digital Training Objects represents one of the most significant knowledge assets generated by the project. Training materials produced throughout the programme were transformed into structured digital resources described through a mandatory set of metadata aligned with the EOSC Training Profile. This approach ensured that training content remains traceable, accessible and reusable over time while facilitating its integration into national and European digital ecosystems. Through their publication within the ITINERIS HUB, these resources have become part of a shared knowledge infrastructure supporting future training activities and the continuous development of competencies across environmental Research Infrastructures.

Knowledge transfer was further strengthened through the establishment of the ITINERIS Semantic Training Platform on Environmental Sciences, known as the Environmental Knowledge Library. Conceived as a strategic bridge between the scientific community and civil society, the platform promotes the dissemination of environmental science knowledge through FAIR principles, structured metadata and semantic technologies. The use of Natural Language Processing tools supports navigation by concepts and topics, facilitating the retrieval of relevant information and improving accessibility for different categories of users. The platform also includes educational resources specifically designed for schools and stakeholders, as well as gamification tools such as BioCross, the Biodiversity Crossword Game, developed to make environmental science topics more accessible and engaging for younger generations. Complementing these resources, 22 scientific talks presenting key elements of selected training courses and of the scientific domains represented within ITINERIS were recorded and made available through the

LifeWatch Italy YouTube channel and integrated into the Training Platform, further supporting the long-term dissemination and sustainability of educational content.

Taken together, these activities have contributed to creating a common environment for training, knowledge sharing, and community development across the ITINERIS ecosystem. The combination of advanced courses, doctoral training, science communication initiatives, digital platforms, and FAIR educational resources enabled the project to support researchers, infrastructure personnel, students and stakeholders through complementary and mutually reinforcing actions. The resulting framework contributes not only to the acquisition of specialised competencies, but also to the accessibility, preservation and circulation of knowledge across environmental domains and institutional boundaries.

The digital infrastructure created by the project includes dedicated systems for the long-term preservation of Digital Training Objects and a set of advanced services designed to support continued user engagement. These include semantic search functionalities, thematic organisation of training resources, dedicated personal areas where users can build their own environmental knowledge libraries, and mechanisms through which users can contribute to new Digital Training Objects, following a controlled process of review, revision and approval by the Training Centre. The future enlargement of participation to additional national institutions and to the European components of the Environmental Research Infrastructures contributing to ITINERIS is expected to further strengthen both the user community and the pool of training providers. Through these mechanisms, the Training Centre and its digital platforms are positioned to evolve into a reference hub for high-quality environmental training materials and services at national, European and international levels, ensuring the continued availability, growth and impact of the knowledge resources generated within ITINERIS.

4. PART IV - DOMAIN-SPECIFIC RESULTS OF THE VERTICAL WORK PACKAGES

The previous sections presented the main cross-cutting achievements of ITINERIS, including the development of the ITINERIS HUB, FAIR implementation and interoperability frameworks, access and training activities, and the system of Virtual Research Environments. These results, largely corresponding to the activities carried out within WP1, WP2, WP3 and WP8, were discussed from a project-wide perspective because of their transversal role in strengthening the integration, accessibility and interoperability of the national environmental Research Infrastructure ecosystem. The objectives of these Work Packages were successfully achieved, as documented in the previous chapters, where their contribution to the overall project outcomes has already been extensively described.

The following chapters focus instead on the scientific, technical and infrastructural results achieved within the domain-oriented Work Packages (WP4–WP7), covering the atmosphere, marine, terrestrial biosphere and geosphere domains. While these activities are presented according to their primary scientific domain, many of the reported results contributed directly to the cross-domain achievements described earlier, providing the observational capacities, facilities, datasets, services and expertise that enabled project-wide integration. To facilitate comparison across domains, each chapter follows a common reporting structure including Work Package overview, scientific and technical results, infrastructures and services, scientific impact, and future developments. More detailed descriptions of activities, methodologies, outputs and results are available in the public project deliverables accessible through the ITINERIS website.

4.1. WP4-Atmosphere

Overview

The WP4 focuses on integrating and empowering the RIs operating in the national territory involving the atmospheric domain. Over the 42 months of project implementation, WP4 developed and carried out a series of structural and scientific actions aimed at enhancing the Italian atmospheric observational capacity. Five national and international RIs were involved in these activities. This portfolio included: i) well-established RIs operating at the international level and recognized within the European Research Infrastructure Consortium (ERIC), such as the Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS ERIC) and the Integrated Carbon Observation System (ICOS ERIC); ii) European-level RIs that have not yet obtained ERIC status, such as the European Facility for Airborne Research (EUFAR) and the Svalbard Integrated Arctic Earth Observing System (SIOS); iii) national research infrastructures, such as the Centre for Trace Analysis (CeTra). The overarching objective was the development of an integrated atmospheric observation system capable of fostering knowledge transfer from more mature RIs (ERIC) to less advanced ones, while promoting the development of shared services and avoiding unnecessary duplication of efforts.

WP4 activities were structured around four main objectives, each contributing to both infrastructural integration and scientific advancement.

OBJ1 - Integration and harmonization within the Italian Network of Environment RIs. Several examples of integration across different components of atmospheric observation were achieved by the ITINERIS Operating Units throughout the project. Observational capacity was enhanced both through the strengthening of individual components—such as the expansion of airborne observations and the establishment of an isotopic observation network—and through cross-domain synergies. A notable example is the installation of lidar instrumentation on the Gaia Blu research vessel, enabling the observation of marine aerosols.

OBJ2 - Pilot service on Aerosol types and sources. The scientific impact of ITINERIS on the atmospheric observing system is also reflected in advancements in aerosol characterization. In particular,

new aerosol typing algorithms were developed at CNR-IMAA, alongside an intensification of both online and offline source apportionment activities at CNR-ISAC.

Moreover, the national capacity to characterize aerosol properties was further strengthened through enhanced experimental activities using simulation chambers at INFN.

OBJ3 - Pilot service on Planetary Boundary Layer height and its impact on aerosol and trace gases concentration at ground. Significant progress was achieved in the analysis of the Planetary Boundary Layer within the ITINERIS framework. Major advancements were obtained at CNR-IMAA through the development of a PBL estimation algorithm (MIPA), trained using data from a multi-instrument observational campaign. Additional scientific results were obtained by CNR-ISAC through the investigation of PBL dynamics in highly polluted regions, such as the Po Valley, contributing to a better understanding of its role in modulating aerosol and trace gas concentrations near the surface.

OBJ4 - Pilot service on impact of natural and anthropic fires on atmospheric composition. Substantial work was carried out on fire-related observations at CNR-ISAC, particularly focusing on the identification of specific fire tracers. The study integrated different types of instrumental data, including gaseous species and aerosol particles, in conjunction with the detection of simultaneous fire emissions. The analysis was based on long-term observational datasets, which also supported the development of a fire registry with a temporal coverage comparable to that of the available instrumental records.

WP4 objective saw the participation of all WP4 OUs to strengthen the Italian atmospheric RIs. OBJ1 saw the contribution of all the OUs for the realization of its ten related activities (T4.1 to T4.10). OBJ2 was achieved thanks to the contributions of CNR-IMAA, CNR-ISAC and INFN in activity 4.11, 4.12, 4.13. OBJ3 achievement saw the contributions of CNR-ISAC and CNR-IMAA in activity 4.14 and 4.15, and finally CNR-ISAC was the contributor of activity 4.16 linked to OBJ4.

All planned objectives were achieved. The work package completed all expected deliverables and intermediate objectives, and the implementation of activities was monitored through the specific KPIs defined for the work package.

Scientific and technical results

The commitment and high research profile of all the UOs within WP4 have enabled the achievement of results that go well beyond the expectations set at the beginning of the ITINERIS project. As anticipated, a significant consolidation of the observational capacity of the atmospheric RIs has been achieved. This has been accomplished through the establishment of strong and in-depth connections among the atmospheric RIs and UOs involved in the project. This aspect has proven to be one of the major outcomes of the ITINERIS project, making the Country more responsive and efficient in addressing scientific and societal needs related to the atmospheric system.

In achieving Objectives 2–4, the Italian atmospheric RI community has defined state-of-the-art methodologies for investigating and linking boundary layer dynamics to ground-level pollution, which are essential for air quality understanding and management. It has also implemented aerosol typing methodologies currently applied at all ACTRIS/EARLINET sites, developed novel and advanced source apportionment approaches, and significantly enhanced the Italian observational capacity through the deployment of a high-performing atmospheric chamber for characterization under controlled environments. In addition, innovative methods for the identification of fire events through in situ observations have been designed.

Beyond these achievements, ITINERIS WP4 has enabled Italy to establish the first and most extensive national network for carbon isotope measurements, currently comprising four sites across the Country. The chemical analysis capability of samples has also been substantially strengthened across several sites, also thanks to the investment in the INFN Florence reactor. Furthermore, an ACTRIS-compliant aerosol lidar has been deployed for the first time on a research vessel to investigate atmosphere–marine exchange processes in a critical region such as the Mediterranean. Complementary to this, and thanks to ITINERIS, in situ aerosol samplers designed for aircraft deployment have been developed, equipping Italy with an unprecedented observational capability.

All these advancements position the Italian atmospheric RIs, and ITINERIS as a whole, as key actors in the implementation of the new EU Air Quality Directive. This is demonstrated by the success of the event

“Towards the New European Air Quality Directive: Dialogue and Synergies between Research Infrastructures, Local Authorities, and Environmental Agencies,” as well as by the subsequent collaborations established between ACTRIS Italy and regional and national air quality agencies.

Facilities, scientific instrumentations and technological equipment

The total investment related to WP4 amounts to around 26 MLN. This investment includes also the big investments in ICT which will benefit the atmospheric domain and the whole ITINERIS. This investment updated and empowered the ACTRIS ARES data centre hosted by CNR IMAA which serves the whole ACTRIS aerosol remote sensing and EARLINET community. As shown in Figure 1, the economic investment also empowered the aerosol in situ and aerosol remote sensing components as well as chemical analysis for chambers’ activities and for ambient collected samples, and greenhouse gases analysis capacity. Many instrumentations were acquired to strengthen the Italian observational capabilities in compliance with European RI but also beyond that. Examples of experimental synergies inherited through ITINERIS can be found in the acquisition of lidar systems for the Gaia Blu research vessels, allowing a new approach to marine aerosols study, and the empowerment of airborne instrumentations for further explorations via the EUFAR and other RIs synergies. This allows from one side to have a better temporal and geographical coverage of RI observations and from the other side to add knowledge about atmospheric state with further components characterization (e.g. pollen, carbon isotopic, chemical analysis measurements).

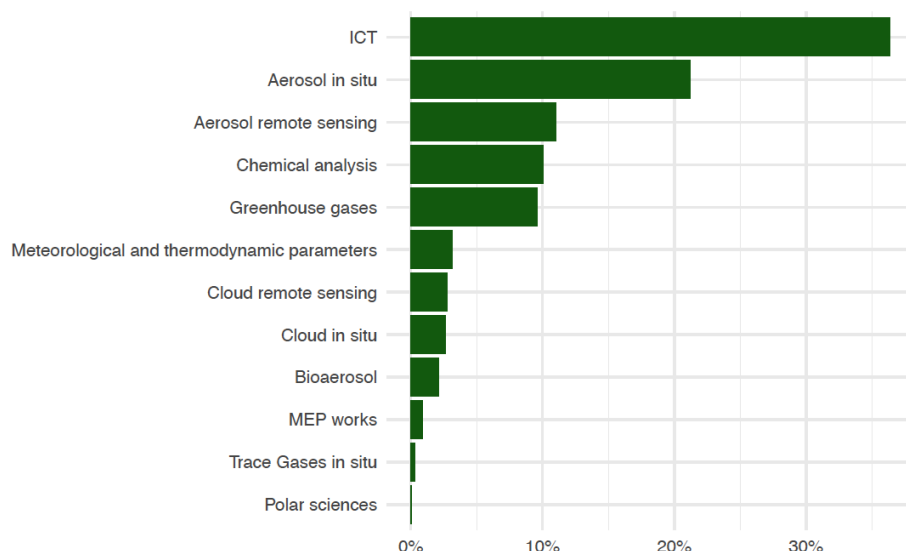


Figure 20: The investment effort that will benefit the Italian atmospheric Research Infrastructures Network

Scientific impact

WP4 has already generated a significant scientific impact, as demonstrated by approximately 70 papers published in peer-reviewed scientific journals and more than 170 scientific contributions. The four prizes awarded to WP4 researchers further confirm the high level of scientific activity achieved within the work package. Additionally, WP4 has produced 60 new datasets with associated DOIs, enhancing the traceability and usability of ITINERIS observations and increasing their overall impact.

Overall, the ITINERIS initiative has positioned Italy at the forefront of atmospheric characterization, both in terms of cutting-edge observational capabilities and state-of-the-art technologies and analysis methodologies. Methods developed for aerosol typing, source apportionment, and boundary layer investigation place Italian research at the leading edge of knowledge and have the potential to influence future advancements in this scientific field. The implementation of data products directly usable by services such as CAMS and for satellite validation activities (e.g. EarthCARE) can generate both direct impacts, through evaluation and validation efforts, and indirect impacts, through improvements in models and satellite retrieval algorithms.

Furthermore, the unique and unprecedented Italian capability to characterize carbon isotopes in atmospheric carbon, together with the enhanced chemical analysis capacity and the multi-technique pollen measurement capabilities, addresses key scientific needs identified also during the latest WMO GAW symposium, including the demand for more carbon isotope observations, improved pollen characterization, and a better understanding of the air quality–health linkages. These observational capabilities, strengthened by ITINERIS, have strong potential in terms of scientific relevance, excellence, and international attractiveness.

The characterization of the Canadian wildfire plume that occurred in the summer of 2025, through methods and instruments developed or acquired through ITINERIS, represents a concrete example of how these results can converge to provide a more comprehensive understanding of complex phenomena with multiple impacts. Such an integrated observational capability is currently achievable in Italy thanks to the overarching effort of the ITINERIS project within the PNRR framework.

Future developments

The long-term sustainability of the existing services, datasets, and technological assets developed within WP4 is supported by the activities, services and management of the involved RIs.

The additional services and instrumentation developed within ITINERIS are expected to remain sustainable thanks to their scientific relevance and their capacity to attract users and stakeholders at both national and European levels. Equally important is the human capital generated through the project. The training of young researchers, technologists, and technical personnel through the WP3 activities, have significantly strengthened the competencies available within the Italian atmospheric research community, ensuring the availability of skilled professionals capable of operating, maintaining, and further developing the infrastructures and services established during the project.

4.2. WP5-Marine Domain

Overview

In the framework of the ITINERIS, the WP5 has supported Italy in promoting a comprehensive vision of the global ocean observing system as an interconnected network of research infrastructures, platforms, technologies, and data management systems.

The Marine Domain established the Italian Integrated Ocean Observing System (IT-IOOS), designed as a comprehensive framework to integrate, harmonize, and strengthen research infrastructures (RIs), monitoring activities, and data services across the country. IT-IOOS brings together the Italian nodes of key European RIs, including EMSO, EuroArgo, DANUBIUS, ICOS, JERICO, eLTER, EUROFLEETS and SIOS—as well as major national infrastructures such as the Laboratori Nazionali del Sud, the research vessel Gaia Blu, R/V Laura Bassi, and GeoSciences.

At the beginning of the ITINERIS Project, the state of the art of the Italian Ocean Observing System based on RIs was assessed, in order to identify data gaps and to better plan project actions. The analysis confirmed that the observation facilities, managed by different research centers and belong to different RIs, suffer from fragmentation, lack of standardization, and limited accessibility, preventing effective management of Italy's seas and their resources.

ITINERIS Marine Domain addresses the fragmentation by harmonizing data from Italy's dispersed marine research institutions, creating a unified system. By aligning their complementary capacities, these infrastructures form the ITINERIS Marine Domain foundation of a national “system of systems” for marine observation and data access. A central element of this integration effort was the development of IT-IOOS HUB, composed of the Marine data Store and IT-IOOS portal providing single access point to the national marine data. This integration improves data accessibility, standardization, and quality, enabling efficient management of marine resources and supporting evidence-based policymaking, ecosystem health assessments, climate resilience (e.g., Italy's National Recovery and Resilience Plan), and marine conservation.

The WP main overall aim was to integrate the Italian nodes of all marine relevant RIs and build up the Italian Integrated Ocean Observing System (IT-IOOS) to guarantee access to facilities, services, and marine data, and to ensure long-term monitoring of Essential Ocean Variable (EOVs), Essential Biodiversity Variable (EBVs) and Essential Climate Variable (ECVs) able to contribute to European and International efforts on ocean observations (GOOS & EOOS).

On this aim, the Marine Domain identified major objectives and implementation actions:

- **Obj-1: Integration and harmonization** of Marine Domain RIs towards Italian Integrated Ocean Observing System (IT-IOOS)
- **Obj-2: Expanded the Italian marine observation capacity**
- **Obj-3: Fill the gaps in biological and ecosystem** observations
- **Obj-4: Expand the capability of NRT ship-based ocean observations**
- **Obj-5: Develop Pilot services** to tackle overarching marine issues

The WP activities were completed as expected with the contribution of all Operating Units. All participating Operating Units successfully completed the activities foreseen in the project proposal and achieved the planned objectives. All the WP5 KPI were reached.

Scientific and technical results

The Marine Domain of the ITINERIS harmonized data and products from diverse marine RIs and developed an integrated “system of systems” ensuring continuity of data and services while meeting user needs. The Italian Integrated Ocean Observing System (IT-IOOS), has been designed during ITINERIS to coordinate national ocean observations and provide unified access to RI data, products, and services in support of climate monitoring, operational activities, and marine ecosystem assessment.

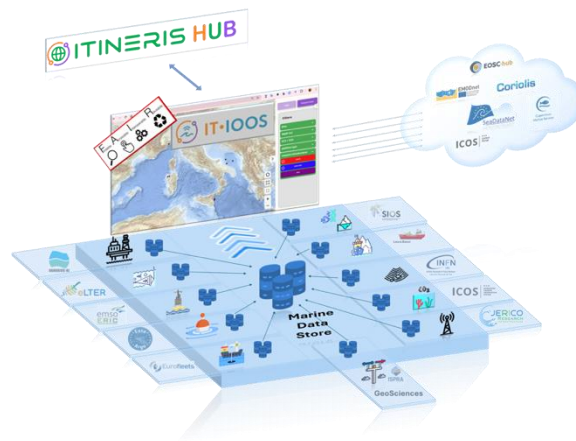


Figure 21 - IT-IOOS system architecture

IT-IOOS is built as a federated and scalable system (Figure 1) composed of 13 subsystems: **11 RI-based subsystems**, plus the **Marine Data Store** and the **Marine Data Portal**, which together provide the backbone for data integration, archiving and user access constituting the **IT-IOOS HUB**. A key outcome is the fully operational **IT-IOOS platform** (<https://it-ioos.eu/>), which provides a single access point to marine data and services, supports both Near Real Time (NRT) and Delayed Mode (DM) data streams, and hosts integrated datasets and model products.

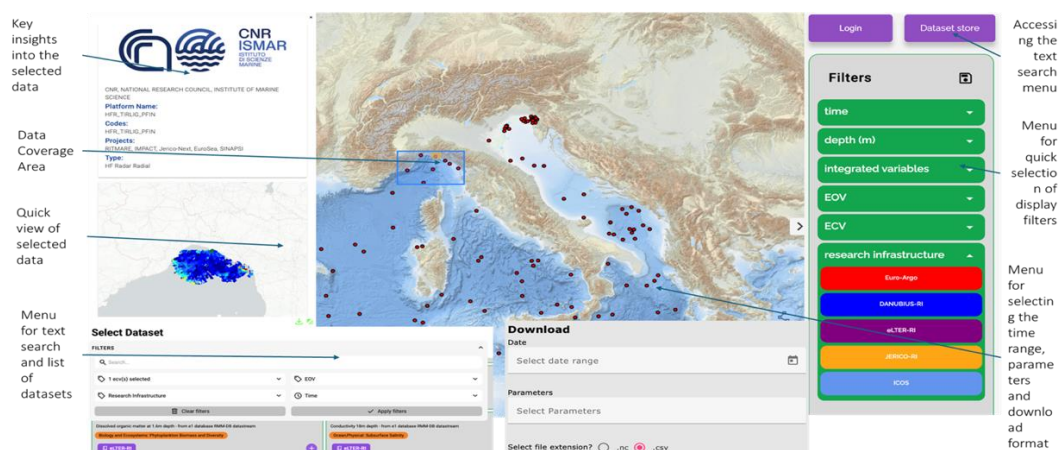


Figure 22 - IT-IOOS portal

Since the end of April 2026, IT-IOOS HUB provides access to: 19 Essential Ocean Variables (EOVs) defined by GOOS, 11 Essential Biodiversity Variables (EBVs) defined by GEO BON, and 23 Essential Climate Variables (ECVs) defined by GCOS, demonstrating that the project goal of making 39 Essential variables accessible to the users has been achieved. This distribution highlights the broad thematic coverage achieved by the project, spanning atmospheric, physical, biogeochemical, biological, and ecosystem domains. The possibility to manage both NRT and DM data also allows the system to support operational applications, data quality control, reprocessed datasets, and future links with European services such as Copernicus Marine Service, EMODnet, and the Digital Twin Ocean.

The ITINERIS Marine Domain has enhanced national ecosystem observations by expanding measurements of BioEco Essential Ocean Variables and Essential Biodiversity Variables (EBVs), contributing to major international frameworks. The Marine Domain introduced innovative and automated technologies (such as gliders, drifters, and floats), including biogeochemical and bio-optical sensors, to improve the monitoring of marine ecosystems. Activities carried out in the Mediterranean and Arctic regions. Thanks to ITINERIS, the Italian ocean observing system expanded its spatial coverage, improved continuous data collection from coastal to offshore areas, and significantly increased automatic measurements of EOVs from 60% to 76% and EBVs from 38% to 50% for EBVs (Toller et al 2026).

The WP5 expanded near-real-time ship-based observations and demonstrated the added value of cross-infrastructure integration. R/V Gaia Blu and R/V Laura Bassi were upgraded with automated

instrumentation, data acquisition, transmission and interoperability capabilities, strengthening the chain from measurement to IT-IOOS data access.

The Marine Domain also envisaged the development of five pilot services, which have been tested within Virtual Research Environments (VREs). These pilots have addressed pressing marine and environmental issues, such as climate-driven changes, marine pollution, resource management, and the implementation of nature-based solutions, demonstrating how integrated data and shared infrastructures can support scientific research and inform evidence-based decision-making.

Finally, the WP5 decided to organize two field experiments not planned in the proposal. Implemented through a substantial organizational, logistical, the two cruises (ITINERIS-EYES and EMSO-SA 2025-LB cruises) also served as demonstrative actions of the benefits of RI integration. Together, these oceanographic campaigns provide a strong example of the ITINERIS approach, demonstrating how the coordinated contribution of multiple RIs, platforms, and observing strategies can enhance interoperability, improve data quality, and strengthen the scientific value of the Italian integrated ocean observing system. In particular, they showed how coordinated observations can advance the understanding of marine processes, increase the availability and comparability of data, and reinforce the overall scientific and operational capacity of the observing system.

Facilities, scientific instrumentations and technological equipment

The ITINERIS Marine domain supported a major renewal of the equipment portfolio, covering the full observing workflow from data acquisition at the marine observing sites to data transmission, management, integration, and delivery services (IT-IOOS portal). The investment strategy combined scientific instrumentation with the digital and infrastructural components needed to support autonomous operation, telemetry, remote management, and end-to-end data workflows. As shown in Figure 3, the largest budget share was allocated to scientific instrumentation (€18.76 million; 39%), but a comparably important effort also targeted the enabling digital backbone, including software and IT services, data acquisition and transmission systems, automation/digitalisation, remote monitoring and control, and computing infrastructure. Scientific instrumentation represented the core operational layer of the portfolio. A total of 580 instruments were procured for an overall value of €18,757,026.

This includes a major investments in autonomous and mobile platforms, including 45 Argo floats (€3.56 million), 6 gliders (€2.02 million), 254 standard drifters (€0.54 million), and 8 bio-optical drifters (€0.55 million), as well as fixed or semi-fixed systems such as HF radars, smart observatories, ADCPs, buoys, FerryBox systems, and ROVs. As regard data transmission, a major investment was the replacement of wiring cable of EMSO (€8.7 million).

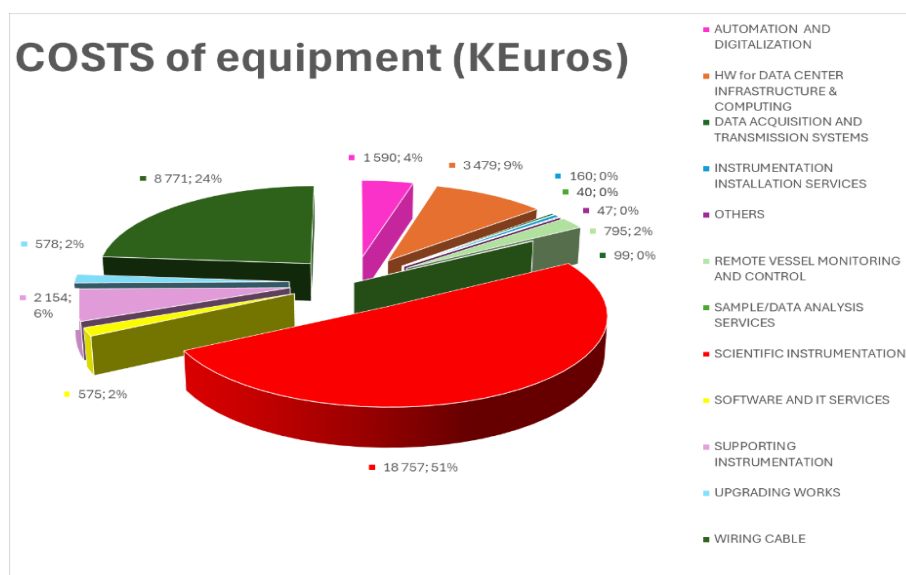


Figure 23 - Cost breakdown of the Italian investment for IT-IOOS equipment portfolio (k€)

Scientific impact

The Marine Domain has already generated a substantial scientific result, reflecting the intensity of its research, observation, and data integration activities. More broadly, considering peer-reviewed journal articles, conference contributions, technical reports, and other dissemination outputs, the Marine Domain has produced more than 230 scientific products. The scientific community involved in the ITINERIS Marine Domain has published up to now 120 papers in peer-reviewed literature, several scientific papers are in preparation. To date, 16 DOI-registered products associated with the IT-IOOS code (10.82175) have been recorded, including new datasets assigned with DOI, further strengthening the accessibility, traceability, and long-term value of the data produced within the project. These results highlight the scientific relevance of the activities carried out within the project and confirm the role of the Marine Domain in advancing knowledge, supporting collaboration, and increasing the visibility and reuse of its scientific outputs. The IT-IOOS is also present in the UN SGD partnership. <https://sdgs.un.org/partnerships/italian-integrated-ocean-observing-system-it-ioos>

Future developments

IT-IOOS transforms Italy's marine research landscape by unifying fragmented efforts and elevating its global standing in ocean observation. Nationally, it drives innovation and policy coherence; internationally, it reinforces Europe's leadership and advances global sustainability agendas. IT-IOOS strengthens Italy's role within the Global Ocean Observing System (GOOS), in the EOOS (European Ocean Observing System) and G7 Future of the Sea Ocean Initiative (FSOI). This is already evident from the attention IT-IOOS has received when presented at various international events, and from the interaction with the GOOS secretariat and national focal points of GOOS and G7 FSOI. By integration with European RIs, IT-IOOS enhances Europe's Ocean observation capacity and supports the EOOS. The impact at European and global level can be furthermore expanded by future integration of IT-IOOS with Copernicus Marine Service, EMODnet, and DTO. This will allow to contribute to European Copernicus services like CMEMS and C3S, and EU policies like the Marine Strategy Framework Directive.

Strengthening interconnections with GOOS, EuroGOOS, and other European countries national initiatives will also position IT-IOOS to actively contribute to emerging European ocean monitoring initiatives, including OceanEye, recently launched by the President of the European Commission, Ursula von der Leyen. This will enhance Italy's contribution to global ocean observing efforts while increasing the visibility, accessibility, and reuse of Italian marine data and services.

4.3. WP6-Terrestrial Biosphere

Overview

WP6 was dedicated to strengthening and integrating the Italian nodes of seven major Environmental and Life Science Research Infrastructures (RIs): ANAEE, DiSSCo, eLTER, EMPHASIS, IBISBA, ICOS and LifeWatch. The activities focused on the enhancement of scientific facilities, acquisition of advanced instrumentation, development of interoperable services, harmonization of protocols and datasets, and implementation of FAIR data management practices.

The work package covered a broad spectrum of scientific domains, including ecosystem experimentation, biodiversity digitization, long-term ecological monitoring, plant phenotyping, industrial biotechnology, carbon cycle observations, environmental monitoring and biodiversity informatics. Across the participating institutions, new laboratories, monitoring sites, analytical platforms, digitization facilities and digital services were established or upgraded, contributing to the creation of a more integrated, interoperable and service-oriented national RI ecosystem.

A major effort was devoted to strengthening interactions among Research Infrastructures through shared standards, common digital environments, harmonized workflows and coordinated access services, while consolidating Italy's contribution to the corresponding European ESFRI Research Infrastructures.

The overall objective of WP6 was successfully achieved through the coordinated enhancement of distributed RIs and the development of integrated services supporting environmental, ecological, agricultural and biotechnology research.

The main objectives accomplished include:

- acquisition and deployment of advanced scientific instrumentation and facilities across all participating infrastructures;
- development of innovative methodologies and standardized protocols for data acquisition, processing and interoperability;
- generation, harmonization and FAIRification of large volumes of scientific data and digital resources;
- implementation of repositories, metadata catalogues, cloud services and Virtual Research Environments;
- strengthening of national and transnational access services;
- consolidation of national coordination structures and Joint Research Units;
- promotion of interoperability and cross-RI collaboration.

These achievements significantly increased the scientific capacity, visibility and operational readiness of the participating infrastructures, while reinforcing their integration within the European RI landscape.

All participating Operating Units successfully completed the activities foreseen in the project proposal and achieved the planned objectives.

The acquisition and deployment of instrumentation, implementation of data infrastructures, development of services, establishment of monitoring facilities, production of datasets and creation of digital resources were completed according to the project work plan. In several cases, the achieved results exceeded the original expectations through the activation of additional collaborations, new service developments and participation in follow-up national and European initiatives.

No major deviations affecting the overall objectives of the work package were identified. Minor adjustments concerned optimization of equipment deployment and alignment of activities with emerging scientific and infrastructural opportunities.

Scientific and technical results

WP6 generated substantial scientific, technological and organizational outputs across all participating RIs.

Within ANAEE, new experimental and monitoring capacities were established through advanced hyperspectral sensing systems, ecosystem manipulation platforms and greenhouse gas monitoring infrastructures. eLTER strengthened long-term ecological observations through upgraded terrestrial and freshwater monitoring sites, including new limnological and biodiversity observation capabilities. ICOS

expanded ecosystem monitoring through the deployment and upgrade of eddy covariance stations, multi-gas flux measurements and integrated ecosystem observation sites.

In EMPHASIS, major advances were achieved in digital agriculture and high-throughput phenotyping through the establishment of the DEMETRIS HUB and associated field and laboratory platforms. IBISBA strengthened national biotechnology capabilities through integrated workflows supporting metagenomics, enzyme discovery, biomolecule characterization and bioprocess development. DiSSCo significantly expanded the digitization and FAIRification of Natural Science Collections, while LifeWatch enhanced biodiversity data services, computational infrastructures and Virtual Research Environments supporting advanced ecological analyses.

Among the most representative achievements:

- deployment of new ecosystem and freshwater monitoring sites, including upgraded eddy covariance stations and integrated environmental sensor networks;
- establishment of advanced facilities for ecosystem experimentation, digital agriculture, high-throughput phenotyping, metabolomics, metagenomics and industrial biotechnology applications;
- digitization and FAIRification of biodiversity resources, including more than 350,000 digitized specimens, over 55,000 curated specimen records, and large collections of images and datasets made available through international biodiversity infrastructures;
- deployment of new instrumentation and analytical platforms supporting greenhouse gas monitoring, biodiversity assessment, plant phenotyping, biotechnology workflows and ecosystem observation, including more than €500,000 of new instrumentation within the ICOS network alone;
- development of interoperable digital services, cloud infrastructures, repositories, metadata catalogues and Virtual Research Environments supporting FAIR data management, advanced analytics and long-term accessibility;
- generation of new harmonized datasets spanning biodiversity, ecosystem functioning, environmental monitoring, greenhouse gas fluxes, plant phenotyping and biotechnology domains, now accessible through national and international RI services.
- Collectively, these achievements transformed a distributed set of facilities into a coordinated, interoperable and service-oriented infrastructure ecosystem, significantly strengthening Italy's contribution to environmental and life science research.

Facilities, scientific instrumentations and technological equipment

WP6 enabled the acquisition and deployment of advanced scientific infrastructures across ANAEE, DiSSCo, eLTER, EMPHASIS, IBISBA, ICOS and LifeWatch. Investments included UAV-based hyperspectral systems, eddy covariance stations, environmental sensor networks, limnological monitoring platforms, biodiversity digitization laboratories, microscopy and imaging systems, high-throughput plant phenotyping facilities, metagenomics and biotechnology platforms, cloud computing infrastructures and Virtual Research Environments. These facilities strengthened experimental, observational and analytical capacities while supporting FAIR data generation, interoperability, transnational access and long-term sustainability of services across the national RI ecosystem. In ICOS an hub of instrumentation has been built and ICOS and eLTER sites, but also sites part of the Italian network not directly involved in RIs, accessed the hub to install instrumentations and collect data that are shared through the RIs and ITINERIS HUB.

Scientific impact

WP6 significantly enhanced the scientific excellence, visibility and international competitiveness of the participating Research Infrastructures.

The upgraded infrastructures now provide advanced capabilities and potential that will be crucial for their role also at European and international level. Particular scientific value derives from the production of high-quality interoperable datasets, the adoption of common standards and workflows, and the development of digital infrastructures that increase accessibility and reusability of data but also their safe storage with complete metadata.

The number of papers and presentations went above the expectations defined at the project start.

Future developments

The infrastructures strengthened through WP6 have already become central components of several national and European project proposals, providing a solid basis for long-term sustainability beyond the conclusion of ITINERIS.

Future developments will focus on expanding access services, increasing interoperability among infrastructures, and further strengthening the scientific and technological assets created within the project. ANAEE, eLTER and ICOS will continue consolidating long-term monitoring activities, ecosystem experimentation and environmental observation networks, while extending data availability and integration with European initiatives. DiSSCo and LifeWatch will further expand biodiversity data mobilization, digital services, Virtual Research Environments and FAIR data resources. EMPHASIS will continue developing advanced phenotyping services, digital agriculture platforms and cloud-based analytical environments, while IBISBA will strengthen biotechnology services, access procedures and training activities within the emerging European biotechnology ecosystem.

National coordination structures established during the project, including Joint Research Units and shared service frameworks, will continue supporting collaboration, access provision and strategic planning. The enhanced visibility of the infrastructures is already attracting new users, stakeholders and funding opportunities at both national and international levels.

The combination of advanced facilities, standardized services, interoperable data resources and strong scientific communities represents a key asset for ensuring the long-term sustainability and growth of the Italian RI ecosystem.

4.4. WP7-Geosphere/Landsurface

Overview

The ITINERIS WP7 Geosphere and Landsurface, with its research infrastructures such as SMINO, ATLaS, and EUFAR, aimed to enhance the availability to the scientific community, the public, and decision-makers of a rich, multidisciplinary set of open digital data on environmental observations of the Geosphere/landsurface. To this end, WP7 contributed to the improved integration of the various, currently not closely interconnected, national research infrastructures operating in the geosphere research and monitoring field. Advanced instruments and methodologies were acquired, developed, and tested at different ideal scales, and the resulting data were fed into the ITINERIS DOWNSTREAM Virtual Research Environment (VRE), developed within WP8. The work package benefited from three pilot sites (the Friuli Venezia Giulia region, Tito and Potenza in the Basilicata region) where the full integration of data and their joint distribution are being tested, implemented, and optimised by strengthening and updating the IT infrastructures of SMINO, ATLaS, and EUFAR.

The following text summarises the addressing and realisation of the project Objectives. Due to the close relationship between some of them, the first and second, and the fourth and fifth are grouped together.

Objective 1: To harmonize and integrate the data generated by the different Ris following international standards.

AND

Objective 2: To improve the data transfer capability (particularly in real-time and near-real time) of all the infrastructures, by acting on the data storage and access.

These objectives have been the main challenge presented by WP7. The various infrastructures and related data are, in fact, at very different levels of digitalisation and, therefore, of access and transfer. However, the WP succeeded in bringing all observational infrastructures to a higher, more compatible level of digital transfer and storage capabilities, and in implementing procedures to guarantee the FAIR release of raw and post-processed data.

The greatest challenge involved activities 7.1, 7.2, and 7.3, which focused on improving access to scientific drilling infrastructure (ECORD/ICDP) and enabling the sharing, management, and reuse of drilling- and coring-related data in compliance with FAIR principles. For activities 7.4 and 7.5, open-access geophysical datasets for the characterisation and monitoring of surface, subsurface, and built environments in urban areas, with a strong focus on improving data interoperability, were integrated into the ITINERIS platform in compliance with FAIR principles. This is a significant step towards broader accessibility and reuse by the scientific community and stakeholders.

Regarding activity 7.6, the development of the integrated monitoring and early warning platform enables the management of complex 3D datasets and the real-time application of forecasting models. The key results achieved demonstrate that the synergy between these newly acquired sensors and digital platforms can provide robust support for civil protection authorities. The effort in activity 7.7 was to bring the various components of the SMINO infrastructure (seismological and geodetic data), with different degrees of FAIRness, to the same level of access and sharing. This was achieved by creating a centralised online platform that enhanced the visibility, accessibility, and effective use of all SMINO components and data. The SMINO web portal improves the user experience by organising information in an accessible, user-friendly way, collecting and displaying data from multiple sources, making it easier for users to find what they need in one place, and linking to various data access points.

Finally, in activity 7.8, the OGS Seismic data Network Access Point (SNAP) was included in the ITINERIS hub, adopting its standards and developing the necessary infrastructure and software. SNAP is the web portal of the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale-OGS, providing access to approximately 91,073 km of seismic lines and 351,000 km² of multibeam data, mostly in the Mediterranean and Black Sea. The platform is built with PHP, HTML, and Bootstrap Italia, hosted on an internal OGS server, and integrated with ITINERIS through the development of specific software and tools. The main infrastructure of activity 7.8, PiTOP, thanks to new instrumentation, hosted three Transnational Accesses (TA), in which the performance of different DAS fibre types and interrogators was

evaluated. Following the TA, PiTOP has gained visibility, OGS has strengthened international collaborations, and a large amount of data has been shared on a FAIR basis with the scientific community.

Objective 3: to collect and distribute data from deep earth-drilling experiments and facilitating the participation of the Italian scientific community in the RI access.

Within Activity 7.1, digital workflows for archiving and metadata description were developed and tested, while multi-proxy data derived from marine and coastal sediment cores were disseminated, using the CNR-ISMAR CoRe-Core Repository as the reference infrastructure. Activity 7.3 enabled the cataloguing and archiving of thousands of records from structural geology samples, original sedimentary rock or sediment samples, smear slides, vials containing powders for nannofossil or geochemical analyses, foraminifera wash residues, thin sections, and sediment cores from seven oceanographic expeditions. Metadata has been added to the ITINERIS DOWNSTREAM VRE developed within WP8. Through an ITINERIS version of the Mobile Data Information System (mDIS), with contributions from activities 7.1, 7.2, and 7.3, significant progress has been made in data accessibility and the long-term preservation of stratigraphic records within a standardised international system. Furthermore, there has been a notable increase in Italian researchers' access to the ECORD-IODP-ICDP infrastructures, as well as in their participation in scientific cruises and associated research.

Objective 4: to improve the collection of geochemical, geophysical, geological, geodetic, and seismological observational data of near-surface processes in a more holistic framework.

AND

Objective 5: to improve the multi-parameter observation of the surface processes (mass movements, subsidence and ground deformation in general) with spaceborne and airborne SAR infrastructures, and to develop a facility for the digital data distribution.

The project successfully advanced multi-scale, multi-resolution, and multi-sensor integration approaches, with new sensors tested at pilot sites in Basilicata, including Potenza and Tito (7.4 and 7.5). The extensive use of dark optical fibre was incorporated into the SMINO seismic monitoring infrastructure (7.7). The developed methodologies have supported broader national initiatives, such as seismic microzonation activities in high-risk areas (e.g., Campi Flegrei) and projects funded under PRIN2022 and PRIN2022PNRR, thereby contributing to improved risk assessment, sustainable territorial planning, and geothermal resource exploitation. A key result is the establishment of a new multi-parametric observatory at the landslide test site in Tito (Basilicata), designed to monitor thermo-hydro-mechanical parameters in the vadose zone under natural conditions. This facility provides an experimental framework that integrates advanced geophysical and hydrological techniques to investigate landslide-triggering processes in peri-urban environments. The newly acquired instrumentation was also tested at pilot sites in Campania, including Verteglia and Atripalda (Avellino), and methodologies for correlating processed outputs – namely, the images derived from collected data – were developed and applied. Within ITINERIS, the RI ATLaS, on which activity 7.6 is focused, achieved a significant improvement in leading-edge instrumentation that was tested and deployed at a pilot site at Passo della Morte (Friuli Venezia Giulia Region), in collaboration with activity 7.7 and the Civil protection of Autonomous Region Friuli Venezia Giulia. The resulting datasets were made available through the ITINERIS DOWNSTREAM VRE developed within WP8, which enables users to explore, visualise, and download geospatial data and time series generated by the monitoring system. The key results achieved demonstrate that the synergy between these newly acquired sensors and digital platforms can provide robust support for civil protection authorities.

Activity 7.7 is primarily centred on RI SMINO and its monitoring capability for both seismic and instability phenomena. The use of existing standard linear optical fibres of 45 kilometres in length allows for both cost reduction and the possibility of continuously and thoroughly monitoring ground motion associated with seismic phenomena. The five lines illuminated by the interrogators acquired through the ITINERIS project significantly improve the detection and early warning capabilities for seismic phenomena, as well as ensuring more effective monitoring of medium- and long-term deformations, such as subsidence. The implementation of the OGS PiTOP infrastructure of Activity 7.8, with transnational

access to test instruments and technologies, is also important for SMINO, being located within its monitoring area. All these implementations represent fundamental advancements for Civil Protection, increasing the capacity to respond to and mitigate natural risks. Within Activities 7.4 and 7.5, the airborne geophysical instrumentation was increased and tested in Basilicata and Campania. Activity 7.9 also improved the airborne geophysical instrumentation for ultra-high-resolution aeromagnetic surveying of shallow subsurface targets and investigations of glaciated terrain. Moreover, total-field and fluxgate magnetic sensors, a navigation system, magnetic and GPS base stations, and a state-of-the-art strapdown airborne gravity system, complete with thermal stabilisation and GPS and gravity processing modules, enable imaging of deeper intracrustal features from both helicopter-borne and fixed-wing platforms.

All units involved in WP7 successfully completed the planned activities in line with the original project objectives, with no significant deviations from the proposal. Minor delays related to instrumentation procurement occurred but did not affect the expected outcomes.

Scientific and technical results

Important results lay the foundations for an Italian marine and continental scientific drilling infrastructure through advances in digital archiving of samples and data and improved access for Italian researchers to the ECORD and ICDP global infrastructures. The digitalisation of borehole geological samples and data is still in progress, but ITINERIS has helped raise awareness of its necessity and initiate the process. Moreover, facilitating access to the ECORD IODP-ICDP infrastructures is already yielding results, with more Italian researchers involved in international projects and surveys.

Other important results include the creation and further development of two pilot sites with multi-sensor, multi-resolution, and multiscale sensors for monitoring natural risks: Tito (Basilicata) and the Friuli Venezia Giulia region. The first is a new multi-parametric observatory at the landslide test site in Tito (Basilicata), designed to monitor thermo-hydro-mechanical parameters in the vadose zone under natural conditions. This facility provides an experimental framework that integrates advanced geophysical and hydrological techniques to investigate landslide-triggering processes in peri-urban environments. The second is the area where SMINO (Sistema di Monitoraggio dell'Italia Nord-orientale) operates, with a newly established network of five lines based on the dark fibres of the Regional Council infrastructure, complementing the traditional monitoring network with more effective monitoring of medium- and long-term deformations, such as subsidence, and providing an enhanced capability for detection and early warning of seismic phenomena. The two sites were presented to national and local stakeholders at public events, further strengthening the bonds among research institutions, infrastructure, professionals, and governance authorities. The project also contributed to strengthening human resources: various researchers and technologists were recruited, and several PhD students were trained within the project's activities. The courses organised for both PhD students and infrastructure personnel, in collaboration with WP3, contributed to the development of skilled scientists and the formation of a national community operating in the geosphere and working towards reducing natural risks.

Facilities, scientific instrumentations and technological equipment

The national facilities for sample analysis and geophysical logging for scientific drilling (ECORD-ICDP) have been upgraded and integrated with state-of-the-art equipment, both for borehole observations and for in-depth sample analyses in refurbished laboratories (CNR_ISMAR and OGS_GEO). Additional investments have established an Earth Observation infrastructure based on airborne X/L Band SAR data sensors for disaster and crisis management. Aerogravity, aeromagnetic and GPR sensors, together with drones, have transformed national capabilities in airborne geosphere research, enabling next-generation studies from deep to shallow crustal levels, including groundwater (enhancing EUFAR) (OGS_GEO). Significant improvements in geophysical prospecting instrumentation, both land-based and airborne, have been made at units located in southern Italy. The pilot site at Tito (Potenza) has thus become a multi-sensor, multi-resolution and multiscale site for monitoring natural risks (CNR_IMAA, CNR_IREA).

ATLaS capability in landslide monitoring and early warning has been greatly enhanced through substantial investments in remote sensing and local and regional landslide forecasting models. Notably, the new instruments have been temporarily installed at the other pilot site in the Friuli Venezia Giulia region, at the

Galleria Passo della Morte (UD), while efforts have led to the creation of a platform hosting data from various landslides (UNIFI-CPC).

Regarding SMINO, the Coastal Gauge Meda Buoy, equipped with an ocean-bottom seismometer, has been deployed in the northern Adriatic to address a gap in network coverage. DAS interrogators have enabled continuous digital acquisition in urban areas at the two pilot sites. In particular, the interrogators acquired through ITINERIS have added five fibre lines to the SMINO monitoring system, making it one of the most comprehensive monitoring systems in the world. The calibration centre, renewed and implemented within ITINERIS, will serve both internal users and professionals (OGS_CRS).

Scientific impact

Leading-edge equipment reinforced all the infrastructures involved in WP7 and laid the foundations for the creation of new ones focused on the use of applied geophysics for natural risks. The use of DAS for monitoring and surveying is a cutting-edge research field in geophysics and seismology. Another challenge is combining different physical properties to solve complex problems, such as monitoring and studying volcanic areas or landslides.

Although the full results of the investments will become evident in the coming years, with the instrumentation fully operational and its various applications in place, the activities have already produced more than 30 contributions, consisting of papers and presentations at international conferences. These include works comparing the performance of the new instrumentation with more standard equipment, as well as reports on its first use in various environments.

The project also contributed to strengthening human resources: various researchers and technologists were recruited, and several PhD students were trained within the project's activities. The courses organised both for PhD students and for infrastructure personnel, in collaboration with WP3, contributed to the formation of skilled scientists and, hence, to the development of a national community operating in the geosphere and to the reduction of natural risks.

Future developments

Several complementary PRIN and PRIN PNRR projects have already benefited from instrumentation acquired through ITINERIS, confirming the sustainability of the infrastructures.

Access to the ECORD infrastructure has already led to an increase in the participation of Italian researchers in campaigns and international projects on ECORD-ICDP, that we hope will continue in the future.

Being inserted in the EU project Geo-INQUIRE, the OGS_GEO infrastructure PiTOP, a unicum in Europe, had three Transnational Accesses within the ITINERIS project and will continue in the future.

The new Earth Observation infrastructure based on airborne systems is being integrated into various project proposals at both national and international levels. A broader and tighter collaboration with the Autonomous Region Friuli Venezia Giulia, both Civil Protection and Information System Services, is behind the inclusion of the five fibre lines in SMINO, and of the joint activity at the Passo della Morte between UNIFI-CPC and OGS_CRS.

The expertise and instrumentation gathered through ITINERIS in 7.5 have also enabled the acquisition of additional funding, including financial support from the strategic project Harlock and the competitive project MARS-LAVA, within the framework of PRORIS.

The presentation of the facilities at the Tito pilot site and SMINO to stakeholders and professionals aimed to raise awareness among a broader community of potential users about the opportunities available for monitoring and studying the Earth and potential natural risks. The positive comments and strengthened bonds suggest that we can expect increased participation by the institutions involved in WP7 in complex projects, at both national and international levels, further fostering and contributing to the sustainability of WP7's research infrastructures.

5. PART V — IMPACT, COLLABORATIONS AND SYNERGIES

This section examines the broader impact and legacy generated by ITINERIS beyond the specific scientific and technical results achieved by the project. Building on the infrastructure developments, services, datasets, access mechanisms and Virtual Research Environments described in the previous sections, this part analyses how these achievements translated into scientific and technological impact, strengthened national and international collaborations, and created opportunities for innovation and engagement with stakeholders and the private sector. Together, these dimensions illustrate the systemic contribution of ITINERIS to the development of a more integrated, visible and sustainable environmental Research Infrastructure ecosystem at national and European level.

5.1. Scientific and technological impact

ITINERIS generated a deep and systemic impact by transforming a fragmented national landscape of environmental Research Infrastructures into a more integrated, interoperable and visible scientific ecosystem. Its value is not limited to the number of datasets, publications, instruments or users produced during the project: the real achievement is that these outputs were brought into a common framework that made them more discoverable, reusable and scientifically effective across domains. In this sense, ITINERIS did not simply strengthen individual infrastructures, but changed the way they operate together, creating a national environment in which observation, analysis, training and access are no longer separate activities but connected elements of one system.

A strategic impact of ITINERIS lies in the fact that it represented the first large-scale national exercise aimed at coordinating the Italian environmental Research Infrastructure ecosystem across atmospheric, marine, terrestrial and geosphere domains. While the participating infrastructures were already part of established European and international networks, they had previously operated largely within separate disciplinary and organisational frameworks. ITINERIS created, for the first time, a common national coordination layer connecting infrastructures, services, data resources, facilities and communities through shared standards, governance mechanisms and digital services. In this sense, the project did not simply support individual Research Infrastructures; it demonstrated the feasibility and value of a coordinated national environmental RI ecosystem.

A major aspect of this transformation was the creation of the ITINERIS HUB, which acted as the main digital and organisational layer of the project. The HUB federated the resources of the Research Infrastructures through a common access framework, shared metadata, interoperable services and coordinated workflows, allowing users to navigate a very large and heterogeneous research ecosystem through a single-entry point. This was not a cosmetic result or a simple web interface: it was the operational condition that made cross-RI integration possible, because it linked datasets, services, facilities, training resources and virtual environments in a coherent structure. By doing so, ITINERIS reduced the fragmentation that had previously characterised the environmental RI landscape and created a more robust basis for long-term scientific collaboration.

FAIR implementation and semantic interoperability were among the project's most significant scientific contributions. ITINERIS developed one of the most structured national efforts to assess and improve FAIR adoption across environmental RIs, including 16 FAIR Implementation Profiles, and a systematic assessment of FAIR practices. The project also advanced semantic interoperability through the ITINERIS Terminology Service, the publication and FAIRification of semantic artefacts, and the deployment of semantic search and annotation tools in operational use cases. The impact of these actions is that FAIRness became a shared infrastructural language rather than an isolated best practice, improving the traceability, machine-actionability and reusability of environmental data while creating tools that can continue to serve the broader community beyond the project lifetime.

The project also generated a substantial scientific impact by enabling new methods, new observational combinations and new forms of cross-domain research.

The atmospheric domain provides some of the clearest examples of scientific impact translated from project outputs into wider methodological relevance. WP4 produced more than 60 new datasets and 174 outputs, including 67 peer-reviewed articles, and the work was recognised with four scientific awards, confirming the external quality and visibility of the research developed within ITINERIS. More

importantly, the project generated methodological advances in aerosol typing, source apportionment, boundary-layer analysis and fire-tracer identification that have already been adopted in broader European workflows, including ACTRIS data products and downstream applications linked to CAMS and EarthCARE validation activities. This is a strong impact signal because it shows that methods developed within the project entered European observing and service chains, strengthening the role of Italian atmospheric science in internationally standardised contexts.

WP4 also strengthened national observational capacity in a way that has direct scientific consequences. The project established the first national network for atmospheric carbon isotope measurements, expanded analytical capabilities for sample chemistry, improved pollen observation methods, developed atmospheric simulation facilities and installed the first ACTRIS-compliant aerosol lidar on board the Gaia Blu research vessel. These are not merely equipment upgrades; they broaden the range of questions that can be investigated, from aerosol sources and atmospheric transport to atmosphere-ocean exchanges and climate-related tracing of carbon-cycle processes. The impact therefore lies in the fact that ITINERIS made Italian atmospheric research more capable of producing integrated, high-quality observations that are relevant both for science and for operational environmental services.

A similar logic applies to the marine domain, where ITINERIS supported the development of IT-IOOS as a federated national ocean observing system connecting 13 subsystems and integrating the Italian nodes of major marine Research Infrastructures into a single national framework. By the end of the project, the IT-IOOS HUB provided access to 19 Essential Ocean Variables, 11 Essential Biodiversity Variables and 23 Essential Climate Variables, demonstrating broad coverage across physical, biogeochemical, biological and ecosystem dimensions. The impact of this result is that Italian marine observation moved closer to a coherent, operationally relevant and internationally interoperable system aligned with GOOS, EOOS and GCOS principles, making the data more useful for both research and environmental governance.

This impact was reinforced by the expansion of continuous and near-real-time marine observing capacity. WP5 increased automatic EOVS measurements from 60 to 76 and EBVS measurements from 38 to 50, deployed new sensors and mobile platforms, and upgraded the research vessels Gaia Blu and Laura Bassi with better instrumentation, data transmission and interoperability. The project also procured 580 instruments overall, but the real significance is not only volume: it is that Italy now has a stronger capacity to observe the marine environment continuously, from coastal to offshore settings and across environmental gradients, with data streams suitable for integration into European services such as Copernicus Marine Service, EMODnet and the Digital Twin Ocean. In impact terms, ITINERIS therefore improved the scientific reliability and operational relevance of marine observation at national level.

The value of integration is especially visible in the project's large-scale campaigns and pilot services. The ITINERIS-EYES and EMSO-SA 2025-LB cruises became concrete demonstrations of cross-RI integration, combining platforms and expertise from multiple scientific domains in shared observational strategies. Their impact lies in proving that integrated infrastructure can produce observational configurations and interdisciplinary analyses that no single RI could achieve alone, thus making integration itself a scientific capability rather than only a governance objective.

The terrestrial biosphere and life-science domain produced another layer of impact, especially through digitisation, harmonisation and the strengthening of long-term environmental monitoring. WP6 supported the integration of infrastructures such as ANAEE, DiSSCo, eLTER, EMPHASIS, IBISBA, ICOS and LifeWatch through common digital services, shared workflows and more interoperable data structures. One of the most visible results was the digitisation of more than 350,000 specimens and the management of more than 55,000 curated records, which significantly improved the accessibility and scientific value of biodiversity resources. At the same time, the project strengthened ecosystem monitoring, phenotyping, metagenomics, biotechnology and carbon-cycle observation, making these assets more useful for integrated research on biodiversity loss, ecosystem change and climate-related pressures. The real impact is therefore not only the availability of more data, but the fact that those data can now be used more effectively within a shared infrastructure logic.

Activities in the geosphere and land-surface domain show how ITINERIS improved the scientific and operational value of geoscientific data. WP7 harmonised data streams, upgraded access systems and integrated geophysical, geological and monitoring datasets into the ITINERIS DOWNSTREAM VRE, making them more accessible and more reusable for the scientific community and for decision-makers. The work also improved support for drilling, coring, subsurface monitoring, hazard analysis and forecasting, with direct implications for civil protection, territorial planning and the management of natural

risks. In this domain, ITINERIS did not only increase the quantity of available information: it improved the capacity to convert geoscientific observations into actionable knowledge. This is a clear example of scientific impact that already reaches beyond the academic sphere, while still remaining fundamentally grounded in research infrastructure development.

One of the strongest cross-domain impacts of the project lies in the development of Virtual Research Environments. The nine VREs created within ITINERIS allowed data, models, workflows and analytical services to be combined in modular e-science environments addressing complex environmental questions across the atmosphere, marine, terrestrial and geosphere domains. These environments are important because they operationalise integration: they make it possible to work across domains without forcing all data into one central repository, and they support both expert users and broader scientific communities with shared, interoperable tools. Through the VREs, ITINERIS turned distributed resources into collaborative research spaces, which is one of the clearest signs that the project created not just infrastructure, but a new research capability.

The project's impact is also visible in the way it strengthened access, training and community building. The Training Centre delivered 70 courses to almost 950 participants and produced more than 1,200 digital learning resources, including 603 FAIR-compliant Digital Training Objects, helping build the next generation of RI operators and users. This matters because environmental infrastructures are only sustainable if they are accompanied by a skilled community capable of using, maintaining and developing them over time. In parallel, the access framework supported coordinated and transparent use of resources across domains, broadening the user base and making the infrastructure system more open to interdisciplinary research, young scientists, public institutions and other stakeholders. In other words, ITINERIS improved not only the scientific instruments, but also the human and organisational conditions that make those instruments truly effective. Beyond the direct benefits for users, these activities contributed to creating a new generation of researchers, technicians, data stewards and infrastructure operators capable of maintaining, operating and further developing environmental Research Infrastructures in the years ahead.

Another major impact of ITINERIS is the way it increased the international relevance and visibility of the Italian environmental RI ecosystem. The project aligned methodologies, services and observing practices with major European and global frameworks such as GOOS, EOOS, GCOS, GEO, WMO, ESA and related initiatives. This alignment is not a formal exercise: it makes the results more credible, more comparable and more reusable in transnational research and operational contexts. It also positions Italy as a more integrated contributor to European RI networks and international environmental science, which is a key legacy of the project.

Beyond the scientific outputs generated within individual domains, ITINERIS also strengthened the strategic positioning of the participating infrastructures within the European Research Infrastructure landscape. By improving service provision, interoperability, observational capacities and digital integration, the project increased the visibility and relevance of Italian nodes within major European Research Infrastructures and ERICs. This enhanced positioning facilitated new international collaborations and strengthened participation in European and national research initiatives, creating opportunities that extend well beyond the duration of the project.

Evidence collected through the final survey of participating Research Infrastructures confirms these trends. Most infrastructures reported improvements in their national and international visibility, the establishment of new scientific and institutional collaborations, and a stronger capacity to participate in national and European research initiatives. Many respondents also indicated expectations of increasing demand for their data, services and facilities after the project's completion, suggesting that the benefits generated by ITINERIS are already extending beyond its formal lifetime. These results provide concrete evidence that the project strengthened not only scientific and technological capacities, but also the attractiveness, recognition and long-term strategic positioning of the Italian environmental RI ecosystem.

The impact is therefore visible not only in the scientific results produced, but also in the increased capacity of the Italian environmental RI community to contribute to international programmes, collaborative projects and strategic research agendas.

The project's broader relevance is confirmed by its scientific production and dissemination record. ITINERIS produced 461 peer-reviewed publications, 280 datasets, 228 deliverables, and an extensive programme of dissemination through conferences, presentations, posters, proceedings and public-facing

communication. Notably, 321 peer-reviewed publications involved at least one researcher recruited through ITINERIS, demonstrating the project's contribution not only to scientific output but also to the development of new research capacities and the professional growth of early-career and specialised personnel within the environmental RI ecosystem. These numbers are important not because they stand alone, but because they document the scale of the community that the project activated and the amount of knowledge that was made available through it. The quantity of outputs is therefore best understood as evidence of a much larger systemic effect: the creation of an integrated environmental research environment that is scientifically productive, technically coherent and institutionally durable. Further scientific output is expected beyond the project lifetime as research activities initiated within ITINERIS continue to mature and exploit the capabilities established by the project.

Overall, the impact of ITINERIS should be read as a transformation of the national environmental research system rather than as a sum of isolated achievements. Its most important legacy is the combination of integrated access, interoperable data, shared digital services, advanced instrumentation, cross-domain VREs, training capacity and international alignment. These elements together have made the Italian environmental RI landscape more connected, more visible and more capable of addressing complex scientific and societal challenges in a sustained way.

5.2. Collaborations and synergies

ITINERIS significantly strengthened the collaborative landscape of environmental Research Infrastructures (RIs) in Italy by creating a coordinated framework that connected research organisations, universities, public authorities, international initiatives, and user communities across the atmospheric, marine, terrestrial, and geosphere domains. By bringing together the Italian nodes of major environmental RIs within a common operational framework, the project consolidated existing collaborations and enabled new cross-domain interactions, establishing ITINERIS as a national platform for cooperation across the environmental sciences.

At national level, the project reinforced cooperation among research organisations, universities and public institutions operating in the four environmental domains. The integration activities promoted through the ITINERIS HUB, common access mechanisms, shared digital services and coordinated governance structures fostered regular interaction among communities that had previously operated largely within disciplinary boundaries. In the atmospheric field, WP4, particularly relevant is the cooperation with the regional agencies for the environment about the application of the new EU Air quality directives, initiated thanks to a ITINERIS funded meeting in April 2025. In the marine field, WP5 reinforced collaboration with marine research institutions and operational stakeholders such as the Italian Coast Guard, as well as with users involved in ecosystem observation, marine risk management and coastal monitoring. In the terrestrial and biodiversity field, WP6 strengthened cooperation with biodiversity monitoring networks, botanical and zoological collections, ecological observatories, and research-performing institutions involved in long-term ecosystem monitoring and data mobilization. In the geosphere domain, WP7 linked research infrastructures with geological services, civil protection actors and territorial monitoring bodies, supporting improved integration of data and workflows for hazard assessment and land-surface observation.

ITINERIS strengthened the international positioning of the Italian environmental RI system by consolidating targeted collaborations with major global organisations, programmes and data frameworks. Rather than creating new bilateral partnerships from scratch, the project built on the scientific and operational roles of the participating infrastructures and translated them into structured links with international bodies that define standards, data exchange practices and observation priorities across the Earth system.

In the atmospheric domain, WP4 reports strong collaboration with ESA ESRIN, WMO, and C3S, through the involvement of their experts as part of an External Advisory Board of ITINERIS WP4. Furthermore, close collaborations with EUMETSAT, CSIC and JRC have also been established. These interactions helped position Italian atmospheric capacities within global Earth-observation and climate-monitoring ecosystems, while also increasing the relevance of project outputs for operational services and international scientific communities.

In the marine domain, WP5 connects ITINERIS to GOOS, EOOS, GEO BON and the G7 Future of the Sea Ocean Initiative, showing that the integrated Italian ocean-observing system was designed not only as a national facility but as a contribution to global ocean-observation governance. The same domain also points to future and partially already active links with Copernicus Marine Service, EMODnet and the Digital Twin Ocean, reinforcing the role of Italian data and observing systems within broader European and international marine information infrastructures and the valorisation of research outcomes through the creation of service-oriented products: developed tools and specific indicators required by the Water Framework Directive, Marine Strategy Framework Directive, and the Ecosystem Integrity framework.

In the terrestrial and biodiversity fields, the project strengthened relations with GBIF and CETAF, supporting biodiversity data mobilisation, digitisation, standardisation and long-term interoperability. These links are particularly relevant because they connect ITINERIS-generated datasets and services to international biodiversity information infrastructures, increasing discoverability and reuse beyond the national context.

In the geosphere and land surface domain, WP7 strengthened ITINERIS links with the international scientific drilling community through ECORD, ICDP and IODP, while also aligning data harmonisation and access procedures with international standards. This allowed the project to improve the accessibility and reuse of geological, geophysical and drilling-related data, and to embed Italian geosphere capacities within long-standing international research and observation systems.

Overall, the international collaborations developed through ITINERIS should be read as a positioning strategy: they do not merely add external contacts but embed the Italian environmental RI system in the standards, workflows and service ecosystems that shape global environmental science.

An important aspect of the project was the development of synergies with other National Recovery and Resilience Plan (NRRP) initiatives. ITINERIS established collaborative links with NBFC through shared activities and joint scientific outputs, while the ITINERIS HUB provides services, metadata access mechanisms and digital resources that support biodiversity-related activities and data integration. Additional synergies were developed with MEET, GeoSciences-IR, EMBRC-UP, ECCSELLENT and MIRRI-SUS through joint discussions aimed at mapping complementary capabilities, identifying common services and exploring coordinated stakeholder engagement strategies. Collaboration with CN AGRITECH supported the use of environmental observations, data and modelling capacities for sustainable agriculture applications, while interaction with CN HPC contributed to the exploitation of advanced computing resources for environmental modelling, simulation and data analysis.

Overall, ITINERIS acted as a catalyst for a more integrated national and international collaboration ecosystem. Its contribution extends beyond the number of partnerships established, as it created shared operational frameworks, interoperable services and durable relationships that provide a foundation for future scientific cooperation, joint projects, stakeholder engagement activities and strategic initiatives at national and international level.

5.3. Valorisation of research and strategic cooperation with the private sector

ITINERIS created significant industrial valorisation potential by transforming environmental Research Infrastructures into a more visible, accessible and collaborative innovation ecosystem. The project not only generated scientific knowledge, advanced observational capacities and digital services, but also strengthened the conditions through which these assets can be accessed and exploited by companies, technology providers, public authorities and other non-academic users. In this sense, ITINERIS contributed to reducing the distance between research and practical deployment, particularly in environmental sectors where innovation depends on reliable observations, validated datasets, advanced instrumentation and trusted digital infrastructures.

A key factor enabling this valorisation process is the existence of a common and user-oriented access environment. Through the ITINERIS HUB, environmental data, services, facilities, Virtual Research Environments and training resources became accessible through a coordinated framework that improves discoverability, interoperability and usability. This is particularly relevant for industrial users, who can only benefit from Research Infrastructures when resources are visible, understandable and accessible through predictable workflows. By integrating environmental Research Infrastructures within a common

digital ecosystem, ITINERIS created the conditions for a broader use of environmental knowledge beyond the scientific community.

The industrial relevance of ITINERIS is also linked to its role as an intermediate environment for testing, validation and refinement. Research Infrastructures often help bridge the gap between research and market deployment by providing facilities and operational conditions where technologies, methods and services can be evaluated before large-scale adoption. This contribution is especially important in overcoming the so-called “valley of death”, where promising innovations frequently fail to reach operational maturity due to insufficient validation, scalability or reliability. Through access to state-of-the-art facilities, harmonised observation systems, advanced instrumentation and interoperable data services, ITINERIS created favourable conditions for co-development, experimentation and future innovation partnerships across environmental domains.

A main dimension of industrial valorisation derives from the significant investment generated through the project’s procurement activities. The acquisition of advanced scientific instrumentation, monitoring systems, laboratory equipment, sensors, ICT components, data-management solutions and specialised services mobilised a substantial volume of resources towards the industrial and technological sector. Beyond the immediate economic effect, these investments contributed to strengthening relationships between Research Infrastructures and technology providers, creating opportunities for the adaptation, testing and refinement of products and services in demanding operational environments. In many cases, suppliers were not simply vendors of equipment but became partners in a broader innovation process, interacting with research teams to address specific technical requirements and supporting the deployment of cutting-edge solutions within environmental observation systems.

A main area of interaction concerns digital infrastructures and data services. Beyond environmental observations themselves, ITINERIS generated demand for interoperable ICT solutions supporting metadata management, catalogue publication, semantic interoperability, access workflows, dashboards, validation tools and user-facing interfaces. The project highlighted the importance of user-oriented design, standard metadata schemas and advanced visualisation tools to ensure that environmental information can be effectively exploited not only by researchers but also by institutional and private-sector users. The development of the ITINERIS HUB and its associated digital services created opportunities for collaboration with technology providers, software developers and system integrators. Experiences involving companies such as Arista Networks (a leader in the data centre networking sector) and ETT Solutions (a company with strong expertise in data platforms, geospatial solutions and digital transformation for research and industry) demonstrated the potential for co-development of advanced digital solutions supporting data discovery, interoperability, visualisation and access to distributed environmental resources. In this respect, ITINERIS generated innovation opportunities not only around scientific measurements and monitoring technologies, but also around the digital infrastructures required to transform environmental data into operational knowledge and decision-support tools.

The atmospheric domain provides a clear example of this valorisation pathway. Advanced aerosol classification procedures, improved source-apportionment methodologies, strengthened boundary-layer analysis and innovative observational configurations increased the reliability and sophistication of atmospheric monitoring systems. These developments are relevant for industrial valorisation because they can be translated into specialised instrumentation, calibration services, atmospheric monitoring systems and downstream analytical applications used by environmental agencies, technology providers and operational service developers. The project also strengthened lidar observational capabilities. These developments create opportunities for specialised equipment manufacturers, sensor-integration providers and environmental monitoring companies. The participation of industrial actors such as Advanced Lidar Applications (ALA), an Italian company working in the atmospheric lidar development, further demonstrated the potential for interaction between Research Infrastructures and companies operating in advanced environmental sensing and observation technologies.

The marine domain also offers significant valorisation opportunities through its interaction with operational sectors and private users. The development of an integrated ocean observing framework, enhanced near-real-time data streams, autonomous observing systems and upgraded vessel instrumentation increased the availability of environmental information relevant to shipping, fisheries, aquaculture, offshore energy and marine risk assessment. These sectors increasingly depend on reliable oceanographic observations for planning, monitoring and operational decision-making. The interaction with stakeholders from the maritime production sector highlighted the practical relevance of marine observations for

economic activities directly dependent on environmental conditions. In particular, the collaboration with La Spezia Mussel Farmers Cooperative illustrated how environmental observations can support productive activities requiring continuous monitoring of marine conditions and ecosystem quality. In this context, valorisation is not limited to technology transfer but also includes the creation of stronger connections and service provision between research capacities and economic sectors that rely on trusted environmental information.

The terrestrial biosphere domain generated industrial relevance through the strengthening of infrastructures supporting biodiversity monitoring, ecosystem observations, biotechnology applications, experimental agriculture and environmental data services. ITINERIS enhanced access to biological collections, ecosystem datasets, phenotyping facilities, cloud-based analytical services and interoperable digital resources, creating opportunities for interaction with sectors such as biotechnology, environmental consulting, precision agriculture, ecosystem restoration and biodiversity monitoring. By improving the FAIRness, interoperability and accessibility of biodiversity and ecosystem information, the project increased the potential reuse of these resources beyond the academic community. Companies and organisations working on environmental assessment, sustainable agriculture, Nature-Based Solutions and ecological restoration increasingly require high-quality environmental information and testing environments. In this context, the infrastructures involved in the biosphere domain provide a valuable framework for future collaboration, validation activities and service development, particularly in areas where environmental monitoring and biological resources support innovation processes.

The geosphere also provided pathways for industrial valorisation through advanced monitoring technologies, geospatial services and hazard-oriented applications. ITINERIS strengthened digital platforms, monitoring systems and forecasting capabilities relevant to land-surface monitoring, geophysical analysis and risk management. These activities create opportunities for collaboration with technology suppliers, software developers, geospatial service providers and companies operating in environmental monitoring, hazard assessment and digital Earth observation. Particularly relevant in this respect are developments related to advanced geophysical monitoring methods and sensing technologies with potential applications in environmental management and the energy transition. The collaboration with companies and stakeholders such as ENI demonstrated the relevance of geoscientific infrastructures for geospatial services, environmental monitoring and energy-related applications. These interactions confirm that Research Infrastructures can generate specialised demand for technologies and services while simultaneously benefiting from industrial innovation and technological expertise.

The geosphere domain generated concrete opportunities for industrial valorisation through the co-design, customisation and testing of advanced monitoring technologies, geophysical instruments and digital services. A particularly relevant case is the development of an IoT-based distributed sensing system for deep geoelectrical investigations, carried out in collaboration with ITACA IOT, a company specialised in structural monitoring sensors. The industrial relevance of these developments was further confirmed by the interest expressed by Eni, especially about applications connected to the energy transition and advanced geospatial monitoring. Collaboration with the private sector was also strengthened through the research agreement with IDS GeoRadar S.r.l., focused on the joint development and testing of advanced strategies for GPR data processing. In parallel, ITINERIS created value for external public stakeholders as well, as shown by the geophysical survey conducted for the Comune di Atripalda. Further examples of valorisation are provided by the SMINO infrastructure in Friuli Venezia Giulia, whose fibre interrogators and fibre seismic lines were implemented in close collaboration with INSIEL, the Regional Information System services and the Civil Defence department of the Autonomous Region. Overall, these interactions show that ITINERIS did not merely improve geoscientific observation capacities but also supports both scientific advancement and downstream innovation.

The industrial relevance of ITINERIS was further demonstrated through dedicated stakeholder-engagement activities. During the ITINERIS Final Meeting, a specific round table on “Enterprises and Innovation” brought together companies, technology providers and end users operating in environmental monitoring, ICT, geospatial services, energy and marine production sectors. Case studies presented during the discussion addressed enhanced ICT infrastructures, marine applications supporting productive activities and innovative geophysical methods relevant to the energy transition. The event confirmed the existence of a concrete demand for the services, technologies and facilities offered by the Italian environmental Research Infrastructures through ITINERIS. Discussions highlighted how infrastructures operating at the technological frontier can stimulate innovation by generating specialised demand, while simultaneously providing access to advanced facilities, expertise and validation environments.

Similar conclusions emerged during the national workshop “Research Infrastructures for Innovation”, where ITINERIS contributed to discussions on the role of Research Infrastructures as strategic enablers of innovation ecosystems. A central message emerging from these discussions was that integration alone is not sufficient unless accompanied by clear access mechanisms, user support and the capacity to develop concrete use cases together with companies and stakeholders. In this perspective, the value of Research Infrastructures lies not only in providing access to resources, but also in facilitating co-development, testing and adoption of innovative solutions. An important step in this direction was represented by the launch of the Operational Partnerships initiatives in the work coordinated by ITINERIS within the Environment cluster in collaboration with NRRP projects such as MEET, GeoSciences, EMBRC-UP, ECCSELLENT and MIRRI, ITINERIS contributed to the creation of a broader framework aimed at strengthening interactions between Research Infrastructures, companies, public administrations and end users. The initiative promotes a shift from isolated service provision towards long-term collaborative relationships capable of supporting innovation pathways across the entire value chain. In this regard, ITINERIS demonstrated that collaboration can take multiple forms, ranging from upstream interactions, where infrastructure needs stimulate the development of tailored technological solutions by suppliers, to downstream applications, where environmental data, services and scientific products are incorporated into operational workflows, decision-support systems and commercial services. Between these two extremes, ITINERIS promoted several forms of co-development and collaborative innovation, in which researchers, technology providers and end users jointly contributed to the design, testing and validation of new solutions.

More broadly, ITINERIS strengthened the national innovation environment by connecting environmental Research Infrastructures with other NRRP initiatives operating in areas such as high-performance computing, agriculture, biotechnology, marine biodiversity, geosciences and environmental monitoring. These synergies increase the potential for future cooperation with companies and innovation actors working in sectors including environmental technologies, digital infrastructures, environmental consulting, biotechnology and the green transition.

Besides the immediate innovation benefits, these relationships are also strategically important for the long-term sustainability of Research Infrastructures. Stable interactions with industrial users, technology providers and innovation ecosystems can expand the user base of infrastructures, stimulate new service opportunities, support future investments and increase the societal relevance of RI activities. In this sense, collaboration with the private sector should not be seen only as a valorisation pathway, but also as one of the mechanisms through which environmental Research Infrastructures can strengthen their resilience, visibility and long-term sustainability beyond individual funding cycles.

While collaboration with industry represents one important pathway for research valorisation, ITINERIS also demonstrated that environmental Research Infrastructures can generate broader societal value through engagement with public institutions, local communities and third-sector organisations.

ITINERIS, through the development of its user strategy, also explored new approaches to engaging underrepresented user groups, working with third-sector organisations, schools and municipal social services to maximise the societal value of Research Infrastructures. This experience showed that the value generated by Research Infrastructures cannot be assessed solely through scientific outputs, but also through their capacity to address societal needs, strengthen territorial cohesion and create tangible benefits for local communities. One example was provided through the Ecosystems of Territorial Cohesion initiative, which promotes social and economic development by addressing educational poverty in marginal areas today’s facing demographic and cultural desertification. Within this initiative, LifeWatch and ACTRIS organised a training programme involving 34 students (9–14 years old) from Southern Salento experiencing educational poverty. Through hands-on laboratory activities "Hidden Biodiversity" at LifeWatch (University of Salento and CNR-IRET) and "Sky Discovering" at ACTRIS (CNR-IMAA), participants experienced research infrastructures first-hand, interacting directly with scientists and advanced scientific facilities. Beyond scientific outreach, the initiative demonstrated how Research Infrastructures can contribute to territorial cohesion by fostering curiosity, strengthening motivation towards science and increasing awareness of the scientific excellence available within local communities. For children experiencing educational poverty, these activities proved particularly effective in fostering intrinsic motivation through direct experience, curiosity and a supportive, non-judgemental learning environment. An additional source of inspiration was the opportunity to discover internationally recognised scientific

excellence operating within their own region in Southern Italy. Participants' feedback was collected through dedicated video interviews.¹²

Overall, ITINERIS demonstrated that industrial valorisation in environmental research is most effective when it is based on accessibility, interoperability, co-design and trust. The project did not merely open data; it created conditions for companies and other non-academic actors to engage with research infrastructures in ways that support validation, adaptation and innovation.

By combining shared digital systems, advanced instrumentation, stakeholder engagement, collaborative innovation and inclusive user-oriented initiatives, the project created conditions for both industrial innovation and broader societal impact.

6. PART VI - CONCLUSIONS, LEGACY AND FUTURE OUTLOOK

ITINERIS was conceived as a strategic investment to strengthen the Italian environmental Research Infrastructure ecosystem and to enhance its capacity to contribute to national and international environmental science. Over the course of the project, this objective evolved into the construction of a coordinated framework capable of connecting infrastructures, scientific communities, data resources, services, facilities and expertise that had previously operated in parallel or within separate disciplinary and organisational contexts. The project showed that integration is not only an organisational improvement, but a scientific and strategic value in itself: when infrastructures are connected through common standards, interoperable services and shared access mechanisms, the result is a more coherent and effective system for environmental observation, experimentation, data management and scientific collaboration.

The project's most important legacy is not a single platform or equipment upgrade, but the creation of the conditions for a more mature national ecosystem of environmental Research Infrastructures. ITINERIS was conceived to create and consolidate a national network of environmental Research Infrastructures, harmonising their development to strengthen integration, access and interoperability. In this sense, the network itself represents the project's principal legacy, because it provides the structural basis for future collaboration, shared services and system-wide growth.

The project demonstrated that the Italian system could operate as a federated network rather than as a collection of isolated assets, and that this approach makes it possible to combine distributed resources into a common framework without reducing the autonomy of the individual infrastructures. This is a key point of strength: the project did not centralise the system in a rigid way, but created shared digital, methodological and governance layers that can support long-term cooperation while preserving the identity and mission of each infrastructure.

Through the ITINERIS HUB, coordinated governance mechanisms, shared policies and common digital services, the project transformed a fragmented landscape into a more visible, accessible and interoperable national system. This transformation has implications at several levels. At the scientific level, it increased the capacity of participating infrastructures to support multidisciplinary research, cross-domain analysis and integrated environmental studies. At the operational level, it improved the discoverability and usability of resources, making it easier for users to identify facilities, datasets and services relevant to their needs. At the institutional level, it strengthened the collective capacity of the network, helping the participating infrastructures to act together more effectively within the national research system and in European and international contexts.

A particularly relevant achievement concerns the progressive maturation of the national Research Infrastructure ecosystem. The participating infrastructures entered the project with different levels of digital, operational and organisational maturity. Some were already strongly embedded in European frameworks and had consolidated service provision capabilities, while others were still in a phase of consolidation or digital expansion. ITINERIS helped reduce these asymmetries by promoting common methodologies, shared standards, coordinated training activities, FAIR implementation processes and digital integration mechanisms. In this sense, the project did not only strengthen the most advanced infrastructures; it also supported the growth of less mature components, contributing to a more balanced

¹² Video and participants' feedback is available at <https://youtu.be/ZoUUtKpnyIQ?feature=shared>

and resilient ecosystem and improving the overall readiness of the network to operate according to common principles and practices.

The project also generated a substantial scientific and technological legacy. Its outputs included new observation systems, upgraded facilities, interoperable digital platforms, harmonised datasets, semantic services, Virtual Research Environments and advanced training resources. However, the real value of these outputs lies in the way they interact with one another. ITINERIS created a framework in which data, tools, services and expertise are not isolated products but connected components of a broader ecosystem. This connectivity increases the scientific value of each individual asset, because it enables reuse, combination and extension across domains. It also improves the ability of the infrastructures to respond to emerging research questions and policy needs that require integrated environmental knowledge rather than single-domain results.

A central part of this legacy is the ITINERIS HUB, which should be considered the backbone of the future national environmental Research Infrastructure system. The HUB is not simply a catalogue or a visibility tool. It is the main access layer through which datasets, services, facilities, virtual environments and training resources can be discovered and used in a coordinated way. By supporting interoperability, metadata harmonisation, FAIR data management and common access workflows, the HUB provides the foundation for sustained collaboration among the participating infrastructures. Its importance is not limited to the project duration: it has the potential to remain the reference point for the national environmental RI ecosystem, provided that adequate governance, curation and maintenance are ensured over time.

The sustainability of the system depends on a mixed model that combines institutional commitment, network coordination and project-based development. Most of the services, facilities and observational systems strengthened through ITINERIS are already embedded within the operational plans of the participating infrastructures and organisations. This is a major advantage because it reduces dependence on temporary funding streams and makes it possible for the project's benefits to continue through ordinary institutional activity. At the same time, the continuation of targeted development actions is necessary to keep the system evolving, especially in relation to interoperability upgrades, automated metadata harvesting, access mechanisms and digital services. For this reason, sustainability should not be understood as simple preservation, but as the ability of the system to remain active, adaptable and responsive over time.

This long-term perspective is reinforced by the integration pathway towards the Italian EOSC Node and the broader EOSC and ENVRI ecosystems. ITINERIS has already aligned its services, catalogues and FAIR implementation practices with European Open Science principles, creating the conditions for wider visibility and reuse of Italian environmental resources at European level. Future integration within the EOSC framework will further strengthen discoverability, interoperability and accessibility, while also increasing the contribution of Italian environmental science within the European Research Area. The relevance of this step is not only technical. It also places Italian environmental infrastructures within a broader European digital and scientific landscape, where they can be more easily connected to cross-border services, shared standards and international research communities.

The sustainability and relevance of ITINERIS are further demonstrated by its capacity to generate follow-on initiatives, new project proposals and additional investments that extend the impact of the original NRRP funding. The collaborative frameworks, digital services and scientific networks established through ITINERIS have strengthened the ability of participating organisations to engage in new national and European initiatives. This leverage effect indicates that the project has not only produced direct results but has also created favourable conditions for attracting future resources, expanding collaborations and generating additional scientific, technological and societal impacts.

The project has also strengthened the international positioning of the participating infrastructures. Through improved coordination, stronger interoperability and more coherent service provision, the Italian nodes have increased their visibility and relevance within the European RI landscape and within their respective ERICs and international programmes. This is particularly relevant for infrastructures participating in frameworks such as ACTRIS, ICOS, EMSO, Euro-Argo, DANUBIUS, JERICO, eLTER, LifeWatch, DiSSCo and ANAEE, because it enhances their ability to contribute to shared strategic agendas, governance structures, operational services and transnational scientific initiatives. In practical terms, this means that the Italian environmental RI system is now better positioned to participate in future European projects, international collaborations and large-scale research programmes.

Another important dimension of the legacy concerns human capital and community building. Beyond infrastructures and digital systems, ITINERIS has contributed to the formation of a new generation of researchers, technologists, data stewards, infrastructure operators and service providers with expertise in FAIR data management, digital services, interoperability, environmental observation and interdisciplinary science. Through training activities, collaborative scientific initiatives and cross-domain pilot actions, the project has strengthened a community capable of working across disciplinary boundaries and using shared infrastructures in a more coordinated way. This human capital is one of the most durable results of the project because infrastructure systems only remain effective when the community around them has the skills and the culture needed to operate them.

The project also demonstrated the strategic importance of environmental Research Infrastructures as enabling platforms for innovation, knowledge transfer and societal applications. The interactions established with public authorities, environmental agencies, protected-area managers, civil protection bodies, technology providers, industrial stakeholders and international organisations show that the value of Research Infrastructures extends well beyond scientific production. Environmental observations, digital services, analytical tools and experimental facilities are increasingly relevant for the management of climate change, biodiversity loss, environmental degradation, natural hazards, pollution and sustainable resource use. This broader role should be seen as part of the long-term sustainability of the system, because infrastructures that are able to generate value for multiple user groups are also more likely to remain institutionally relevant and supported over time.

Beyond the tangible investments in facilities, instrumentation and digital services, ITINERIS has demonstrated the strategic value of coordinated Research Infrastructure development at national scale. Rather than strengthening individual infrastructures in isolation, the project created common governance mechanisms, interoperable digital services, harmonised access procedures and collaborative scientific practices that allow the participating RIs to operate as parts of a coherent national ecosystem. This systemic dimension represents one of the project's most significant achievements, as it provides a model that can be replicated in other scientific domains where distributed Research Infrastructures require stronger coordination and integration.

Looking ahead, the main challenge is no longer the creation of integration mechanisms, but their consolidation and expansion. Future developments should focus on completing the onboarding of infrastructures, facilities, services and resources that are not yet fully represented within the HUB, strengthening the participation of less mature infrastructures, and progressively integrating additional nationally relevant environmental resources originating from other projects, initiatives and institutions. The scalability of the ITINERIS architecture provides a real opportunity to extend the national ecosystem beyond the original project perimeter, increasing its completeness, representativeness and long-term value. This is especially important if the system is to become a stable reference point for the whole environmental domain rather than only for the infrastructures directly involved in the original project.

Particular attention should also be devoted to the further development of cross-domain science. The integration achieved among atmospheric, marine, biosphere and geosphere communities has already demonstrated the scientific value of combining observations, services and expertise across traditionally separate domains. Future efforts should build upon this foundation by exploiting the interoperability enabled by the ITINERIS architecture and by promoting new scientific workflows capable of addressing complex Earth-system questions through integrated approaches. The Virtual Research Environments, semantic interoperability services, shared access mechanisms and broader digital ecosystem developed within the project provide a robust basis for this evolution. Their future use should not be limited to maintaining what already exists, but should support new forms of collaboration, new analytical combinations and new scientific questions that require integrated environmental knowledge.

The long-term sustainability of ITINERIS is also reinforced by the broad network of relationships established during the project. Durable partnerships with universities, research organisations, public authorities, international infrastructure communities, industry and stakeholder organisations create a strong foundation for future collaborations, funding opportunities and service evolution. These relationships reduce the risk of fragmentation and ensure that the project remains embedded within wider scientific, institutional and innovation ecosystems. This is important because sustainability is not achieved only through internal governance or technical maintenance; it also depends on the existence of a wider community that recognises the value of the infrastructure and continues to use and support it.

Ultimately, the long-term vision emerging from ITINERIS extends beyond the continuation of a project network. The project has demonstrated the feasibility and value of a coordinated national environmental Research Infrastructure ecosystem capable of integrating observations, facilities, services, expertise and digital resources across domains. By increasing the maturity, visibility, interoperability and international competitiveness of participating infrastructures, strengthening their role within European and global RI frameworks, building a skilled community capable of sustaining future developments, and establishing a scalable digital backbone for continued integration, ITINERIS has laid the foundations for a national environmental infrastructure system capable of evolving over the coming decades. Its most enduring legacy is the creation of a more coordinated, interoperable and internationally connected environmental RI ecosystem, better positioned to contribute to future scientific advances, environmental policies, innovation processes and societal needs.

More broadly, ITINERIS demonstrates that long-term competitiveness in environmental science increasingly depends on the ability to integrate infrastructures, services, expertise and digital resources across institutional and disciplinary boundaries. The project has shown that interoperability, coordinated governance and shared digital ecosystems are not merely technical solutions, but strategic enablers of scientific excellence, innovation and international competitiveness. This broader vision extends well beyond the duration of the project and provides a reference model for the future evolution of the Italian Research Infrastructure landscape.

In this perspective, the ITINERIS HUB represents not only the principal digital legacy of the project, but also the natural foundation for a permanent national environmental Research Infrastructure. Its role is likely to grow over time, if governance, curation, interoperability and institutional commitment remain strong. If this path is sustained, the project will have achieved something more significant than a successful conclusion: it will have created the structural basis for a durable, interoperable and internationally connected national environmental Research Infrastructure ecosystem, capable of supporting scientific excellence, innovation and evidence-based environmental policies for many years to come.

7. REFERENCES

All deliverables produced within the ITINERIS project are publicly available through the ITINERIS project website, in the dedicated [Deliverables](#) section. The table in the ANNEX I provides the complete list of project deliverables, including their identification code, title, responsible Operational Unit, and release date.

ANNEX I – LIST OF DELIVERABLES

WP1 – Coordination and Management

Code	Title Deliverable	Operating Unit	Release date
D1.1.1	First Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	31/12/2022
D1.2.1	First Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	31/12/2022
D1.4.1	Report from the Kick off General Project Meeting, including the list of participants, presentations and report on the main outcome including list of actions for the following months.	CNR-IMAA	31/12/2022
D1.1.2	Second Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	28/02/2023
D1.2.2	Second Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	28/02/2023
D1.1.3	Third Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	30/04/2023

Code	Title Deliverable	Operating Unit	Release date
D1.2.3	Third Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	30/04/2023
D1.3	Communication plan	CNR-IMAA	30/04/2023
D1.1.4	Fourth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	30/06/2023
D1.2.4	Fourth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	30/06/2023
D1.1.5	Fifth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	31/08/2023
D1.2.5	Fifth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	31/08/2023
D1.1.6	Sixth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	31/10/2023
D1.2.6	Sixth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	31/10/2023

Code	Title Deliverable	Operating Unit	Release date
D1.1.7	Seventh Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	31/12/2023
D1.2.7	Seventh Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	31/12/2023
D1.1.8	Eighth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	29/02/2024
D1.2.8	Eighth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	29/02/2024
D1.4.2	Report from the Second General Project Meeting, including the list of participants, presentations and report on the main outcome including list of actions for the final year of the project.	CNR-IMAA	29/02/2024
D1.1.9	Ninth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	30/04/2024
D1.2.9	Ninth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	30/04/2024
D1.1.10	Tenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	30/06/2024

Code	Title Deliverable	Operating Unit	Release date
D1.2.10	Tenth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	30/06/2024
D1.1.11	Eleventh Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	31/08/2024
D1.2.11	Eleventh Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	31/08/2024
D1.1.12	Twelfth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	31/10/2024
D1.2.12	Twelfth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	31/10/2024
D1.1.13	Thirteenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis.	CNR-IMAA	31/12/2024
D1.2.13	Thirteenth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	31/12/2024
D1.1.14	Fourteenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and risks analysis	CNR-IMAA	28/02/2025

Code	Title Deliverable	Operating Unit	Release date
D1.2.14	Fourteenth Financial Report including financial reporting for each WP/activity and for each partner, analysis of critical financial-administrative aspects and proposed solutions to solve possible deviation from the original plan in the reference period.	CNR-IMAA	28/02/2025
D1.1.15	Fifteenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and final results.	CNR-IMAA	30/04/2025
D1.2.15	Fifteenth Financial Report including financial reporting for each WP/activity and for each partner for the reference period.	CNR-IMAA	30/04/2025
D1.1.16	Sixteenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and final results.	CNR-IMAA	30/06/2025
D1.2.16	Sixteenth Financial Report including financial reporting for each WP/activity and for each partner for the reference period.	CNR-IMAA	30/06/2025
D1.1.17	Seventeenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and final results.	CNR-IMAA	31/08/2025
D1.2.17	Seventeenth Financial Report including financial reporting for each WP/activity and for each partner for the reference period.	CNR-IMAA	31/08/2025
D1.1.18	Eighteenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and final results.	CNR-IMAA	31/10/2025
D1.2.18	Eighteenth Financial Report including financial reporting for each WP/activity and for each partner for the reference period.	CNR-IMAA	31/10/2025

Code	Title Deliverable	Operating Unit	Release date
D1.1.19	Nineteenth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and final results.	CNR-IMAA	31/12/2025
D1.2.19	Nineteenth Financial Report including financial reporting for each WP/activity and for each partner for the reference period.	CNR-IMAA	31/12/2025
D1.4.4	Report from the 3rd General Project Meeting, including the list of participants, presentations and report on the main outcome of the project.	CNR-IMAA	31/12/2025
D1.1.20	Twentieth Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and final results.	CNR-IMAA	28/02/2026
D1.2.20	Twentieth Financial Report including financial reporting for each WP/activity and for each partner for the reference period.	CNR-IMAA	28/02/2026
D1.1.21	Twenty-first Technical Progress Report including description of the performed activities, released deliverables, IO achieved, and final results.	CNR-IMAA	30/04/2026
D1.2.21	Twenty-first Financial Report including financial reporting for each WP/activity and for each partner for the reference period.	CNR-IMAA	30/04/2026
D1.4.3	Report from the Final General Project Meeting, including the list of participants, presentations and report on the main outcome of the project.	CNR-IMAA	30/04/2026
D1.5	Business plan for long term sustainability after the end of the project, including a consolidate financial plan for the long-term sustainability of the project, prepared with input from external experts, and including also the measures and actions how to continue to monitor the status of the different activities after the end of the project.	CNR-IMAA	30/04/2026
D1.6	Final Report including all the projects results.	CNR-IMAA	30/04/2026

WP2 - Access to facilities, fair data and related services

Code	Title Deliverable	Operating Unit	Release date
D2.11	Review on the existing terminologies and terminology services relevant for ITINERIS partners	CNR-IRET-Lecce	30/04/2023
D2.10	Draft and final Data Management Plan	CNR-IRET-Lecce	30/04/2023
D2.7	State of the Art review of FAIR-enabling best practices	CNR-IRET-Lecce	30/06/2023
D2.8	Fair Implementation Profiles (FIPs)	CNR-IRET-Lecce	30/06/2023
D2.13	Description of the Terminology Interoperability Framework architecture	CNR-IRET-Lecce	31/08/2023
D2.4	ITINERIS HUB specifications and release	CNR-IMAA	31/08/2023
D2.1	User-Strategy	CNR-IMAA	31/10/2023
D2.12	FAIR terminologies	CNR-IRET-Lecce	31/10/2023
D2.9	Design document describing FAIR implementation choices for the ITINERIS catalogue	CNR-IRETLE	31/12/2023
D2.2	ITINERIS Access Master plan	CNR-IMAA	29/02/2024
D2.5	Catalogue of data and services - specification document: First Release / Second Release / Final Release	CNR-IMAA	29/02/2024

Code	Title Deliverable	Operating Unit	Release date
D2.6	Access Platform Specification document	CNR-IMAA	29/02/2024
D2.19	DOI_Assigment_ITINERIS_Guide	CNR IMAA	28/02/2025
D2.14	Release of the ITINERIS TERMINOLOGY service	CNR-IRET-Lecce	30/04/2026
D2.15	Integration of ITINERIS TERMINOLOGY in three use-cases	CNR-IRET-Lecce	30/04/2026
D2.3	Recommendations for the future National Access Programme	CNR-IMAA	30/04/2026
D2.16	ITINERIS ACCESS policy	CNR-IMAA	30/04/2026
D2.17	ITINERIS Access Management Plan	CNR-IMAA	30/04/2026
D2.18	Pilot call ITINERIS ACCESS: challenges and results	CNR-IMAA	30/04/2026
D2.5.1	Catalogue Administrative Guideline	CNR-IMAA	30/04/2026
D2.5.2	Catalogue Onboarding	CNR-IMAA	30/04/2026
D2.20	ITINERIS HUB Data Policy	CNR-IMAA	30/06/2026

WP3 - ITINERIS Training Programme

Code	Title Deliverable	Operating Unit	Release date
D3.1	Asset ITINERIS Training Centre Platform	CNR-IRET-Lecce	30/06/2023
D3.2	Report Training Executive Working Plan for the second year	CNR-IRET-Lecce	31/08/2023
D3.3	Report First activity report of Activity 3.1, 3.2, 3.3, 3.4, 3.5	CNR-IRETLE	31/10/2023
D3.4	Report First activity report of Activity 3.6	CNR-IRET Montelibretti	31/10/2023
D3.5	Report First activity report of Activity 3.7	CNR-IRET Montelibretti	31/10/2023
D3.6	Report First activity report of Activity 3.8	CNR-IRET-Lecce	31/10/2023
D3.7	Assets First release of the training resources made available by the Environmental RIs on the ITINERIS FAIR Training Catalogue	CNR-IRET Montelibretti	31/10/2023
D3.8	First scientific and financial report of WP3	CNR-IRET-Lecce	31/12/2023
D3.9	Asset ITINERIS Semantic Training Platform on Environmental Sciences - first draft	CNR-IRET-Lecce	10/01/2024
D3.10	Report Training Executive Working Plan for the third period	CNR-IRET-Lecce	31/08/2024
D3.9	Assets: ITINERIS Semantic Training Platform on Environmental Sciences-update	CNR-IRET-Lecce	31/10/2025

Code	Title Deliverable	Operating Unit	Release date
D3.11	Report: Second activity report of Activity 3.1, 3.2, 3.3, 3.4, 3.5	CNR-IRETLE	28/02/2026
D3.12	Report: Second activity report of Activity 3.6	CNR-IRET Montelibretti	28/02/2026
D3.13	Report: Second activity report of Activity 3.7	CNR-IRET Montelibretti	28/02/2026
D3.14	Report: Second activity report of Activity 3.8	CNR-IRET-Lecce	28/02/2026
D3.15	Assets: Second release of the training resources made available by the Environmental RIs on the ITINERIS FAIR Training Catalogue	CNR-IRET Montelibretti	28/02/2026
D3.16	Report: Second scientific and financial report of WP 3	CNR-IRET-Lecce	28/02/2026
D3.17	Report: Training Centre sustainability and business Plan	CNR-IRET-Lecce	28/02/2026
D3.18	Report: Final Activity report of WP 3	CNR-IRETLE	30/04/2026
D3.19	Report: Final scientific and financial report of WP 3	CNR-IRET-Lecce	30/04/2026

WP4 – Atmosphere

Code	Title Deliverable	Operating Unit	Release date
D4.1.1	Atmosphere WP implementation plan	CNR-IMAA	28/02/2023
D4.1.2	Implementation plan for the enhancement of CNR IMAA atmospheric observatory (CIAO) for the provision of RIs integrated and synergistic data products	CNR-IMAA	28/02/2023
D4.2.1	Implementation plan for the CNR ISAC Bologna integrated facility and harmonized with the network	CNR-ISAC-Bologna	28/02/2023
D4.4.1	Implementation plan for the CNR ISAC Lecce integrated facility and harmonized with the network	CNR-ISAC-Lecce	28/02/2023
D4.10.1	Implementation plan of an integrated and accessible digital platform architecture for CeTrA	UNIVE-DAIS	30/04/2023
D4.11.1	Report on the organization of test cases for aerosol typing method improvements	CNR-IMAA	30/04/2023
D4.16.1	Survey on observational data available at the atmospheric environmental RIs as suitable/promising to trace open fire emission plumes	CNR-ISAC-Lamezia Terme	31/10/2023
D4.6.1	Definition of the specific observational requirements and installation of an innovative lidar	CNR-ISMAR-Roma	31/10/2023
D4.7.1	IMPLEMENTATION PLAN of the integrated polar data repository	CNR-ISP-Bologna	31/10/2023
D4.8.1	Implementation plan for the operation of the 3 MV Tandetron accelerator at LABEC with the upgraded computer control systems	INFN-FI	31/10/2023
D4.15.1	Report on atmospheric boundary layer height measurement campaign	CNR-IMAA	31/12/2023
D4.11.2	Documentation of desert dust product	CNR-IMAA	29/02/2024

Code	Title Deliverable	Operating Unit	Release date
D4.12.1	Development of semiautomatic method for identification and characterisation of new particle formation events	CNR-ISAC-Lecce	29/02/2024
D4.13.1	Release of a dataset on bioaerosol characterization	INFN-GE	29/02/2024
D4.14.1	Definition of the minimum requirements for a common, matched database of measured/derived variables for both atmospheric composition and atmospheric dynamics	CNR-ISAC-Bologna	29/02/2024
D4.2.2	Progress report on the acquisition of equipment that will be integrated in the facilities of CNR ISAC Bologna OU and harmonized with the network	CNR-ISAC-Bologna	29/02/2024
D4.3.1	Progress report on the acquisition of equipment that will be integrated in the facilities of the CNR ISAC Lamezia OU and harmonized with the network.	CNR-ISAC-Lamezia Terme	29/02/2024
D4.4.2	Progress report on the acquisition of equipment that will be integrated in the facilities of CNR ISAC Lecce OU and harmonized with the network	CNR-ISAC-Lecce	29/02/2024
D4.5.1	Report on the acquisition of aero portable instrumentation for the optical and microphysical characterization of atmospheric particulate	CNR-ISAC-Bologna	29/02/2024
D4.9.1	Testing report of the updated version of the ChAMBRé DAQ and data storage system	INFN-GE	29/02/2024
D4.1.3	Report on the implementation at CNR IMAA of systems for improving NRT data provision, connectivity and data security	CNR-IMAA	30/06/2024
D4.10.2	DOCUMENTATION of the platform catalogue of services giving access to all modules of the CeTrA platform in its beta-version	UNIVE-DAIS	30/06/2024

Code	Title Deliverable	Operating Unit	Release date
D4.15.2	Report on the optimization of morphological image processing approach algorithm for ABLH determination	CNR-IMAA	30/06/2024
D4.16.2	Report on optimal strategy for integrating the identified tracers	CNR-ISAC-Lamezia Terme	30/06/2024
D4.6.2	Implementation of new Lidar acquisition channels at the Rome ACTRIS	CNR-ISMAR-Roma	30/06/2024
D4.7.2	Report on high level science products based on polar data	CNR-ISP-Bologna	30/06/2024
D4.9.2	Testing report of the new equipment for off-line aerosol speciation at INFN Genova	INFN-GE	30/06/2024
D4.4.3	Report on the operation in the laboratory and in the field of the acquired instruments at CNR ISAC Lecce and calibration/comparison with reference methods	CNR-ISAC-Lecce	31/10/2024
D4.5.2	Definition of the customizations necessary for the instrumentation and the aircraft to make the instrumentation airborne	CNR-ISAC-Bologna	31/10/2024
D4.8.2	Report on improved analytical performances at LABEC for laboratory and real-time in-situ aerosol analysis	INFN-FI	31/10/2024
D4.9.3	Testing report of the new plants for technical gases distribution at INFN Genova	INFN-GE	31/10/2024
D4.12.2	Identification and characterization of aerosol sources based on offline integration of physical and chemical properties	CNR-ISAC-Lecce	28/02/2025
D4.2.3	Report on the operation in the laboratory and in the field of the acquired instruments at CNR ISAC Bologna and calibration/comparison with reference methods	CNR-ISAC-Bologna	28/02/2025

Code	Title Deliverable	Operating Unit	Release date
D4.3.2	REPORT on the operation in the laboratory and in the field of the acquired instruments at the CNR ISAC Lamezia and calibration/comparison with reference methods.	CNR-ISAC-Lamezia Terme	28/02/2025
D4.1.4	Report on the enhancement of CNR IMAA atmospheric observatory for the provision of RIs integrated and synergistic data products	CNR-IMAA	28/02/2025
D4.14.2	Definition of indicators/metrics providing information on air quality in relation to the atmospheric stratification and dynamics	CNR-ISAC-Bologna	30/04/2025
D4.10.3	Report on CeTrA digital platform performances	UNIVE-DAIS	30/04/2025
D4.7.3	Documentation of fully developed integrated polar data repository	CNR-ISP-Bologna	30/04/2025
D4.11.3	Documentation of aerosol typing products and tools	CNR-IMAA	30/04/2025
D4.13.2	Release of a dataset on aerosols compositional and optical characterization	INFN-GE	30/06/2025
D4.2.4	Realization of the technological systems, installation, and operability of the instruments at CNR ISAC Bologna	CNR-ISAC-Bologna	30/06/2025
D4.3.3	Realization of technological systems, installation, and operability of instruments at CNR ISAC Lamezia	CNR-ISAC-Lamezia Terme	30/06/2025
D4.4.4	Realization of technological systems, installation, and operability of instruments at CNR ISAC LECCE	CNR-ISAC-Lecce	30/06/2025
D4.5.3	Implementation of the customizations necessary for the instrumentation to make it airborne	CNR-ISAC-Bologna	30/06/2025

Code	Title Deliverable	Operating Unit	Release date
D4.15.3	Report on optimization of morphological image processing approach algorithm results on lidars and ceilometers observations	CNR-IMAA	30/06/2025
D4.6.3	Production of Near Real Time atmospheric and marine geophysical variables for CNR-ISMAR Rome	CNR-ISMAR-Roma	31/10/2025
D4.8.3	Report on the aerosol analysis made at INFN Firenze	INFN-FI	31/10/2025
D4.12.3	Methodology for identification and characterization of natural and anthropogenic aerosol sources based on online measurements	CNR-ISAC-Lecce	31/10/2025
D4.13.3	Release of a catalog of procedures for the characterization of the atmospheric aerosol properties by atmospheric simulation chamber	INFN-GE	31/10/2025
D4.14.3	Documentation of developed data products capable of providing information on air quality in relation to the atmospheric stratification and dynamics	CNR-ISAC-Bologna	31/10/2025
D4.16.3	Report on natural and anthropic fires product: data acquisition procedures and documentation	CNR-ISAC-Lamezia Terme	30/04/2026

WP5 - Marine Domain

Code	Title Deliverable	Operating Unit	Release date
D5.1	Management needs, service requirements, governance for the distributed and federated system	OGS_OCE	30/04/2023
D5.2	Report on Marine Data Store planning with data flows and connection standards for the distributed and federated system interfaced with ITINERIS central hub	CNR-ISMAR-Napoli	30/04/2023
D5.3	Report on gap analysis of the national marine facilities and equipment and access procedures	CNR-ISMAR-Venezia	30/06/2023
D5.4	Report on gaps identification in data acquisition of the Arctic region. Definition of the new architecture of SIOS infrastructure; procedures for implementation of the observatory platform	CNR-ISP-Messina	30/06/2023
D5.5	Report on the gap analysis of biological and ecosystem observations	CNR-ISMAR-Lerici	31/08/2023
D5.6	Report on the design of the Italian Integrated Ocean Observing System (IOOS) based on gap analysis and governance	CNR-ISMAR-Venezia	31/12/2023
D5.7	Report on the state of the art of integrated data products for Good Environmental Status, Good Ecological Status, and Ecosystem Integrity assessment; and modelled products provision	CNR-ISMAR-Venezia	31/12/2023
D5.8	Report on the installation processes and delivery of an updated RV Specification Sheet of the RV Laura Bassi	OGS_CGN	31/12/2023
D5.9	Report on the installation processes and delivery of an updated RV Specification Sheet of the RV Falkor	CNR-ISMAR-Napoli	31/12/2023
D5.10	NO PUBLIC - Report on desktop study for cable provision	INGV-WIS	30/04/2024

Code	Title Deliverable	Operating Unit	Release date
D5.11	Report and release of IOOS metadata catalogue of data and facilities	OGS_OCE	30/04/2024
D5.13	Report on EMSO facility storage and data acquisition upgrade and functioning tests	INGV-WIS	31/10/2024
D5.14	Report on the implementation on new prototyping model products in the North Adriatic; and on new integrated data products for Good Environmental Status, Good Ecological Status, and Ecosystem Integrity assessment	CNR-ISMAR-Venezia	31/10/2024
D5.15	Report on the progress on the modelling system set up and improvement on the implementation of the data assimilation modules	OGS_OCE	31/10/2024
D5.16	Report on results of the survey on the distribution of the multidisciplinary data and on the catalogue of multidisciplinary data selected to implement the prototype	OGS_OCE	31/10/2024
D5.17	Report providing the algorithms' theoretical background, ATBD, and data driven model validation, initial version	CNR-ISMAR-Napoli	31/10/2024
D5.21	REPORT on demo of the prototype web applications	INGV-BO	28/02/2025
D5.22	Report on common FAIR metadata catalogues, vocabularies, services, and data for the marine data centre, with the involvement of all participating RIs	OGS_OCE	28/02/2025
D5.26	Final report on equipment successfully installed on the RV Falkor, including preliminary assessment of measured seawater properties and automatic systems RV Gaia Blu (ex Falkor)	CNR-ISMAR-Napoli	28/02/2025
D5.29	Final report on the implementation and improvement of physical and biochemical variables in the northern and southern Adriatic	OGS_OCE	28/02/2025

Code	Title Deliverable	Operating Unit	Release date
D5.31	Final report on data-driven model validation, consolidated version	CNR-ISMAR-Napoli	28/02/2025
D5.12	ITINERIS Report and release of IOOS catalogue of services	CNR-ISMAR-Napoli	28/02/2026
D5.18	Test report on the connection among RI distributed systems with IOOS Marine Data Store	CNR-ISMAR-Napoli	28/02/2026
D5.19	Report on the new digital equipment portfolio of IOOS and installation/deployment	CNR-ISMAR-Venezia	28/02/2026
D5.20	IOOS integration with ITINERIS central Hub	CNR-ISMAR-Napoli	28/02/2026
D5.23	Final report on the enhanced capability of biological and EOVS observations in polar regions	CNR-ISP-ME	28/02/2026
D5.24	Final report on the implementation and improvement of new biological and ecosystem observations and data release	CNR-ISMAR-Bologna	28/02/2026
D5.25	Final report on equipment successfully installed on the RV Laura Bassi including preliminary assessment of automatic systems	OGS_CGN	28/02/2026
D5.27	Final report and release of datasets (monitoring modelling) for specific environmental issues	ISPRA	28/02/2026
D5.28	Final report and release of new modelled and integrated products provided in the data centre	CNR-ISMAR-Venezia	28/02/2026

Code	Title Deliverable	Operating Unit	Release date
D5.30	Final report and release on prototype for the integration of cross-infrastructural data for the representation of open sea environment	OGS_OCE	28/02/2026
D5.32	WP5 Final report and roadmap for future development	CNR-ISMAR-Venezia	30/04/2026

WP6 - Terrestrial Biosphere

Code	Title Deliverable	Operating Unit	Release date
D6.1	Coordination center fully operative and HPC dedicated to data processing and demonstration tower operational at the ICOS ETC	CNR-IRET-Montelibretti	31/10/2023
D6.2	Cross-RI service to contrast climate change (elevated N, CO2, O3) impacts on Italian terrestrial ecosystems, with focus on: grain quality, sanitary risk and crop selection; O3 and N deposition critical levels. D6.3 (B11, Activity 6.12, CNR-IBBA)	CNR-IRET-Firenze	31/08/2024
D6.3	Standards for data acquisition and storage developed and tested to facilitate digitalization of bioprocess analysis and accelerate bioprocess development digitalization of bioprocess analysis	CNR-IBBA	31/08/2024

Code	Title Deliverable	Operating Unit	Release date
D6.7	Long term, distributed Phen-Italy infrastructure ready and operational for state-of-the-art plant phenotyping experimental platforms aiming to improve crop performance to cope with climate change	CNR-IPSP-Napoli	31/12/2024
D6.8	Report and guidelines on the new developments of the LIFEWATCH-Italy Virtual Research Environments	CNR-IRET-Lecce	31/12/2024
D6.10	Release of the general Italian NBS database and related services, including results of the UAV fleet used for selected NBS surveys	CNR-IGG	31/12/2024
D6.13	Harmonized environmental metagenomic and enzyme characterization datasets to build standardized and interoperable data files to be stored, shared, and used for data integration into process models.	CNR- IBBR-Napoli	31/12/2024
D6.16	Guidelines on good phenotyping practices based on the strengthening and integration of existing phenotyping platforms and technologies aiming at the development of pipelines to assess agricultural and forestry resilient traits	CNR-IPSP-Firenze	31/12/2024
D6.17	All ICOS stations equipped with the new connection, power, loggers and sensors to ensure real time data transmission to the ICOS portal and ITINERIS HUB.	CNR-IRET-Montelibretti	28/02/2025
D6.18	Completion of three open-air terrestrial platform repositories (FO3X, Durum FACE, Ndep) for automatization, near Realtime transfer and long-term storage of data, and transfer of harmonized data from the repositories to the project hub	CNR-IRET-Firenze	28/02/2025
D6.22	Release of the datasets on species tropho-energetics and space use behavioural traits	CNR-IRET-Lecce	28/02/2025
D6.23	Digitalized IBISBA-IT distributed platforms, protocols, and validated pipelines for biomolecule/microorganism discovery, characterization, and engineering for bioprocess development and a circular economy transition	CNR-IBBR-Napoli	28/02/2025

Code	Title Deliverable	Operating Unit	Release date
D6.12	Users access to centralized information systems and services to provide protocols on data set interoperability, advanced data-fusion and data-harmonization approaches, and to produce a training-testing dataset and machine learning approaches	CNR-IPSP-Firenze	30/04/2025
D6.14	Climate-related prioritization of the aquatic NSC and taxa/specimens selection for the “extended digital specimen” descriptors. Digitization of selected NSC and return of the digital dataset and metadata. Networking of digitized (meta)data	CNR-ISMAR-Venezia	30/04/2025
D6.15	Biological diversity and ecosystem function indicators (EBV, ECV) data collection and provision with a focus on freshwater ecosystems (lakes)	CNR-IRSA	30/04/2025
D6.9	Implementation of the new, extended LIFEWATCH VRE with the new functionalities for an easy access and use	INFN-BA	30/04/2025
D6.11	All sites equipped with the new sensors for NOx, O3 and aerosol fluxes and submitting real time data to the ITINERIS hub through the Terrestrial Biosphere hub.	CNR-IRET-Montelibretti	30/06/2025
D6.19	Climate-related prioritization for the museum’s natural history collections (NHCs) and taxa/specimens selection for the “extended digital specimen” descriptors. Digitization of selected NHCs and return of the digital dataset and metadata. Networking of digitized (meta)data	UNIFI-SMA	30/06/2025
D6.20	Tools for novel approaches to identify phenotyping pipelines to assess crop properties across scales from lab to field combined with central access to coordinated information systems for data management and storage	CNR-IPSP-Napoli	30/06/2025
D6.21	Harmonized, distributed IBISBA-IT platforms for metagenomic analysis, biomolecule production and structural/functional characterization in support of the accelerated generation of customized bioprocesses)	CNR-IBBA	31/08/2025

Code	Title Deliverable	Operating Unit	Release date
D6.24	Cross-RI dataset provision of UAV multiplatform hyperspectral data and site level measurements over different RI ecosystem sites (eLTER, ICOS, ANAEE) and comparison with satellite products.	CNR-IBE	31/08/2025
D6.4	Shared protocols and best practices for acquisition, organization, standardization and long-term maintenance of (meta)data related to NSC; set-up of the centralized IT platform including a bioinformatic toolbox with web-GIS and modelling facilities	CNR-IBBR-Bari	28/02/2026
D6.5	Provision of harmonised, integrated and enhanced experimental and modelling data for the study of cropping systems treatments	UNIFI-DAGRI	28/02/2026
D6.6	Continuous and operational data provision from improved monitoring observations (automatic sensors, buoys, phenocam, camera traps, flux stations) at relevant temporal and spatial scales (within and between ecosystems) in Italian northern terrestrial and freshwater ecosystems	CNR-IBE	28/02/2026

WP7 - Geosphere/Landsurface

Code	Title Deliverable	Operating Unit	Release date
D7.1	New components of the Scientific drilling infrastructure ECORD-ICDP	CNRISMARBO	30/04/2024

Code	Title Deliverable	Operating Unit	Release date
D7.3	Implementation of an ICT facility for geophysical and airborne data archiving and sharing Data acquisition and sharing will be managed through the implementation of a multi-user, multi-profile, and multi-project webGIS platform.	CNR-IMAA	31/10/2024
D7.6	Integrated data portal for SMINO data archiving and sharing M24, B12Data acquisition and sharing will be managed through the implementation of a multi-user, multi-profile, and multi-project webGIS portal.	OGS_CRS	31/10/2024
D7.8	Implementation of new geophysical data management system with dedicated storage and computing facilities Metadata will be produced and linked to vintage and newly acquired data, populating a database that will be queried by a web-based system that will allow discovery and interoperability with other international data-sharing initiatives. All data will be identified through Digital Object Identifiers (DOI) to make possible the link from within scientific publications.	OGS_GEO	31/10/2024
D7.9	Development of aero geophysical infrastructure To image geological structures, we will acquire for the fixed-wing platform: i)Optically pumped Cesium digital magnetic sensors for Total Magnetic Intensity(TMI) measurements; ii) gamma-ray sensors; iii) a strapdown gravity system. Additionally, we will acquire two very high-resolution magnetic drones and on every high-resolution Ground Penetrating Radar drone.	OGS_GEO	31/10/2024
D7.4	Demonstration to the end-users of the integrated geophysical and airborne networking capabilities at the pilot sites The demonstration activities will be carried out in the two southern Pilot sites of ITINERIS	CNR-IMAA	28/02/2025
D7.5	Integrated platform for ground deformation observation and forecasting	UNIFI-CPC	28/02/2025
D7.7	Demonstration to the end-users of the SMINO capabilities including fiber cable and geophysical drone tests at the pilot site.	OGS_CRS	28/02/2025
D7.2	Accessible thematic digital archive of data generated by scientific drilling activities	CNRISMARBO	31/10/2025

WP8 - Virtual Research Environments and Cross-disciplinary Activities

Code	Title Deliverable	Operating Unit	Release date
D8.1	Report on the network of existing CZ observatories in Italy and analysis of the missing information, including identification of the needs for new measurement sites and/or field measurement facilities to provide full CZ services.	CNR-IGG	30/04/2023
D8.2	Report on the existing gaps in the network of isotope laboratory facilities in Italy, including the planning of gap-filling actions and the definition of the characteristics of the new instrumentations needed to fill such gaps and provide the isotope services.	CNR-IGG	31/08/2023
D8.3	Report on the existing information and possible data gaps for the definition of climate and climate change impact indicators	CNR-ISMAR-Lerici	31/10/2023
D8.4	Prioritisation and selection of the Essential Variables (mainly, EBVs and ECVs) to be measured by the different field observatories and to be included in the EV VRE service	CNR-IBE	31/10/2023
D8.5	Design of the AERO VRE characteristics needed to implement atmospheric and aerosol data exploitation services, and report documenting the algorithms and methods used for the AERO VRE.	CNR-IMAA	31/12/2023
D8.6	REPORT ON THE ACQUIRED INSTRUMENTATION TO FILL THE KNOWLEDGE GAPS IN THE CONSTRUCTION OF THE CZ VRE SERVICES	CNR-IGG	29/02/2024
D8.7	Report on the operational implementation of the carbon monitor infrastructure existing stations upgrade and expansion of the terrestrial ecosystem measurement site network	CNR-IRET-Montelibretti	30/04/2024
D8.8	REPORT ON THE COMPLETE VERSION OF THE AGRO-ECOLOGICAL MODELLING PLATFORM API SOLUTION, AS THE FIRST COMPONENT OF THE CCP VRE, AND THE ASSOCIATED USER GUIDE	CNR-IRET-Firenze	30/04/2024

Code	Title Deliverable	Operating Unit	Release date
D8.10	PRELIMINARY VERSION OF THE biomass VRE including the relevant data and analysys modelling tools	CNR-IRET-Lecce	30/06/2024
D8.11	REPORT INDICATING THE FULL IMPLEMENTATION OF NEW LABORATORY FACILITIES CONSTITUTING THE ITALIAN ENVIRONMENTAL ISOTOPE NETWORK	CNR-IGG	30/06/2024
D8.9	Report on the available information on downstream environmental and climate change effects, including identification of knowledge gaps	OGS_OCE	30/06/2024
D8.12	OPERATIONAL THE ASSOCIATED USER GUIDE.	CNR-IGG	31/10/2024
D8.13	Operational version of the CLIMAVRE and user guide of the Virtual Research Environment dedicated to climate indicators.	CNR-ISMAR-Lerici	31/10/2024
D8.14	Operational implementation of the EV VRE including the selected EBVs and ECVs, and the associated user guide.	CNR-IBE	31/10/2024
D8.16	Operational version of the CARBON VRE service providing spatial data information related to carbon cycle and budget, harmonized carbon cycle data, spatial-temporal model sand the associated user guide.	CNR-IRET-Montelibretti	31/12/2024
D8.20	Operational version of the DOWNSTREAM VRE service on downstream effects of climate and environmental change, including geophysical, landslide, carbon and scientific drilling data access portal, and the associated user guide.	OGS_OCE	28/02/2025
D8.21	Operational implementation of the ISOTOPE VRE, including information on the network of isotope laboratory facilities and the access rules, and the associated user guide.	CNR-IGG	28/02/2025

Code	Title Deliverable	Operating Unit	Release date
D8.15	Operational implementation of the AERO VRE services, and associated documentation and the associated user guide	CNR-IMAA	31/12/2025
D8.17	Operational version of the BIOMASSVRE including the selected use cases, and the associated user guide.	CNR-IRET-Lecce	31/12/2025
D8.18	REPORT ON THE COMPLETE VERSION OF THE AGRO-ECOLOGICAL MODELLING PLATFORM API SOLUTION OF THE CCP VRE, AND THE ASSOCIATED USER GUIDE	CNR-IRET-Firenze	31/12/2025
D8.19	Report on the identification and use of climate change indicators and related impacts change based on the CLIMA VRE	CNR-ISMAR-Lerici	31/12/2025
D8.22	Final workshop with internal personnel and external users to illustrate the ensemble of VRE services.	CNR-IGG	30/04/2026