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# D1.2 Ongoing analysis of technology/service needs and gaps

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# 1. Introduction

Technological innovation is rapidly transforming the landscape of environmental research infrastructures (ENVRIs), opening new frontiers for data collection, analysis, and collaboration. As the urgency to address complex environmental challenges intensifies, research infrastructures — from sensor networks and remote sensing platforms to data repositories and modeling systems — are evolving to become more interconnected, intelligent, and in this process also more resilient. This report explores the pivotal role that emerging technologies are playing in enhancing the capabilities of environmental research infrastructures. By examining current services and technologies and future opportunities, we aim to highlight why new services might be needed, and how technological advancements are not only improving scientific understanding of the environment but also supporting more effective policy-making and sustainable management practices.

The ENVRIs share several characteristics that make it possible to analyse the broader innovation processes and identify the outcomes needed. Among these shared features is their distributed structure, with *in-situ* observational sites forming the backbone by providing essential elements such as data and access for RI services. These sites are not only data providers but also potential users of many centralised services, particularly those related to observational technologies, data management structures, and interactions with business stakeholders. In many cases, the successful adoption of new technologies within ENVRIs relies heavily on direct collaboration between researchers and small and medium-sized enterprises (SMEs), as well as on the capacity of RI staff to engage effectively with these businesses.

Naturally, the ENVRIs are at various stages of development — some have been operating for a long time as ERICs or other legal entities, while others are still evolving and actively building their tools and services. They also occupy different positions and domains in the broader effort to understand the Earth system. Each ENVRI domain has developed distinct features, focusing primarily on the specific needs of its own RI rather than designing services for broader, general use. As a result, although there are commonalities in service provision and innovation across ENVRIs, identifying and leveraging these requires stepping back to first address the barriers that hinder joint efforts in finding synergies in technology development.

According to the ESFRI Landscape report (2024), '*The complex character of environmental challenges (such as climate change, chemical pollution, and biodiversity loss) requires the exploitation of synergies between RIs across different domains. It necessitates joint development of more holistic approaches and interdisciplinary capacity to produce knowledge and innovation underpinning future solutions.*'

This deliverable discusses the aspects of the ENVRIs related to their technology/service offerings and the currently identified service development needs and gaps. The focus is in technological and methodological convergence and innovation, sustainability of services, adaptive capacity to address emerging global grand challenges, transformation towards data-intensive research methodologies and the ethical and societal responsibility of ENVRIs. Finally, it discusses the future outlook and the sustainability challenges of RI operations, and ways of reducing the fragmentation of the research and innovation landscape in the ENVRIs. The results from a foresight survey with ENVRIs are presented and the results elaborated in the ESFRI Landscape Analysis framework, focusing on technology and service innovation needs and the currently existing service frameworks like ENVRI-Hub.

# 2. Methods

ENVRINNOV WP1.2 implemented a two-phased survey among the ENVRIs, with the aim to collect their views on the possible gaps, challenges and priority needs for services in the field of technologies. As such, this survey focused on current and future users and services, as well as interoperability between RIs and needs for expanding the current ENVRI-Hub services from the domain specific viewpoint.

The survey was done in spring-summer 2024, using an online questionnaire where replies for 15 predefined questions and one open question were collected. The list of recipients invited to participate in the survey was the ENVRI community at large, so also beyond the actual ENVRINNOV consortium. Responses to the questionnaire were received from ICOS ERIC (3), eLTER (2), Euro-ARGO ERIC, DANUBIUS-RI, EISCAT_3D, and ACTRIS ERIC. The online questionnaire is presented as Annex A.

Another (follow-up) part of the online survey was done by expert interviews (Delphi method), where the respondents could expand their answers further and bring in aspects of their own interest that were not included in the survey. This included 30 questions, with the aim to gather the opinions of a group of experts on the future potential of service and technology development in ENVRIs. The interviews were done in September-October 2024. EMBRC ERIC, EUROFLEETS, AQUACOSM, eLTER, ACTRIS ERIC, SIOS and ICOS ERIC participated in these expert interviews. The questions for the Expert interviews are included as Annex B.

Since the questions were partly overlapping we combined the answers, and if needed, refer to the question according to the Annex ID (Annex A = online questionnaire, Annex B = Expert interview questions).

# 3. Results and discussion

## 3.1. Overview of ENVRIs responding to the survey and their current services

The **survey participants** covered the Atmosphere, Marine and Multidomain RIs, whereas Biosphere only received one reply and Solid Earth none. However, the multidomain RIs likely include RIs that work on these domains as well. Two respondents were ESFRI Landmarks, three ESFRI projects and eight ERICs or other legal entities. The distribution of establishment of legal entities spanned from 1975 (1) to 2026 (anticipated, 1), but the majority (6) were established 2015-2016.

The **most important current services** offered were clearly Access to concurrent data and/or data products, while Access to technology services and instrumentation or Access to sites and laboratories, Digital collections and specimens and legacy data were also mentioned by several respondents as their main services. Only two RIs offer services related to Publishing and visualisation. Technology development, Training and knowledge exchange or Innovation services received a few mentions, but only as the second or third most important service. In the free comments, the respondents mentioned Radar techniques, International programs and RDI projects development, Outreach and Development of advanced reproducible data pipelines, services and VREs.

Most of the **services of ENVRIs are currently used** by Researchers and scientists, or Research networks and infrastructures. Also Monitoring networks, Business and industry, Public authorities and decision makers and Regional authorities received several mentions. Less important users were Civil society and public and Citizen scientists. Also, operational users (e.g. modellers) were mentioned as a separate user group (different from researchers).

The **primary pathway (Annex B: Q11-Q14)** to find/access the services is via the internet (either a generic website address or dedicated service portal). Most users require both an M2M and GUI interface. Services are mostly fully open (sometimes with embargo time), but also partly open or open for members only. Some services have a defined cost for users.

**Innovation potential (Annex B: Q15)** is realised as patents from two RIs, their number being still rather low (1…10). One RI reported on an innovation award, granted every other year to develop and test new observation methodologies and techniques to decrease the environmental footprint of science.

**ENVRI-Hub Catalogue (Annex B: Q16-Q17)** was used by three respondents, while eight RIs had not used it at all. ACTRIS ERIC services are part of the ENVRI-Hub catalogue of Services. The ENVRI-Hub services were considered moderately useful (average 3.5 / 7).

The comments on ENVRI-Hub **challenges or limitations (Annex B: Q18):**

> 'It is almost impossible to get entries in. The interface for both providers and users is not user friendly and the hub is mainly designed for m2m access, but there is no vision on how the m2m access should be usable in actual workflows.'

> 'On the landing page, entering any word into the search field leads to https://envri-hub.envri.eu/ . In the catalogue, checking "atmosphere" or "biosphere" as a science domain just yields "SIOS Svalbard" as a result although surely more projects (including ICOS) provide such data? The promising tile "dashboard for the state of the environment" leads to a "preview is currently unavailable" message and a link to EOSC that however returns a timeout error.'

The suggestions for **additional services (Annex B: Q19)** that would increase the usefulness of ENVRI-Hub yielded following answers:

> 'A service enhancing the interoperability between the RIs/ERICs, maybe something like a single data portal allowing to access the data portals of several RIs simultaneously.'

> 'The ENVRI-Hub is for us an endpoint and not something we actually need ourselves, its purpose would be to attract more users to our data and services, but this has not materialized.'

> 'Co-designed services…many of the services are targeted at one specific RI, but they are not useful for another…'

> 'A quick glance and test use suggests that it is probably better to first get issues like the ones mentioned above [Question 18] running, before expanding services.'

## 3.2. Technology and innovation foresight

**The future perspectives (5 years' timescale)** were an important part of both the questionnaire and interview.

There were only minor **changes in the Users of RIs** when compared the situation today and in 5 years' time. This may reflect the status of the RIs: most believe their services are currently well defined and matching the future needs, and the users are finding them sufficiently well. The most important services in future would continue to be Access to concurrent data and/or data products, Access to technology services and instrumentation and Access to sites or laboratories, and the by far biggest User groups were

Researchers and scientists and Research networks and infrastructures. One RI mentioned they would need to connect more with policy makers, commercial partners and societal stakeholders in the future. Several RIs expected their user composition to broaden within the previously existing groups (e.g. involving EOSC, Horizon EU projects, new networks).

The specific needs of users that have been identified as **unmet or not adequately addressed** yielded answers such as: near real time data provision and easier access to harmonised data/data products (both mentioned in several answers), better engagement with industry to open services supporting innovation and technical consultation, access to data descriptions and metadata, support for mobilising and merging legacy data with current datasets, data FAIRification, and capacity building. One RI mentioned digital services that could support the needs of the new EU directives. Also, one RI mentioned a significant gap in concrete logistical services, since in harsh Arctic conditions logistical help for scientists in the field is required. The main obstacles the researchers meet in those challenging conditions are laws, rules and regulations; for example rifle training and permits, and health, safety and environment regulations are different with different institutions and nations. There is also a lack of resources and prioritisation from the service providers.

Key challenges and barriers related to **uptake of new services** included inadequate funding (several answers), lack of sufficient and skilled workforce (several answers), and insufficient interface with various sector stakeholders (for example EU policy makers) to find out their needs. A key challenge is that different vocabularies and standards exist between disciplines, related to e.g., data management. Geopolitics (for RIs that are working in the Arctic or close to conflict areas) and different data policies with different institutions and continents are creating – sometimes unexpected - barriers.

The key **gaps in innovation (Annex B: Q26)** related to emerging technologies and services were linked to using the data in different disciplines, working with data in emergency situations, using AI to generate high level data products, functional links to private sector, gaps in spatial coverage of observations, development of standards and tools (calibration, QA), reliability in automated sensors, cost of sensors and their deployment on mobile platforms, and automation of data standardisation and quality control.

**Annex B: Q27** placed a direct question on the **technology development strategies and innovation potential** in the RIs. Such a strategy should adapt to changing operational landscape to develop services that would benefit users the best. It seems that some RIs have already quite well developed and broad strategies with clear and ambitious goals, while others either did not yet consider it relevant or had very specific, focused ideas on their future technology needs. These needs were related to sensor development with manufacturers, data products with AI tools, or hardware and system software development. The concrete examples on how to promote innovation and exploit the potential in RIs were e.g., organising innovation workshops, establishing innovation pipeline for coordinating technology development and onboarding new technologies, and better management of intellectual property rights. Development of AI and related tools will be part of the future strategy in several RIs.

### 3.3. Sustainability of services

The long-term perspective and need for innovation relate to the overall sustainability of RI operations and the attractiveness of RI services to their users. A strong element in this is the potential for co-design and co-development of services together with all user groups, in particular with industry and business as well as with other RIs.

**Possible benefits from better integration, collaboration or synergies of services (Annex B: Q28**) could be found in co-development and piloting of prototypes and workflows, testing data processing codes for broadening their use by any other data centres and sharing user experience. One answer reflects possibly a perspective worth considering in a broader context and by many ENVRI's: "Services and products that could benefit from better integration, collaboration and synergies are **all the necessary services for strengthening societal resilience to environmental changes,** for example to face extreme weather event or adverse air quality to long-term evaluation of climate change and policy effectiveness."

***Interoperability*** in organisations is defined by the EU as **the ability to interact towards mutually beneficial goals, involving the sharing of information and knowledge between these organisations, through the business processes they support, by means of the exchange of data between their ICT systems** (European Union 2017). The crucial need for interoperability of their services was recognized by many RIs in the Questionnaire, however there are several barriers for interoperability, e.g. lack of shared vision or necessary skills, not guaranteed long-term sustainability, non-flexible legacy systems and semantic incompatibility. These barriers should be addressed by a ENVRI-community level to create a common vision of how the existing services can be improved for interoperability.

According to respondents, **the interoperability of services between RIs and projects (Annex B: Q29)** could be improved by harmonising metadata, making front end service level more interoperable, encouraging all RIs to develop overarching/ transversal services that enable interoperability with others, and funding for joint projects in service development. An overarching RI co-design approach would be helpful to improve interoperability of data integration, access and quality assurance. Respondents also highlighted a coordinated implementation of common data type specific standards and software interfaces such as the latest OGC standards[1]. Further, development and implementation of domain specific metadata profiles based on the standard interfaces and identification and implementation of cross community vocabulary- and vocabulary mapping services will be crucial for interoperability. Imposing new projects and RIs to use the EOSC standard metadata would also enable interoperability. In any case, communication between RIs about the vision and goals is necessary, within and beyond the existing consortia and clusters.

## 3.4. Capacity for adapting for emerging grand challenges

Environmental RIs in Europe have historically evolved in response to either pressing societal and scientific needs, often driven by international treaties and global policy agendas, or as domain- or discipline-specific activities. Many of these infrastructures were established by research communities to address specific environmental challenges, such as e.g., monitoring greenhouse gas emissions, assessing air and marine pollution, or supporting environmental compliance and reporting obligations.

However, the scale, complexity, and interconnectedness of current and future environmental issues require a more dynamic and forward-looking approach. According to the ESFRI Landscape Analysis 2024, environmental RIs are increasingly expected not only to sustain long-term environmental observations but also to enhance their responsiveness to emerging grand challenges. This includes supporting the implementation of evolving research and innovation Missions under the European Green Deal, the UN Sustainable Development Goals, and climate adaptation strategies.

The capacity of environmental RIs to adapt to emerging grand challenges lies not only in their technical and scientific excellence but also in their strategic orientation toward flexibility, inclusivity, and impact.

[1] https://www.ogc.org/

ENVRIs should build and demonstrate capacity for emerging challenges by:

- **Scientific Agility**: ENVRIs need to deepen their understanding of the drivers, interactions, and impacts of Earth system processes, integrating new disciplines and technologies as scientific knowledge advances. This scientific agility enables timely responses to novel or shifting environmental pressures, such as those related to climate extremes, biodiversity loss, land-use change, or crises such as the ongoing war in Ukraine.

- **Policy Integration**: Bridging the gap between science and policy is essential. Environmental RIs play a crucial role in translating scientific data into actionable knowledge, supporting evidence-based decision-making at national and international levels. This enhances their relevance in helping societies achieve resilience, sustainability, and climate neutrality goals. Some ENVRIs are creating the capacity for such synthesis in a coordinated manner with topic centres on transdisciplinary science.

- **Innovation and Collaboration**: By fostering innovation and leveraging cross-sectoral collaboration — including with industry, public authorities, and civil society — RIs also contribute to the creation of new economic and business opportunities. Their role in improving observational efficiency and reducing operational costs further supports public sector transformation. Some ENVRIs have close collaboration with industry already historically, and these experiences could be shared with those who do not yet have such liaison capacity.

- **Strategic Foresight and User-Centricity**: The uncertain and rapidly evolving nature of global environmental challenges necessitates that RIs maintain a continuous and agile process for identifying not only domain-specific but also multi-domain challenges. This includes regular engagement and screening with their user communities to anticipate emerging demands, receive feedback of user experience, and tailor services accordingly.

The RIs were also inquired about their current readiness and capacity to adapt to potentially novel, emerging research and policy needs, and concrete examples.

**Service offering** was for some RIs clearly anticipated to change in future as a response to emerging challenges. More data repositories have been and will continue to be introduced. One crucial factor in future service development will be changes in the operational landscape with legal contracts and agreements within but also beyond the RIs. Utilization of Artificial Intelligence, machine learning and digital twin concept in both observation techniques and use of the data are expected to be more important in future challenges. The near-real and real-real time data is wanted more and more and opens avenues for engaging new users.

The questionnaire was done in the time when the global political situation was less critical than currently (April 2025), and the need for supporting the research done in other continents (especially climate change research in the US) has emerged on the agendas of ENVRIs only recently. The increasing need to secure observations and data repositories in times when their sustainability is not secured might lead to changes in service provisioning and consequently also require innovative approaches for ensuring their sustainability. Technology foresight for identifying emerging, disruptive and/or critical technologies, and to anticipate their potential future impact would need to be developed to enable agile service development.

The specific question about the **innovation or development services** yielded following:

> 'One of our main goals is to achieve the transition to OneArgo, i.e. to enlarge the BGC and deep missions of Argo into a fully operational array as defined by the scientific community. The second, related to the first, is to provide as reliable as possible datasets, with a higher rate of BGC data processed in delayed-mode.

Thus, in the future, we still aim to provide data and metadata but the content will be greatly enlarged with more BGC and deep data, and with a higher level of delayed-mode processing.'

'Innovation of measurements and instrumentation, Development of advanced reproducible data pipelines, services and VREs'

'Technological development of sensors and measurement techniques towards being more accurate and low cost.'

## 3.5. Transformation towards data-intensive methodologies

As environmental science has become increasingly data-driven, ENVRIs have developed tools towards fully harnessing the potential of data-intensive methodologies. This is a constant process that requires not only technological upgrades and innovation but also strategic shifts in operations, skills, and collaborations.

Most ENVRIs are investing in robust data management systems that support the full data lifecycle — from designing harmonized observation frameworks, acquisition and processing the data to long-term storage, curation, and sharing. This includes implementing the FAIR (Findable, Accessible, Interoperable, Reusable) data principles, adopting standardized metadata, and ensuring compliance with open science requirements.

The growing volume and complexity of environmental data require scalable computing resources, such as high-performance computing, cloud services, edge computing and virtual research environments. RIs are collaborating with e-infrastructures and digital innovation hubs to integrate these capabilities and support advanced analytics like machine learning and AI. To support transdisciplinary research and cross-infrastructure collaboration, RIs should ensure their systems and data are interoperable (see also above). This includes harmonizing data formats, protocols, and vocabularies, and aligning with European and global digital ecosystems such as EOSC (European Open Science Cloud) and GEOSS.

Human capacity and skills were considered equally critical as technological capacity. With the help of external projects, many RIs are offering training programs both for data managers but also for data users. Recognition for emerging new roles such as data stewards and research software engineers are needed in human resources policies of RIs, to enable both staff and users with skills in data science, computational modeling, and digital tool development.

As demand increases for near-real-time monitoring and early warning systems (see above), RIs must develop capabilities to process and analyse streaming data and to ensure the reliability of data flows for users. In a data-rich environment, the credibility of results depends on transparent methodologies, quality control, and traceability. RIs should prioritize data validation procedures, versioning, and clear documentation to build trust among stakeholders, including policymakers and the public. By offering open access to high-quality datasets and digital tools, RIs can act as catalysts for innovation across sectors. This includes supporting co-design of data products with users, participating in living labs, and contributing to citizen science initiatives.

## 3.6. Ethical and societal response of ENVRI's and their services

The ENVRIs play a crucial role in addressing pressing environmental and sustainability challenges through their data collection, research, and innovation. However, beyond that, the ENVRIs should act as models for environmentally consciousness and recognise the impacts of their operations, ensure that their activities align with ethical standards and contribute positively to society, and that the technological and research advancements align with their societal values and standards. Special attention should be given to ensuring inclusivity, gender balance, and fair access to infrastructure and data, fostering equal opportunities for all researchers and users.

Self-evidently, the prevailing research ethics principles and standards are to be followed also by RIs, and many RIs have made explicit ethical statements which outline their commitments to maintaining transparency, accountability, and integrity in scientific practices[2]. This includes e.g. the emphasis on participation and equity; data collection, management, and dissemination; research process and conduct; organisational environmental behaviour, and governance and decision-making structures.

The ENVRIs strive to align their research and operational goals with societal needs, particularly by engaging stakeholders (e.g., policymakers, citizens, NGOs) in the co-creation of knowledge, promoting sustainability in their operations, and enhancing public awareness through education and outreach initiatives, thereby bridging the gap between science and society. One RI reported that their mission is to decrease the environmental footprint of science, especially in the vulnerable pristine environment. New solutions for energy production and data retrievals, AI and remote sensing tools play an important role in this context.

## 4. Future outlook

Looking ahead, the ENVRIs must proactively navigate a landscape shaped by rapid technological advancement, societal transformation, and environmental urgency. To remain at the forefront of science, the future lies in their ability to be agile, innovative, and deeply aligned with societal values and global sustainability goals. By continuously analysing and addressing technological and service needs and revisiting their user landscape, RIs can secure their role as indispensable pillars of environmental science and stewardship and remain in the forefront of environmental and societal challenges. Addressing these issues requires coordinated planning and technological innovation that prioritise end-user requirements and long-term usability. The sustainability of jointly developed services needs to be solved during the projects' lifetime. To be successful in the joint endeavor, trusted relations, open dialogue, consulting the users and support from stakeholders to agree upon sustainable, long-term business models for service provision are needed.

The European RI landscape faces multifaceted challenges, related to sustainable funding, interdisciplinary collaboration, and alignment with EU policies and societal goals, which affect the readiness and capacity for the RIs to engage with novel technological innovations. To remain effective and relevant, RIs must continuously respond to the challenges with technological and social innovations. In particular, technologies like Artificial Intelligence, quantum computing, and digitalisation will revolutionise research methodologies across various domains, fostering a fundamental shift towards more holistic and efficient scientific discovery, innovation and a diverse services portfolio.

[2] ENVRI PLUS: https://www.envriplus.eu/wp-content/uploads/2019/06/Ethical-Guidelines-for-RIs_13.4.pdf; ACTRIS: 10.5281/zenodo.12171210; ICOS: https://www.icos-cp.eu/media/211; eLTER: https://www.elter-ri.eu/storage/app/uploads/public/678/6c4/d81/6786c4d81a7c7491515213.pdf;

Many ENVRIs are directly or indirectly associated with the observation and production of data that allow for understanding of the prevailing environmental issues in space and following their temporal development (ESFRI Landscape Analysis 2024). This means the ENVRIs not only serve the scientific users but are also important for many other stakeholders, e.g. environmental authorities. While many of them maintain their separate official monitoring networks in the context of mandatory environmental regulations, the RIs can often be a 'precursor' of such monitoring or complement it by enabling innovation and novel method development. RIs also provide much needed contextual information (e.g., broader geographical scale information). The legacy methods that have been used often for decades by authorities can be complemented by the RI-driven technological development that offers better precision, cost efficiency or provides advanced or more comprehensive information and data.

The performed analysis among the ENVRIs in ENVRINNOV WP1 reveals that while many RIs have made significant strides in digital transformation, data management, and novel technologies, key challenges still persist in e.g., limited standardization, fragmented data systems, insufficient integration of AI and high-performance computing, and unequal access or uptake to cutting-edge instrumentation and services across regions and domains. Particular emphasis should be placed on the harmonized observation tools, accessibility to cloud-based data platforms, user-friendly interfaces, and interdisciplinary service frameworks that support both scientific research and policy applications. Moreover, cross-RI collaboration is identified as essential for addressing shared technical barriers, including data interoperability, quality control, and service scalability.

The questionnaire revealed the opinion by several respondents that the current, shared framework for services in ENVRI-Hub[3] and its Catalogue of Services is not known by all RIs and could be improved to serve broader groups of users across all RIs. The principal idea and tools of ENVRI-Hub were developed in several consequent ENVRI cluster projects (ENVRI, ENVRI Plus and ENVRI-Hub Next) to serve as the central gateway to environmental data and services offered by the European environmental research infrastructures. The data offered through the hub is interoperable across the Earth system disciplines and therefore easy to use for interdisciplinary environmental research. However, those communities that were not part of these cluster projects or were only loosely engaged have not contributed to the development nor given feedback for improving it to match also their needs.

The potential areas for improvement of ENVRI-Hub to make better use of this tool could include common standards for data formats, metadata, and APIs, so that users can easily combine and compare data from different RIs without needing specialized knowledge or conversion tools. The access and discovery could be improved by creating a single, intuitive access point where users can search, access, and retrieve data, tools, and services from all participating ENVRIs, rather than having to navigate multiple separate systems. It seems also that the focus on data services is not sufficiently responding to the comprehensive service palette in all ENVRIs, and also other services than those related to data should be accessible through the Hub. Further, the visibility of ENVRI-hub could be improved by tutorials, support documentation, online help desks, and training workshops to lower the barrier to entry, especially for new or non-specialist users.

In general, the fragmentation in the environmental research infrastructure landscape limits the efficient use of resources, weakens global competitiveness, and hampers the impact of scientific discoveries. To create a more integrated and coherent R&I environment, the RIs should strengthen cross-domain collaboration by developing more pan-European projects and partnerships (e.g., European Partnerships for Water, Biodiversity, or Climate; or under the Climate, Energy and Mobility Cluster). The further development of EU-wide and regional Innovation Hubs - such as ENVRI-Hub - would enhance interoperability of data and services, promote accessibility for common standards and protocols and open science policies in line with

[3] https://envrihub.vm.fedcloud.eu/

the FAIR principles. Initiatives like the European Open Science Cloud (EOSC) should be further used to create a truly interoperable and federated data ecosystem. User feedback is a crucial element in developing services that fulfil the needs of the intended user groups. Researcher and staff mobility programs could be used to encourage cross-sectoral movement and fertilisation of skills among the RIs. In particular the data stewardship and management issues that are common to all RIs are a good opportunity for developing joint capacity building tools. Public-Private Partnerships (PPP) to strengthen collaborations between academia, industry, and governments would enable RIs to scale innovations faster.

Last, strategic collaboration and signing Memoranda of Understanding among the ENVRIs should be pursued for better alignment between RIs and their stakeholders. The clear need to find and exploit synergies that was called upon in the ESFRI Landscape Analysis (2024) should be recognized and common solutions should be actively searched.

**Recommendations for strategic development of ENVRI's technology and service development:**

To address the identified gaps effectively, the following strategic directions are recommended:

- Foster cross-RI collaborations to address shared technical and operational challenges. Through innovation hubs and research alliances, RIs can foster the co-development of tools and methodologies that bridge technological silos and enhance collaborative research capabilities.
- Invest in interoperable, scalable, and sustainable digital infrastructure that enables also addressing future challenges and fosters the transition toward a data-driven research paradigm.
- Promote co-design of services with diverse user groups, not only scientists and data providers but also policymakers, educators, and citizen science communities.
- Implement FAIR (Findable, Accessible, Interoperable, Reusable) data principles universally
- Support continuous capacity building through training, tools, and open access resources

# References

ESFRI Landscape Analysis (2024) https://landscape2024.esfri.eu/

European Union (2017) New European Interoperability Framework. Promoting seamless services and data flows for European public administrations. doi:10.2799/78681

# Annex A. The online Service development survey questions

### ENVRI service development Interview

The Horizon Europe funded project **ENVRINNOV** (Environment Research Infrastructures Innovation Roadmap, INFRA-2023-DEV-01-05) is conducting a comprehensive analysis of the state-of-the-art ENVRI services. This interview is an integral part of the landscape screening done among the main stakeholders of the involved ENVRIs and aims to collect their views on the possible gaps, challenges and priority needs for services in the field of technologies. As such, this interview focuses on current and future users and services, as well as interoperability between RIs.

In this questionnaire, a **user** is defined as a person or entity that engages with a product or service. In this context, engaging includes interacting, using or consuming said product or service. Similarly, a **service** is defined as a function or support offered by an ENVRI, which facilitates research, monitoring or decision-making.

**BASIC INFORMATION**

1. Name of the Research Infrastructure/Project
2. Domain
3. Maturity level
4. What is the most important service your project or RI offers?
5. Who are the main users of the services offered?

**USERS AND SERVICES**

6. Do you expect a change in the user group composition in the future? If yes, what new user segments do you expect to emerge?
7. Do you recognize any service gaps that are currently unmet? If yes, what are the main obstacles to adopting these services?
8. Continuing on that: what do you see as the primary barriers to the adoption of novel services within your RI in general? Are these challenges technical, organizational, or related to user needs? What could be done to lower these barriers?
9. In your opinion, how has the importance of the services provided by your project or RI evolved over time? How have technological innovations affected this possible change in services?
10. Do you foresee a change in the primary funding source for your project or RI's services in the future, and if so; how might they differ from the current sources?

**FUTURE SERVICE LANDSCAPE & CHALLENGES IN SERVICE UPTAKE**

11. How do you believe your services will evolve in the next five years?

12. Considering the anticipated services for the next 5 years, what emerging trends or technologies do you foresee having the most significant impact on your service offering? How are you preparing for these changes?

## SERVICE INTEROPERABILITY AND FUTURE STRATEGY

13. Which existing services do you believe would benefit most from increased integration or collaboration with other projects or RIs?

14. From your perspective, what are the key technical or policy barriers to achieving better interoperability between services across different projects or RIs and how could they be overcome?

15. Looking ahead, what strategic priorities concerning service offering and technology uptake do you believe your RI should focus on to maintain or enhance its relevance and impact in the research community? Do these priorities align with current user needs?

16. Anything else you want to share with us?

# Annex B. The Foresight survey questions

**ENVRI-Hub Foresight Survey**

Dear Recipient,

The Horizon Europe funded project **ENVRINNOV** (Environment Research Infrastructures Innovation Roadmap, INFRA-2023-DEV-01-05) is conducting a comprehensive analysis of the state-of-the-art ENVRI services and identifying service needs and gaps from the landscape to meet strategic scientific challenges and policy priorities of ENVRIs.

We are approaching you with a motivation to **i) inform you** and **ii) ask for contributions from your RI perspective to the above-described analysis.**

As part of the ENVRINNOV project, the University of Helsinki has designed an online questionnaire which we encourage you to distribute widely among your community, in particular to those who are involved in technology development and innovation. The questions are addressing the foresight and needs for expanding the current ENVRI - Hub services from your domain specific viewpoint. We are also asking about the innovation potential and strategies within your domain, and the potential linkages and synergies with other environmental RIs.

The survey consists of 30 questions. Participating in this survey is voluntary. You can refuse to participate in the study or suspend participation at any time. If you cancel, the answers you have already given will not be saved. The information collected in the survey will be treated confidentially and in accordance with good scientific practice. This survey can be filled anonymously, and the record of your survey responses does not contain any identifying information about you unless a specific survey question explicitly asks for it.

The questionnaire is linked to more in-depth interviews with key experts within the ENVRI domains and external experts. These interviews will be performed during late summer and autumn 2024. **If you would be interested in taking part in an expert interview, simply follow the link that appears on the screen after you have saved your answers** and fill in your email address, as well as your domain and role.

**Please note that the surveys are saved separately and your answers to this survey will not be linked to your email address.**

If you encounter problems while answering the survey, do not hesitate to contact us at jaakko.oivukkamaki@helsinki.fi and jaana.back@helsinki.fi.

**Basic Information**

1. **Name of the Research Infrastructure/Project***

2. **Domain**

   Atmosphere
   Marine
   Solid Earth
   Biosphere and ecosystems
   Multidomain
   Other

3. **Maturity level (select one)**
   Project
   ESFRI roadmap project
   ESFRI Landmark
   ERIC or other legal entity
   Other

4. **Year of establishment of legal entity (If applicable)**

5. **Name of responding person**

6. **Role of the responding person in Project or RI***

**Current users and services**

7. **What is the most important service your project or RI offers? (Select one)**
   Access to technology services and instrumentation
   Access to sites or laboratories
   Access to physical or digital collections, catalogues and specimen
   Access to legacy data
   Access to concurrent data and/or data products
   Access to metadata and semantic assets
   Innovation services (define below)
   Publishing and visualisation services
   Synthesis and policy briefs
   Technology development (define below)
   Training and knowledge exchange

8. **What is the second most important service your project or RI offers? (Select one)**
   Access to technology services and instrumentation
   Access to sites or laboratories
   Access to physical or digital collections, catalogues and specimen
   Access to legacy data
   Access to concurrent data and/or data products
   Access to metadata and semantic assets
   Innovation services (define below)
   Publishing and visualisation services
   Synthesis and policy briefs
   Technology development (define below)
   Training and knowledge exchange

9. **What is the third most important service your project or RI offers? (Select one)**Access to technology services and instrumentation
   Access to sites or laboratories
   Access to physical or digital collections, catalogues and specimen
   Access to legacy data
   Access to concurrent data and/or data products

Access to metadata and semantic assets
Innovation services (define below)
Publishing and visualisation services
Synthesis and policy briefs
Technology development (define below)
Training and knowledge exchange
**If other, please specify (also define here your innovation or development services if applicable)**

10. **Who are the main users of the services offered? (select all that are relevant)**
Researchers and scientists
Research networks and infrastructures
Monitoring networks
Business and industry
Higher education institutions
Public authorities and decision makers (EU, national)
Regional authorities
Civil society, public
Citizen scientists and NGOs
Other
**If other, please specify**

11. **What is the primary pathway to find your services?**

12. **Is there any additional metadata required to answer user needs?**
YES
NO
**If yes, please specify**

13. **Do your users require a machine to machine or GUI interface (or both)?**
My users require a machine-to-machine interface
My users require a Gui interface
My users require both a M2M and a GUI interface
My users do not require M2M or GUI interfaces

14. **Are your services**
Fully open
Partly open
Open for members
Open for a fee
**Open box for explanation if needed**

15. **Has your RI/project created innovation leading to patents or innovation disclosures?**
Yes
No
**If yes, how many?**

16. **Are you using the ENVRI-Hub Catalogue of services as part of your service portfolio?**
    Yes
    No
    **If yes, which services?**

17. **How useful are the ENVRI-Hub services from your perspective (Likert scale 1=Not at all useful, 7=Extremely useful)**

18. **If you are using ENVRI-Hub, have you encountered challenges or limitations in the existing ENVRI-Hub web platform? If so, please specify.**

19. **What additional services would increase the usefulness of ENVRI-Hub to your RI/project?**

**User groups and services in the future**

20. **What do you anticipate will be the most important service your project or RI offers in 5 years?**
    Access to technology services and instrumentation
    Access to sites or laboratories
    Access to physical or digital collections, catalogues and specimen
    Access to legacy data
    Access to concurrent data and/or data products
    Access to metadata and semantic assets
    Innovation services (define below)
    Publishing and visualisation services
    Synthesis and policy briefs
    Technology development (define below)
    Training and knowledge exchange

21. **What do you anticipate will be the second most important service your project or RI offers in 5 years?**
    Access to technology services and instrumentation
    Access to sites or laboratories
    Access to physical or digital collections, catalogues and specimen
    Access to legacy data
    Access to concurrent data and/or data products
    Access to metadata and semantic assets
    Innovation services (define below)
    Publishing and visualisation services
    Synthesis and policy briefs
    Technology development (define below)
    Training and knowledge exchange

22. **What do you anticipate will be the third most important service your project or RI offers in 5 years?**
    Access to technology services and instrumentation

Access to sites or laboratories
Access to physical or digital collections, catalogues and specimen
Access to legacy data
Access to concurrent data and/or data products
Access to metadata and semantic assets
Innovation services (define below)
Publishing and visualisation services
Synthesis and policy briefs
Technology development (define below)
Training and knowledge exchange
**If other, please specify (also define here your innovation or development services if needed):**

23. **Who are the main user groups of your anticipated services in 5 years time**

Researchers and scientists
Research networks and infrastructures
Monitoring networks
Business and industry
Higher education institutions
Public authorities and decision makers (EU, national)
Regional authorities
Civil society, public
Citizen scientists and NGOs
Other
**If other, please specify**

**Open ended questions about foresight**

24. **What are the specific needs of your users that you have identified as unmet or not adequately addressed?***
25. **What are the key challenges related to the uptake of novel services in your RI?**
26. **What are the key innovation gaps related to emerging technologies and services in your RI?**
27. **What are the technology development strategies and innovation potential in your RI?**
28. **Which services could benefit from better integration, collaboration, or synergies to enhance their overall effectiveness?**
29. **How could the interoperability of services between projects or RI's be improved?**
30. **Anything else you want to share with us?**