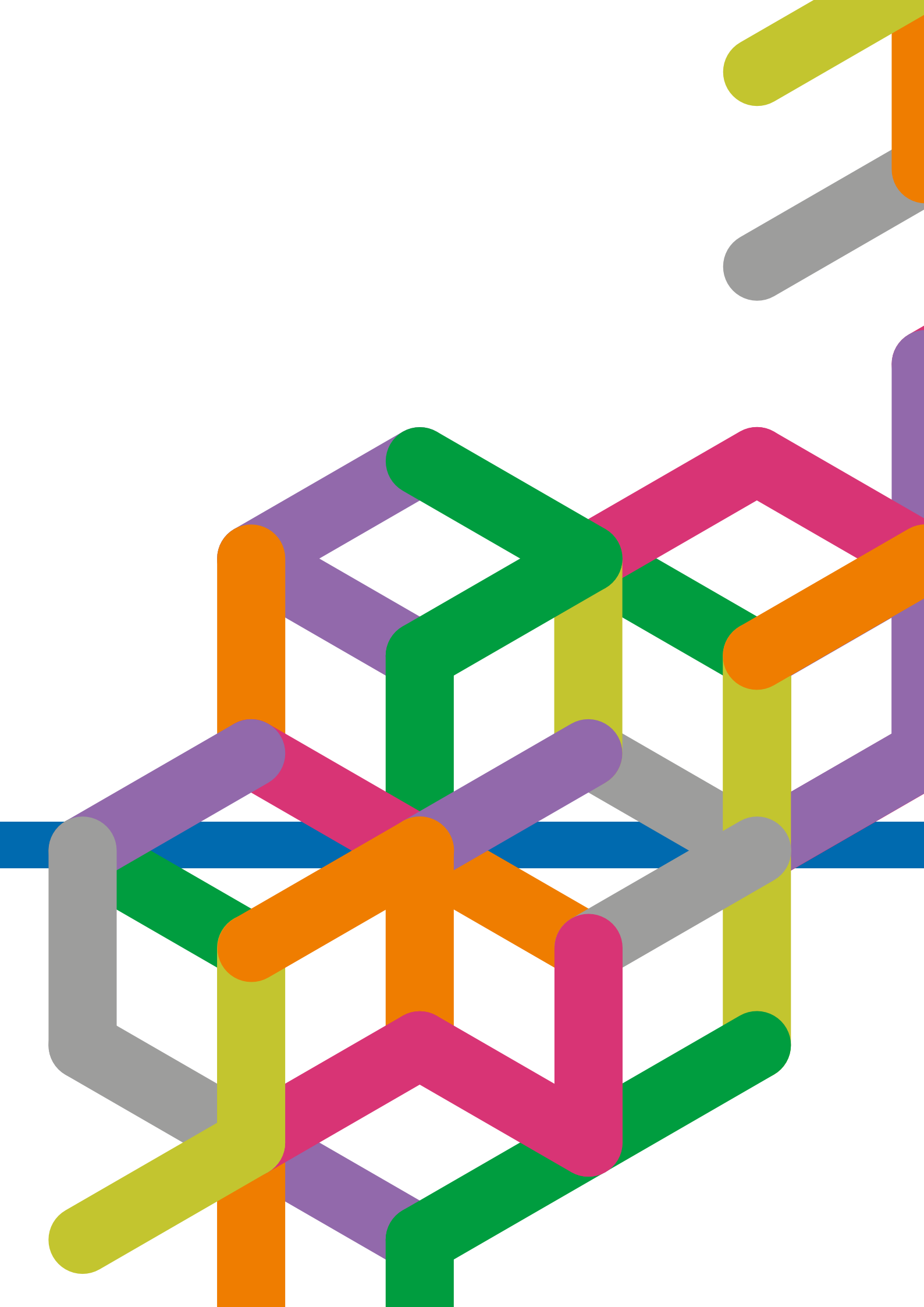

SECTION 2

ESFRI LANDSCAPE ANALYSIS 2024

# CROSS-DOMAIN TRENDS AND CHALLENGES

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# INTRODUCTION: SHAPING THE HORIZON: NAVIGATING RIs FUTURE

Building upon the foundational insights presented in Section 1 of the Landscape Analysis, Section 2 goes deeper into the evolving dynamics of European Research Infrastructures (RIs). This section amplifies the dialogue on the transformative role of RIs in fostering scientific excellence, technological innovation, and societal impact. It further explores the intricate interplay between RIs and European Research and Innovation, underscoring the critical contributions of RIs in addressing global challenges through interdisciplinary collaborations and digital transformation.

This section highlights the pioneering trends that are shaping the future of research, from the integration of Artificial Intelligence (AI) with the corresponding complements of quantum computing to the emphasis on sustainability and ethical responsibility. It also addresses the pressing challenges of sustainable funding, governance evolution, and the necessity for enhanced collaboration across domains. By presenting a comprehensive analysis of current states, future trends, and strategic recommendations, this section aims to guide stakeholders, policymakers, and the scientific community towards a robust, responsive, and innovative European RI ecosystem.

# HORIZON SHIFTS: PIONEERING TRENDS IN RIs

The landscape of scientifically excellent RIs is evolving at a rapid pace, influenced by a confluence of trends in scientific and technological advancements, funding mechanisms, collaborative approaches, governance and human resources, and ecosystem integration. Central to these transformations is the role of Artificial Intelligence, digitalisation, and the increasing emphasis on addressing societal challenges. This chapter synthesises these trends, offering a comprehensive view of the changing landscape of RIs.

## SCIENTIFIC AND TECHNOLOGICAL ADVANCES

### AI REVOLUTION: TRANSFORMING RESEARCH ACROSS DOMAINS

> *AI has the potential of revolutionising research methodologies, enabling more sophisticated data analysis and predictive capabilities. AI is a new driver for quality FAIR data productivity and FAIR data integration, and the AI assisted or automated workflows have potential to become a new tool for data handling. AI can support data curation and categorisation of large datasets, for consistency and coherence tests and for generation of synthetic data.*

In domains like the Social Sciences & Humanities (**SSH**), it is facilitating new understandings of social dynamics, while in the Environmental domain (**ENV**), AI models are predicting climate patterns with unprecedented accuracy. AI's role in Health & Food (**H&F**) RIs is transformative, driving innovations in disease prediction and treatment, drug and diagnostic developments, food security and safety, and in sustainable practices. In Physical Sciences & Engineering (**PSE**) and Energy (**ENE**) Infrastructures, AI may become an important tool supporting complex data processing, enhancing energy optimisation and basic and applied science research efficacy.

AI is not merely a technological tool: it represents a fundamental shift in how we approach research across various domains. By analysing patterns in vast datasets, AI is uncovering insights that were previously inaccessible, pushing the boundaries of human knowledge. Each domain, from **SSH** to **ENE**, is harnessing AI's power to address its unique challenges while contributing to a collective understanding of complex global issues. The integration of AI is a unifying trend across RIs, driving a new era of innovation, efficiency, and discovery. This trend aligns with the overarching progress in digitalisation and the need for interdisciplinary collaboration, as AI can bridge the gap between diverse research areas and foster a more holistic approach to solving critical societal challenges. However, before the promises of AI can be fully realised, it is crucial to address issues related to data privacy, bias in algorithms, interpretability of AI models, and the wider societal impact.

| | |
|---|---|
| DATA TRANSFER AND ANALYSIS | ▪ **Life sciences:** digitalisation has enabled projects like the 1000 Genomes Project to analyse vast genomic data, leading to breakthroughs in personalised medicine<br>▪ **Environmental sciences:** digital technologies applied to satellite, airborne and ground-based observations provide essential data for climate modelling and understanding global environmental changes |
| PROMOTION OF A DATA-DRIVEN RESEARCH CULTURE | ▪ **Cultural shift in Social Sciences and Humanities and Physical Sciences:** the adoption of digital tools in SSH, such as in digital humanities, demonstrates the cultural shift towards data-driven research. Similarly, in Physical Sciences, the use of advanced computing for Particle Physics experiments highlights the significance of digitalisation in managing and analysing large-scale data |
| INTERDISCIPLINARY COLLABORATION FACILITATED BY DIGITALISATION | ▪ **Energy research:** digitalisation is integral to the development and optimisation of smart grids, directly impacting the integration of renewable energy sources and enhancing energy efficiency<br>▪ **Health and Food safety:** the health sector's move towards telemedicine and digital health records showcases the impact of digitalisation on improving patient care. In food safety, digital tools for supply chain monitoring and contaminant detection underline the importance of digitalisation in ensuring public health |

TABLE 1.
Enhanced data capabilities across domains: selected examples

## DIGITALISATION: THE NEW PULSE OF RIS

Digitalisation is transforming RIs by enhancing computing networks and software capabilities. This shift towards integrated digital ecosystems is revolutionising how research is conducted. For instance, the EuroHPC initiative is critical in fields like climate modeling and genomic research, as it provides the computational power needed to process extensive datasets.

EOSC, on the other hand, is pivotal in creating a unified federated platform for sharing and reusing research data, tools and services across disciplines, including **H&F**, **SSH** and **ENV**, but also opens up new avenues for innovation and discovery, solidifying its role as a catalyst in the ever-evolving realm of Research Infrastructures. ***[see Table 1]***

## INTEGRATIVE POWER OF E-INFRASTRUCTURES: A NEW SCIENTIFIC SYNERGY

> *In the evolving landscape of European RIs, a transformative narrative is unfolding, driven by the trend to seamless integration between e-infrastructures and each ESFRI RI, fostering exchange and common approaches. This integration marks a new era of scientific exploration, where digital backbones intertwine with physical research facilities, creating a symbiotic relationship that enhances the capabilities and reach of research endeavours. At the heart of this narrative is the role of e-infrastructures in bolstering the functions of ESFRI RIs. These digital platforms, encompassing advanced data repositories, high-speed networks, and cloud computing, are not mere additions but pivotal elements that empower RIs across various domains.*

In **ENV**, for instance, the integration of e-infrastructures with observational networks has led to a revolution in data collection and analysis, enabling researchers to monitor and predict environmental changes with greater accuracy and detail.

This integration is instrumental in fostering interdisciplinary research. By bridging disparate scientific fields, e-infrastructures facilitate a collaborative arena where data and tools are shared seamlessly. In the H&F sector, e-infrastructures enable the convergence of genomic data with environmental analytics, leading to groundbreaking studies on the interplay between environmental factors and human health. Such interdisciplinary endeavors underscore the transformative power of integrating e-infrastructures in research.

Furthermore, the integration of e-infrastructures in research is reshaping research methodologies, steering them towards a more data-driven approach. In SSH, digital tools and e-infrastructures are unlocking new forms of data analysis, offering fresh perspectives on social phenomena. This digital transformation also aligns closely with the Open Science movement, democratising research by making data more accessible and fostering global scientific collaboration.

The narrative of e-infrastructure integration extends to the realms of PSE as well. Here, the complex demands of research in areas like Materials Science, Astrophysics and Energy are met by the robust computational power provided by high-performance computing facilities within e-infrastructures. This integration not only supports the intricate computational needs but also catalyses innovations in these fields.

The narrative of integration continues to evolve, as e-infrastructures are proving indispensable in the contemporary research infrastructure ecosystem. They are the digital sinews that connect and empower various ESFRI infrastructures, driving forward a future where research is more collaborative, innovative, and impactful. This integration is not just a trend but a paradigm shift in how research is conducted, promising to unlock new horizons in the quest for knowledge and discovery.

# USER SUPPORT: NAVIGATING THE EVOLVING FINANCIAL NEEDS

## ALIGNING EU, NATIONAL, AND REGIONAL FUNDING: THE CHALLENGE OF COORDINATION

One of the primary challenges facing European RIs is the service provision to users often supported by project funding sources at the European Union (EU), national, and regional levels. This requires integration of policies and funding cycles, which can be complex due to differing priorities and administrative processes. Thematic reports focusing on each domain in Section 1 highlight the difficulty in synchronizing EU-funded large-scale infrastructural projects with national and regional funding that often centres on more localised research initiatives[1]. A further challenge is also to coordinate funding sources of distributed RIs that span across a large number of Member States (MS).

## BALANCING SERVICES FOR BASIC AND APPLIED RESEARCH: DISTRIBUTION OF RESOURCES

Another significant challenge is balancing the coverage of basic and applied research. Although this distinction can be seen as being artificial, ensuring that both poles of the spectrum are covered in the RI service portfolio is crucial for the overall health of the research ecosystem. As an example, thematic reports in the Health field indicate the necessity for services encompassing fundamental biological research in medical sciences, as well as medical-oriented initiatives such as translational research aimed at leveraging these findings to develop practical health solutions. Similarly, in the Energy domain, there is a pressing call to support both basic research geared towards uncovering new materials or processes, and applied science efforts which would translate the discoveries to economic innovation and finally to pre-prototype devices. Technology transfer plays a pivotal role in facilitating the transition of research outcomes into practical applications and innovations.

## FOSTERING COLLABORATIVE SERVICE MODELS: INTERDISCIPLINARY AND CROSS-DOMAIN CHALLENGES

As research increasingly becomes interdisciplinary and cross-domain, services often need to adapt to support collaborative projects that span different scientific areas. This requires a shift from traditional service provision, which is often discipline-specific. Energy research, as mentioned in Energy dedicated chapter in Section 1, often involves collaboration across Physics, Engineering, Environmental Science, Social Science and Policy, necessitating a more flexible and inclusive service provision approach.

## SUSTAINABILITY OF LONG-TERM FUNDING: ENSURING CONTINUITY

A perennial challenge for RIs is securing long-term funding that ensures the sustainability and continuity of service provision for enabling excellent research. Short-term grants and fluctuating funding streams can hinder long-term Research Infrastructure implementation and development as well as its maintenance.

1. See Section 1 – Thematic areas

The funding challenges facing services in European RIs are multifaceted, involving the coordination of various funding sources, balancing different types of research and the needs of users coming from a broad range of disciplines and thematic areas, fostering collaborative and interdisciplinary projects for the development of the European Research Area, ensuring long-term sustainability, and aligning with EU policies. Addressing these challenges requires a concerted effort from funding bodies, policymakers, and research institutions to develop more flexible, strategic, and integrated project funding models. Overcoming these challenges is crucial for the advancement and impact of RIs in the European research landscape.

# COLLABORATION AND INTERCONNECTEDNESS

## INTERDISCIPLINARITY AND CROSS-DOMAIN COLLABORATION

The trend towards interdisciplinarity and cross-domain collaboration is becoming increasingly crucial in the landscape of European Research Infrastructures. All ESFRI Strategy Working Groups indicate a growing emphasis on integrating various scientific disciplines in their thematic reports in Section 1. This trend is evident in how RIs are evolving to address complex societal challenges, EU missions, and transitions towards green and digital futures. Such integration is critical to harness the collective strengths of diverse research fields. The identified trend towards interdisciplinarity and cross-domain collaboration underlines a significant paradigm shift in European Research Infrastructures. This shift is characterised by a move away from isolated, discipline-specific research towards more integrated, collaborative approaches that leverage digital technologies and shared resources. This trend manifests itself through cooperation within RI ecosystems, for instance through data exchange and development of common services and technologies. RIs are better equipped to address the multifaceted nature of contemporary scientific challenges and contribute effectively to European Research and Innovation (R&I) strategies. This approach would not only enhance the scientific output of RIs but would also provide tools and skills to help address societal needs and EU strategic priorities.

# SOCIETAL MISSION: ALIGNING RESEARCH WITH GLOBAL CHALLENGES

As prominently highlighted in the thematic reports in Section 1, RIs in the EU are increasingly aligning their efforts with societal challenges and long-term missions. RIs strategic response to global challenges, such as climate change, public health, and sustainable energy closely aligns with EU policy objectives like those outlined in the European Green Deal[2] and key commitments and actions announced by the EU at COP28[3]. Not only are RIs focusing on the scientific and disciplinary aspects of these challenges, but they are also incorporating interdisciplinary approaches that bring together diverse expertise. This approach is crucial in addressing complex issues spanning multiple domains, such as combining **Environmental Science** with **Social Sciences** to tackle climate change impacts on societies.

## STRUCTURAL AND COLLABORATIVE RESEARCH MODELS

To effectively address these challenges, RIs are adopting structured and sustained collaborative research models. These models facilitate long-term commitment and resource allocation, ensuring continuity and comprehensive tackling of issues that require persistent efforts. Examples from thematic reports show that RIs are establishing enduring partnerships across various sectors, including industry, government, and international bodies, fostering a holistic approach to research. Additionally, the advancement of digital technologies, especially AI, is facilitating the creation of data-driven solutions to societal issues, bolstering the capacity of RIs to deliver insightful and impactful research outcomes.

## PUBLIC ENGAGEMENT AND SOCIETAL IMPACT

Lastly, there is an increasing emphasis on public engagement and demonstrating the societal impact of RI activities. RIs proactively communicate their research outcomes, underlining their relevance to societal needs, and engage with the public to ensure that their research is responsive to societal concerns. Through excellence in science and technology, they attract and train the next generation of scientists and engineers essential for the EU. Such trends are reinforcing the role of RIs in society and emphasising their contribution not only to scientific advancement but also to the betterment of societal conditions in line with EU strategic priorities. This underscores the broader impact and relevance of Research Infrastructures in informing and shaping policy decisions.

2. The European Green Deal https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

3. EU at COP28 Climate Change Conference https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/climate-action-and-green-deal/eu-un-climate-change-conference/eu-cop28-climate-change-conference_en

# GOVERNANCE EVOLUTION

The evolution of governance in EU Research Infrastructures is increasingly being shaped by the need to adapt to rapidly evolving and changing Research and Innovation ecosystems. This trend requires a nuanced understanding of the complementarity between fundamental and applied research, the necessity of cross-sectoral collaboration, and the importance of adopting a holistic and open approach.

> *As RIs continue to evolve within these dynamic ecosystems, their governance structures must also transform to support the seamless translation of knowledge across various stages of R&I, ultimately contributing to a robust and responsive European research ecosystem.*

As the European Union navigates an increasingly complex global landscape, the evolution of governance within European RIs must prioritise the strategic forecasting of dependencies and vulnerabilities. This forward-looking governance will necessitate a proactive stance on fostering technological independence, ensuring that Europe's reliance on critical components is matched by an internal capacity to innovate and manufacture. By reinforcing governance frameworks to support Research and Development (R&D) in strategic technologies, Europe can mitigate risks associated with foreign supply chains and enhance its long-term economic and political sovereignty. Such a recalibrated governance approach will ensure that European RIs remain resilient and adaptive, poised to support the continent's green and digital transitions in an autonomous and secure manner.

On the other hand, the governance trends at the European level, particularly within ESFRI RIs and within ESFRI, reflect a dynamic and responsive approach to the needs of the European research ecosystem. These trends underscore the importance of strategic alignment, interoperability, openness, adaptability to digital transformation, engagement with societal challenges, and support for cross-domain research. As these trends continue to evolve, they will shape the future direction and effectiveness of RIs across Europe, ensuring their alignment with both scientific advancements and societal needs.

| | |
|---|---|
| FIT IN VARIED ECOSYSTEMS | ▪ RIs achieve greater impact by aligning with different R&I ecosystems that range from academic research to industry-led innovation. This involves understanding the unique dynamics and requirements of each ecosystem and positioning their services and expertise accordingly |
| ROLE IN VALUE-CHAINS | ▪ RIs contribute to various stages of value-chains, from basic research to applied development and commercialisation. By understanding their role in these chains, RIs can enhance their contributions to the development of new products, services, or policies |
| PARTNERSHIPS WITH TECHNOLOGY INFRASTRUCTURES | ▪ RIs increasingly collaborate with Technology Infrastructures to leverage advanced technologies. This relationship is non-linear and context dependent. In many cases, these partnerships are crucial for enhancing research capabilities and outputs and valorising RIs role in a complete R&I ecosystem or specific value-chain |
| SYNERGY AND COMPLEMENTARITY WITH OTHER ENTITIES | ▪ Effective partnership and complementarity with other entities, such as universities, industry, and government agencies, are key to enhancing the impact of RIs. These relationships enable RIs to leverage additional expertise, resources, and networks |
| ADOPTING TO EVOLVING NEEDS OF STAKEHOLDERS | ▪ RIs remain relevant and impactful by continuously adapting to the evolving needs of their stakeholders. This involves staying attuned to changes in scientific priorities, market demands, and societal challenges |

## TABLE 2.

Strategic positioning in R&I ecosystems

## ECOSYSTEM INTEGRATION

European RIs are progressively becoming more integrated into the R&I ecosystem, marking a pivotal shift in their function and operation. By building interfaces with a diverse range of infrastructures and organisations in industry and academia, and by being responsive to both immediate and long-term challenges, RIs are positioning themselves as key players within the broader R&I ecosystem. Not only does this approach enhance the impact and relevance of RIs, but it also ensures their adaptability and resilience in the face of evolving scientific, technological, and societal landscapes. Research Infrastructures in Europe enhance their impact and relevance by strategically positioning themselves within diverse R&I ecosystems and value-chains.

This strategic positioning involves finding their fit and acting in complementarity to other entities, including Technology Infrastructures (TIs) and partnerships. The distinction between Research Infrastructures and TIs is not clear and, in many cases, it is deemed as artificial. As all infrastructures provide services to industry and support the development of crucial skill sets to capacitate knowledge intensive economies, an ecosystem-based policy should focus on supporting the services provided, not on atomising funding streams by artificially isolating typologies of infrastructures. ***[see Table 2]***

# BRIDGING THE DIVIDE: ADDRESSING KEY CHALLENGES AND NEEDS IN RIs

> *Across various domains of Research Infrastructures, a comprehensive analysis reveals pervasive challenges and unmet needs that transcend specific disciplines. It is crucial to facilitate collaboration and interconnectedness between RIs from diverse domains, fostering synergies in addressing societal challenges, Horizon Europe missions, and the green and digital transition.*

In addition to nurturing collaboration and interconnectedness, a crucial need is the formalised assessment and management of risks associated with the overreliance on external products and technologies. The current geopolitical context, underscored by supply chain vulnerabilities revealed during the Ukrainian conflict, emphasises the imperative for a robust risk assessment framework. This framework should prioritise the development of internal capacities and the strategic foresight to anticipate disruptions. European Research Infrastructures can inform policy decisions that protect and advance Europe's energy independence, ensuring resilience against external economic and political pressures.

European RIs could identify possible technical solutions, including the new digital technologies, for safeguarding strategic autonomy and aligning with the European vision for a sustainable, green, and digitally integrated continent. Indeed, European deep technology is key for tackling the most pressing global challenges such as climate change, sustainable energy, health, as well as for accelerating innovation. Moreover, it would contribute to create new jobs and companies.

Competence development gaps, recruitment problems and the evolving nature of digital infrastructures underscore the necessity for RI-oriented prioritised skill development and training programs, notably through cooperation between RIs and academia. These programs should equip researchers with the capabilities to navigate and harness the benefits of emerging technologies, including Artificial Intelligence. A wider and more informed discussion about the ethical and societal implications related to the application of AI tools, particularly in the **Social Sciences & Humanities** and the **Health & Food** domains, is necessitated.

Retention of highly qualified staff is something that RIs are feeling as urgent. Training and professional development is a key solution to this challenge. Also, the development of HR policies and standardisation of competences for the mobility and career development of staff is needed. Projects such as RItrain 1 and 2 have reflected upon this challenge involving a variety of RIs from different disciplines.

Synergies and interoperability between RIs emerge as critical challenges, with the existing lack of smooth interaction between initiatives such as EuroHPC and EOSC impeding the realisation of potential impacts. To address this, there is a pressing need to focus on developing and promoting solutions, standards, funding instruments, and best practices for seamless data sharing, management, and interoperability across RIs and e-infrastructures.

Sustainable service provision and development of common technologies and corresponding funding models pose a perennial challenge, with fragmented and inadequate funding threatening the long-term added value of RIs. Establishing funding mechanisms that account for the full life cycle of RIs, as well as the dif-

ferent needs of distributed and single site RIs, is paramount to ensure continuity and adaptability to evolving research needs.

While crucial, international collaboration faces hurdles such as fragmented funding and limited coordination. A need exists to strengthen international collaboration efforts, fostering cohesion and aligning goals to address global challenges effectively. Furthermore, crisis preparedness and response mechanisms, despite their potential for cross-domain collaboration, currently lack the necessary interaction. Establishing mechanisms for cross-domain collaborations, assessing the impact of challenges such as air pollution, and exploring socio-economic effects are essential actions aligned with EU strategies.

Efficient policy directionality and governance structures are necessary to align RIs research outputs with societal goals and expectations. Policies and governance should be constructed to support both directed and 'free' research, and the important interactions between them. The evolution of research landscapes and societal demands requires articulating and integrating governance structures at various levels.

In summary, the interconnected nature of challenges and needs in the RIs landscape calls attention to the need of collectively addressing them. This approach would lead to a more cohesive, impactful, and adaptive research ecosystem.

## GOVERNANCE DYNAMICS: CHALLENGES AND SOLUTIONS

*Across all domains, common challenges emerge, including the imperative for cross-disciplinary collaboration, the multifaceted nature of societal challenges, and the need for inter-, multi-, and transdisciplinarity. The current chapter delves into the intricacies of interdisciplinary collaboration, digital integration, and multilevel articulation governance.*

Governance structures at all levels should interact effectively to support the development of efficient, cost-effective, and dynamically developing RIs. Tools to support this include proactive RI self-assessment, governance structures which allow and encourage RI transformation and renewal to match evolving research developments and needs, training programs, and the definition and use of robust and effective Key Performance Indicators (KPIs) in conjunction with qualitative assessments.

Addressing management challenges in several domains involves effective coordination of large-scale experimental facilities, managing the running and renewal of highly complex and expensive infrastructure projects with complex funding flows, and navigating regulatory landscapes. Using tools such as KPIs and structured self- and external evaluations, governance must tackle the unique challenges posed by the scale and complexity of, for example, **Physical Sciences** experiments, demanding highly competent and specialised management personnel and technical and management training programs.

Most critical gaps and needs revolve around ensuring long-term sustainability, with a special emphasis on the challenges of distributed RIs, efficiency, and innovation of Research Infrastructures. Governance interventions are crucial to addressing these gaps, ensuring stable funding, coordinated efforts, and the development of suitable managerial expertise.

Governance trends in **DIGIT** and **ENE** include strategic long-term resource allocation, increased international collaboration, and the need for more adaptable and responsive governance and financing structures for increased flexibility. Addressing challenges related to optimising resource allocation, navigating international regulatory differences, and balancing agility with stability require clear governance structures. This is crucial to shift towards transparent frameworks for resource allocation, streamlined international collaboration protocols, and comprehensive training programs for effective Agile governance. In the case of Digital RIs, governance must additionally address issues such as the smooth integration of digital tools, data management, privacy concerns, and the adoption of Agile governance models for efficient development.

Recognising the trend towards collaboration through digital technologies, Research Infrastructures of the **ENV** domain (with their grouping ENVRI) face challenges in seamlessly integrating digital tools across diverse environmental disciplines. Strategies for ENV RIs include the establishment of robust platforms for digital integration, the implementation of cross-disciplinary training programs, and the creation of standardised frameworks to facilitate smooth collaboration and communication across different organisational levels. Multilevel articulation, emphasising collaboration at both global and regional levels, gains prominence. Governance challenges in this domain emphasise the need for collaboration with RIs, European large initiatives such as Copernicus, space agencies and international programs such as GEO.

In the **H&F** domain, governance trends underscore and increasing focus on inclusive stakeholders' engagement, including those from the civil society (e.g., patient associations and consumer associations). Stakeholders' commitment and awareness and their conflicting interests are also crucial themes demanding attention. Other key challenges for governance include long-term sustainability, transparent data governance, ethical considerations and the need to implement standardised ethical guidelines, and heightened cybersecurity measures.

Within the **SSH** domain, governance trends emphasise a commitment to long-term sustainability planning, smooth integration of digital technologies, and heightened strategies for public engagement. Challenges mainly revolve around stable funding, rapid technological changes, and effective communication of research outcomes to the

public. To effectively tackle them, strategic planning, continuous digital literacy training for researchers, and comprehensive public engagement initiatives are essential. Governance challenges lie in balancing the interests of diverse stakeholders, addressing resource allocation (with special emphasis on the challenges posed by distributed RIs), ensuring transparent decision-making processes, and fostering effective international collaborations.

# FINANCING THE FUTURE: CRAFTING A SUSTAINABLE FUNDING STRATEGY FOR RIS

> *The funding landscape for European RIs stands as a critical determinant of their success and impact. Recognizing the evolving nature of RIs and the diverse challenges they encounter, a more streamlined, collaborative, and comprehensive approach to funding becomes imperative.*

The ESFRI Stakeholders Forum identified, at its second meetup in September 2023, key challenges and proposed actionable recommendations to enhance the funding ecosystem for RIs. These recommendations offer valuable insights and potential solutions to address the intricate funding needs of RIs, facilitating their sustained growth and impact.

The R&I landscape includes a spectrum of activities, from RIs supporting fundamental research to more applied research, from technological development platforms (Technology Infrastructures) to innovation and commercialisation support mechanisms. Governance and funding mechanisms must allow and enhance effective development along the R&I development chain, and seamless interaction between actions and actors at different Technological Readiness Levels (TRL) along this chain.

The challenges within the funding landscape are multifaceted, ranging from distinct funding needs for single site and distributed RIs to complexities in navigating intertwined funding sources across multiple countries. The ESFRI Stakeholders Forum underscored the importance of sustainable funding for operations and upgrades, avoiding over-reliance on a single funding source, and managing node costs, subsistence, and user travel costs.

In response to these challenges, key actions were recommended. Among the proposed solutions, the following were included: stakeholders dialogue, cooperative efforts between RIs, targeted funding for missions and curiosity-driven research, sustainable operational funding with potential EC co-funding, strengthening of Transnational Access (TNA) schemes, addressing health data complexities, and fostering synergies between EU and national funding. The creation of a unified proposal management system and the development of impact assessment methodologies were also highlighted.

Regarding the Horizon Europe Work Programme (HE WP) and the Framework Programme 10 (FP10), recommendations included the establishment of integrated funding schemes, a boost in TNA schemes, and an augmented budget for RI framework programme. The overarching theme emphasises the necessity for a more streamlined, collaborative, and comprehensive approach to funding RIs.

Interdisciplinary collaboration emerges as a crucial aspect in cross-cutting funding considerations for ESFRI domains. Encouraging projects that span multiple domains promotes a holistic approach to research challenges, fostering innovative solutions. Adequate funding for robust data management practices and support for Open Science initiatives ensure transparency, accessibility, and reproducibility of research.

Funds allocated to integrate emerging technologies within Research Infrastructures keep the domains at the forefront of scientific advancements. Recognising the global nature of contemporary challenges, funding should support the competitiveness of the European RIs so to become strategic and attractive at international level.

## DOMAIN-SPECIFIC FUNDING CONSIDERATIONS

The increasing reliance on digital technologies across all scientific domains is a prominent trend. In DIGIT RIs, focus on cybersecurity and data management is essential. Yet, funding gaps for developing and maintaining state-of-the-art digital infrastructures and addressing the digital divide require attention. A much stronger dialogue between all domains should not only be encouraged but realised fully through the awareness of the necessity of interdisciplinary research. Emphasis on digital and data-driven research methodologies is a growing trend.

Energy independence and security are vital for Europe. The ENE domain witnesses a transition towards sustainable and decarbonised energy sources, i.e. technologies that produce low net carbon dioxide emissions and are deemed environmentally, economically and socially viable for the long-term. The integration of smart technologies for efficient energy systems represents a growing trend. However, funding needs arise for the development and maintenance of energy-related Research Infrastructures. Support for research addressing energy storage, grid integration, efficient use of energy as well as the societal and environmental impact of energy transitions is crucial.

In the **ENV** domain, a growing awareness of environmental challenges has led to increased funding. While interdisciplinary collaboration is emphasised to address complex environmental issues, funding gaps persist for long-term observations and data collection projects. Financial sustainability for integrating new technologies into environmental infrastructures remains a critical need. A holistic view involves understanding the interconnectedness of ecosystems, underscoring interdisciplinary collaboration, prioritising long-term sustainability, fostering technological innovation, promoting global collaboration, engaging the public, and adapting to emerging challenges. The governance framework necessitates informed decision-making, aligning national strategies with European environmental goals, and optimising resource allocation for impactful research endeavours.

In the **H&F** domain, funding considerations encompass advances in precision medicine, personalised healthcare, prediction, and treatment, sustainable and resilient agri-food systems. It embraces the integration of big data, AI, and other technologies in health and agri-food research. Funding needs include support for implementation of cutting-edge medical technologies and equipment, as well as for tools in translational research aimed at bridging the gap between laboratory discoveries and clinical applications. Additionally, financial support is required for research on climate-resilient crops, and sustainable and environmentally friendly agricultural practices. Interdisciplinary projects addressing the whole health and the whole agro-food value chains require financial backing to ensure access to services by the RIs.

In **PSE**, advancements in technology and science drive the need for cutting-edge Research Infrastructures. While collaborative projects with industry accelerate innovation, persistent challenges include funding gaps for maintaining and upgrading equipment, financing the implementation and operation phases of large-scale RIs, and bridging the divide between academia and industry.

The recognition of the importance of **SSH** in addressing societal challenges and informing policymaking is evident. However, stronger ties should be established with researchers dealing with missions and societal challenges across all domains. Remote data access and specific questions of data security and privacy demand further development of infrastructure, as well as the integration of AI. Funding for large-scale, cross-disciplinary projects addressing the challenges of digital transformation is limited. However, this challenge requires sustained financial investments. SSH RIs are distributed Research Infrastructures with specific challenges for sustainable funding.

# SHAPING TOMORROW: RIs TRANSFORMATIVE POWER IN SCIENCE, SOCIETY, AND BEYOND

> *The anticipated impacts across diverse Research Infrastructure domains collectively contribute to advancing scientific knowledge, fostering innovation, and addressing societal challenges. This influence extends beyond academia, significantly impacting policy and economic sectors.*

RIs serve as vital sources of data and expertise that inform policymaking, ensuring that scientific advancements are aligned with societal needs and government agendas. Economically, RIs are catalysts for innovation, driving industrial competitiveness and contributing to job creation and economic growth, particularly in high-tech sectors. This is further amplified by the interdisciplinary collaborations spanning across these domains, bringing together diverse expertise and perspectives to drive innovative solutions.

Additionally, the role of RIs in education and training is pivotal for developing skills and building capacity across domains, which is essential for sustaining the European research community and industry. These infrastructures are not only hubs of scientific discovery but also centres of learning and professional development, shaping the next generation of scientists and industry leaders.

In the **PSE** domain, cutting-edge RIs like the **European XFEL**, **ESRF-EBS**, **ILL** and **ELI ERIC** are pivotal in advancing our understanding in fields ranging from Material Science to Pharmaceuticals. These infrastructures exemplify interdisciplinary innovation and serve as platforms for education and skill development, often collaborating with sectors like Biology and Medicine to develop new diagnostic tools and treatments, demonstrating the potential for cross-domain innovation. Extremely powerful telescopes like **SKAO**, **CTAO**, **ELT** and **ET** are designed to transform the understanding of the universe and to provide instruments for new insights in cosmic evolution, composition, and astrobiology.

In the **ENE** sector, RIs such as **ECSSEL ERIC**, **JHR** and **IFMIF-DONES** are crucial in sustainable decarbonised economic development and energy independence and security, including education and training cross-linking disciplines like Environmental Science, Engineering, and Economics, to address energy challenges holistically.

The **DIGIT** domain, with infrastructures like EuroHPC and EOSC, showcases the impact of synergies between digital technologies and various research fields. These digital RIs enable seamless interoperability and future developments, integrating data and tools from various disciplines. They are at the forefront of promoting Open Science, facilitating access to scientific data and resources. The Open Science approach accelerates research, fosters collaboration, and democratises access to scientific knowledge.

In the **SSH** domain, the application of AI and digital tools, facilitated by RIs like **CLARIN ERIC** and **DARIAH ERIC**, offers profound insights and critical scrutiny of AI's ethical implications. These collaborations, involving Computer Science, Ethics, and Social Sciences, highlight the role of SSH in shaping societal values and contributing to the responsible development of technology. They also underscore the importance of integrating digital tools and Open Science principles in SSH research, enhancing its impact and relevance. In the same vein, **ESS ERIC**, **SHARE ERIC** and **GGP** have been key contributors to a more holistic understanding of the COVID pandemic from childhood to old age.

The **ENV** RIs support research through advanced data provision. These infrastructures collaborate with domains such as Climate Science, Biology, and Geology, contributing significantly to our understanding and addressing global environmental challenges. They are also key in educating and training environmental scientists, ensuring a continuous development of skills and expertise in this critical area. Furthermore, RIs in this domain play a critical role in promoting environmental sustainability, climate action and biodiversity loss. Their contributions resonate with global and EU-specific sustainability goals, providing essential data and insights for environmental policy and sustainable development strategies. It is imperative to cultivate awareness regarding the ongoing challenge of effectively communicating with policymakers and the general public to instil trust in ENV RIs advanced datasets, environmental research, and measurements. This aspect necessitates sustained attention and effort.

In the **H&F** domain, RIs are central in addressing health-related challenges. These range from enhancing diagnostic efficiency to advancing drug and treatment development, addressing pandemic threats, ensuring food security and safety, and devising strategies to enhance the food supply chain. Their interdisciplinary collaborations, involving domains such as Genetics, Nutrition, and Public Health, are instrumental in biomedical research, addressing challenges such as infectious diseases and antimicrobial resistance. They also emphasise the importance of skills development and capacity building in the H&F sectors, aligning with HE missions like Cancer and Climate Adaptation.

This chapter has underscored the interconnected and multifaceted nature of Research Infrastructures. Their combined impact on scientific advancement, societal welfare, and the tackling of global challenges is evident. This impact is significantly bolstered by the power of interdisciplinary collaboration, skills and capacity building, and the integration of Open Science and digital technologies. The broader impacts of RIs on policy, the economy, sustainability, and environmental protection highlight their vital role in shaping a more informed, sustainable, and prosperous future. ***[see Table 3]***

| | MAIN CONTRIBUTIONS | IMPACTS | IMPACT IN KEY POLICY AREAS |
|---|---|---|---|
| DATA, COMPUTING AND DIGITAL | Seamless interoperability, promoting Open Science, accelerating Research & Innovation | Democratised scientific knowledge, digital transformation in research | Facilitating the EU's digital single market strategy, promoting Open Science and digital collaboration |
| ENERGY | Sustainable economic development, energy security, skills & workforce development | Sustainable energy transitions, international collaboration, strategic energy independence, economic growth | Aligning with, and contributing to improving, EU's Green Deal and energy policies, contributing to decarbonisation and Sustainable Development Goals |
| ENVIRONMENT | Advanced data provision for environmental research, education and training, promoting sustainability and climate action | Data-driven environmental policy, sustainable development strategies | Contributing to EU environmental policies and sustainability goals, data-driven policy making |
| HEALTH & FOOD | Improving health outcomes, food safety, biomedical research, addressing global health challenges | Advancements in healthcare and nutrition, alignment with Horizon Europe missions | Supporting EU health policies, contributing to public health and food safety initiatives |
| PHYSICAL SCIENCES & ENGINEERING | Multi-Messenger research on fundamental Physics, Astronomy, Quantum Materials Science, Nanoscience | Cross-domain innovation, next-gen diagnostics and treatments | Supporting EU's research and innovation strategies, influencing policy in Material Science, pharmaceuticals, and other application fields |
| SOCIAL SCIENCES & HUMANITIES | Evidence and data about society and cultural heritage. Analysys of societal values and behaviour<br><br>Insights in cultural and societal development, hereunder AI ethical implications, shaping societal values, integrating digital tools in research | Data-driven knowledge about society and culture<br><br>Responsible technology development, enhanced research impact through evidence for policy | Providing evidence for EU policies in various fields, such as social policy, climate policy, R&I policy. Influencing EU policies for the development of fair social policies hereunder on digital ethics, shaping societal values and responsible technology development |

## TABLE 3.

Summary of key contributions and impacts per knowledge domain in the current landscape

# MULTIPLE DIMENSIONS OF THE LANDSCAPE

As we delve into the evolving landscape of Research Infrastructures, we are met with a realm where innovation and tradition intersect, creating a multifaceted tapestry of scientific endeavour. The present chapter aims to unravel this complexity, shedding light on the overarching themes that are redefining the essence of RIs: Technological Convergence, Sustainability and Green Innovation, Adaptive Response to Global Challenges, Data-Driven Research Paradigm, and Ethical and Societal Responsibility.

These themes are not mere facets of scientific progress but are the keystones shaping the future trajectory of Research and Innovation. These dimensions collectively forge a path toward a future that is not only technologically advanced but also ethically grounded and responsive to the ever-evolving needs of society.

## CHARTING THE FUTURE: EMBRACING SUSTAINABILITY, AGILITY, AND ETHICS IN RIS

Technological Convergence: At the heart of several modern RIs lies the convergence of strongly developing technologies. Digitalisation, AI and quantum computing are shaping a new era of scientific discovery and innovation.

Sustainability and Green Innovation: The pursuit of sustainability transcends specific domains and permeates every facet of society, making it a crucial theme in contemporary RIs. This encompasses efforts to develop sustainable energy systems, materials which can be sourced and used sustainably, and environmentally benign practices that align with major goals regarding health, climate, and biodiversity protection. However, this pursuit is often challenging, given that RIs typically operate at the forefront of technological progress where sustainable solutions are still to be developed.

Adaptive Response to Global Challenges: The capacity of RIs to rapidly adapt and respond to global challenges, such as health crises, environmental changes and biodiversity loss, is crucial and has already been proved during the COVID-19 crisis. This involves developing flexible infrastructures that can pivot to meet emerging global needs, such as pandemic response or climate resilience, and the Sustainable Development Goals (SDG) as defined by the United Nations.

Data-Driven Research Paradigm: The shift towards data-intensive research methodologies is redefining scientific inquiry across all domains. This paradigm shift involves harnessing big data, improving data analytics, and ensuring data interoperability for enhanced research outcomes.

Ethical and Societal Responsibility: As RIs advance, there is a growing emphasis on ethical considerations and societal impact, in that future technology and practices should not cause significant environmental or social harm. This dimension encompasses responsible research practices, addressing societal challenges, and ensuring that technological advancements align with ethical standards.

## ENACTING TRANSVERSAL ELEMENTS ACROSS RI DOMAINS

Building upon the foundational understanding established in the previous section, we transition to an analysis of the transversal elements and the practical application and operational realisation of overarching themes across RIs domains. This section delves into the tangible aspects of RIs, dissecting how the key concepts of Digitalisation, Greening, Crisis Preparedness and Response, Data-intensive Approaches, and Inter-, Multi-, Transdisciplinarity are actively woven into the fabric of various RI domains. Each transversal element is intrinsically linked to the broader dimensions previously explored, exemplifying how strategic visions are translated into actionable realities.

As we navigate through these elements, we uncover the synergies between theoretical concepts and practical implementations, highlighting the dynamic and interconnected nature of modern RIs.

***Figure 1*** visually represents the linkage between the transversal elements in the RIs landscape and their corresponding overarching multiple dimensions. Each transversal element (on the left) is connected to the relevant key concept (on the right) through lines, illustrating the practical realisation of the broader themes in specific operational contexts.

## LINKING TRANSVERSAL ELEMENTS TO MULTIPLE DIMENSIONS IN THE RI LANDSCAPE

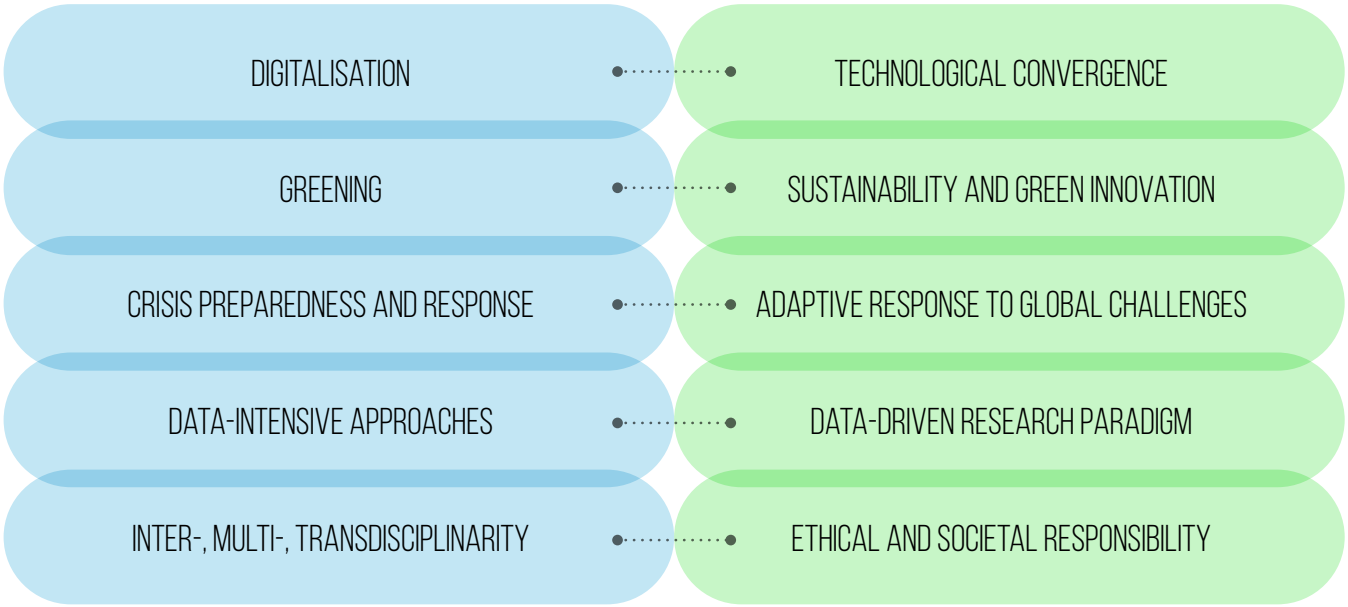


**FIGURE 1.**
Synergy in science: mapping transversal elements to key dimensions in Research Infrastructures.

| | |
|---|---|
| DIGITALISATION | Digitalisation acts as a practical realisation of the technological convergence. For instance, the EuroHPC enables high-performance computing and data sharing across various scientific fields, enhancing research capabilities in domains like H&F and ENV. |
| GREENING | Initiatives for operationalising sustainability, aimed at reducing environmental impacts, are evident in domains like ENE, where technologies with low carbon dioxide emission footprint can be developed. Greening initiatives are transversal, spanning various domains. A general requirement for greening is that domains such as SSH and PSE should also contribute. For instance, PSE can can contribute to reducing the material intensity of the economy. |
| CRISIS PREPAREDNESS AND RESPONSE | Translating adaptive response into action, RIs in the H&F domain have played a crucial role in crisis management, exemplified by rapid Research and Development during the COVID-19 pandemic. |
| DATA-INTENSIVE APPROACHES | Reflecting the shift to data-driven research, RIs across domains emphasise standardised data sharing, security, and accessibility. An example is the ENV domain's reliance on integrated data for climate action and biodiversity conservation. |
| INTER-, MULTI-, TRANSDISCIPLINARITY | Interdisciplinary collaboration is essential for operationalising ethical and societal responsibility. To address complex challenges ethically and responsibly, collaboration across domains is crucial. This is exemplified by the collaboration between RIs from different projects funded under Horizon Europe missions. |

# RESILIENCE IN ACTION: RIS PIVOTAL ROLE IN CRISIS AVOIDANCE AND MANAGEMENT

> *Research Infrastructures across various domains play a crucial role in crisis management, offering crucial support in understanding, responding to, and recovering from diverse challenges.*

In the **DIGIT** domain, the exploitation of synergies between EuroHPC and EOSC holds the potential for immeasurable impacts. e-infrastructures have already influenced RIs and RI Clusters through computing and data infrastructures, establishing a foundation for crisis-related analysis, simulations, and decision-making.

The value of **SSH** research is acknowledged for contributing to societal resilience and policymaking. Building ties between the SSH cluster and EOSC, particularly with the interconnection between EOSC and EuroHPC, presents an opportunity for enhanced integration. SSH RIs, through platforms and coordinated data collections, can play a pivotal role in articulating complex research questions as well as understanding societal shocks and formulating effective crisis responses.

**ENV** RIs collaborate across operational and research ecosystems within their domain, offering essential data for environmental crises. Their transversal elements, including observational platforms and networks, enhance early warning systems and support post-disaster recovery.

**H&F** RIs significantly contribute to Horizon Europe missions, addressing health crises, safe treatments and predictions, and ensuring food safety. Leveraging expertise and collaborative networks, RIs in this domain play a crucial role in crisis preparedness, response, and recovery, providing access to state-of-the-art facilities and data for accelerated research.

Avoiding a crisis is better than managing it. Several major potential future crises relate to energy supply or environmental disruption caused by energy production and use. RIs can enhance Europe's energy security and independence by exploring new scenarios for sustainable energy production, distribution, and use. Optimising the multifaceted energy system demands multidimensional approaches spanning many research fields and the full Research and Innovation cycle.

**ENE** RIs provide a unique base of competences which will be useful in relevant acute situations, providing crucial technical and practical support for society and decision-makers. Recent geopolitical tensions, as evidenced by the Ukrainian conflict, have emphasised Europe's need to reassess its energy supply chain resilience. The current reliance on non-European sources for critical components of the green transition, such as solar cells and batteries, represents a strategic vulnerability. Energy RIs must pivot not only to support the existing transitions but also to ensure Europe's long-term energy independence. By accelerating the development of domestic technologies and securing a self-reliant supply chain, Energy RIs will underpin Europe's strategic autonomy in energy technology, while simultaneously bolstering its capacity for crisis resilience. This strategic realignment is essential as Europe fortifies its energy systems against external shocks and move towards a truly integrated and sustainable energy policy.

The domain of **PSE** illustrates the impactful role of RIs through history and in recent advancements. Their contributions are broad, covering areas from medical technologies and imaging to innovative materials for the circular economy, and pioneering energy solutions like Photovoltaics, Generation IV fission and fusion. These RIs are crucial in diagnosing global challenges, providing essential training, and transferring expertise. They facilitate the development of technological solutions critical during crises, underscoring their vital contribution to societal welfare and economic development. Through their work, PSE RIs are at the forefront of detecting problems and driving technological innovations, demonstrating a pivotal role in crisis management and the broader scientific ecosystem.

Interdisciplinary collaboration is decisive in crisis management, addressing societal challenges, and facilitating transitions. ESFRI's role in fostering cross-domain collaboration is underscored to enhance links for effective crisis response.

Additionally, recognising the significance of AI in crisis management is essential. AI tools applied in the SSH domain contribute to understanding crises. Discussions on AI should incorporate social and cultural dimensions to enable decision-making during crises.

# SCIENTIFIC FRONTIERS: ALIGNING RI LANDSCAPE WITH HORIZON EUROPE'S VISION

*The landscape of European Research Infrastructures has been intricately intertwined with the Horizon Europe (HEU) missions, reflecting a dynamic interplay between scientific endeavours and societal challenges[4]. Across various domains, RIs contribute significantly to the realisation of HEU missions, playing a pivotal role in advancing research, innovation, and addressing key societal goals.*

4. EU Missions in Horizon Europe https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe_en

The **DIGIT** domain's landscape is marked by the potential for synergies between EuroHPC and EOSC, forming a critical foundation for future developments. RIs facilitate the seamless interoperability between these pillars, enhancing computing and data infrastructures. If realised, this synergy promises significant impacts, especially in crisis management scenarios. RIs, through their computing capabilities, contribute to mission-oriented objectives by providing advanced tools and solutions.

The **SSH** landscape emphasises the value of research in contributing to societal resilience, sustainable development, and policymaking. RIs in this domain are particularly called upon to build ties and bridges with EOSC, ensuring that they contribute to the sustainable European advanced computing infrastructure. Integration initiatives, such as interoperability between social surveys, or RIs in the Humanities like **CLARIN ERIC** and **DARIAH ERIC,** are proposed to maximise synergies and create a cohesive core of data for informed policymaking.

Within the **ENV** domain, the landscape encompasses collaboration between observational and research ecosystems, underscoring the multifaceted nature of Environmental Science. Environmental RIs address global challenges outlined in the United Nations' 2030 Agenda[5], aligning with EU priorities such as the Green Deal and digital transition[6]. ENV RIs contribute to sustainable development, climate action, and disaster risk reduction, proving crucial in tackling SDGs, such as 'Climate Action' (SDG 13), 'Life below Water' (SGD 14) and 'Life on Land' (SDG 15), and EU missions, such as 'Adaptation to Climate Change' and 'Restore our Oceans and Waters by 2030'.

The landscape in **H&F** sees RIs as essential contributors to HEU missions. RIs support Horizon Europe missions with particular focus to 'Cancer', 'Adaptation to Climate Change', 'Restore our Oceans and Waters', 'A Soil Deal for Europe', and '100 Climate-Neutral and Smart Cities by 2030'. By providing access to cutting-edge facilities, data, and expertise, RIs accelerate progress towards achieving mission goals. The transformation of RIs in H&F, embracing digitalisation, sustainability, and collaboration, aligns with the broader objectives of HEU.

In the **ENE** domain, RIs are positioned at the core of the green and digital transitions. Rooted in the advances of cutting-edge science and technology, a new wave of innovation is underway: deep tech innovation. New technologies for robust, secure, economic, and socially and environmentally benign energy systems will be a cornerstone of Europe's future well-being. Energy RIs are extremely well-aligned with the currently defined European objectives, and this sector can be expected to remain centrally relevant for the foreseeable future. Moreover, recent geopolitical events, notably the Ukrainian conflict, have highlighted the critical issue of Europe's overreliance on external sources for key energy technologies such as solar cells and batteries. This dependence poses a stark risk to the EU's strategic autonomy and economic security. In response, there is an urgent need to bolster internal capacities through RIs, fostering the development and scaling of homegrown innovations in these sectors. Strengthening Europe's position in the global energy technology market not only supports the green and digital transitions but also ensures a more resilient and self-reliant energy future.

**PSE** RIs have fundamentally transformed our understanding of the universe and our place within it, offering unparalleled insights at the very limits of time and space resolution. By enabling the detection and harnessing of new natural forces, they act as catalysts for disruptive technologies and innovations, thus aligning seamlessly with the transformative goals of Horizon Europe missions. Beyond basic research, these RIs extend their impact to a multitude of domains including environmental, social, cultural and energy research. Their contributions are vast, from exploring the mysteries of Astronomy and Astroparticle Physics, shedding light on the origins and structure of the universe, to advancements in Particle and Nuclear Physics that push the boundaries of what we know about matter and the forces that govern it. The cross-cutting nature of Analytical Physics RIs is evident in their support for research in Materials Science, enabling breakthroughs in medical technologies and treatments for diseases, imaging for H&F, development of materials for a circular economy, and strategies for climate change mitigation. Examples of such pioneering work include the **European XFEL** for probing the atomic details of viruses, or the **ESRF-EBS** for advancements in Materials Science.

5. The United Nations 2030 Agenda for Sustainable Development https://sdgs.un.org/2030agenda

6. A Europe fit for the digital age https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age_en

# EVOLVING PARADIGMS: THE NEXT HORIZON IN RI INTEGRATION AND INNOVATION

The cross-disciplinary and cross-domain challenges within the Research Infrastructures landscape are integral to addressing the complexities of crisis management, Horizon Europe missions, and the green and digital transition. Inter-, multi-, and transdisciplinarity are recognised as crucial, yet the existing domain-oriented structure poses challenges for fostering collaboration across diverse RIs. Synergies between domains should be enhanced, especially by involving RIs from the **SSH** domain in environmental considerations.

Networking and clustering of RI access and services should be prioritised to facilitate seamless cooperation, supporting research communities across all domains. This is essential to harness the collective strength of RIs in addressing societal challenges, HEU missions, and the green and digital transition.

Furthermore, a layer of complexity and opportunity is added by the integration of RIs with advanced technologies and deep tech expertise. This integration aims to accelerate innovation and to engage citizens in new technologies, such as AI and Machine Learning, as well as big data, communications and networks, cybersecurity, data protection, and virtual reality. AI tools are increasingly applied in all domains, demanding a wider, informed discussion about the potential ethical implications and societal values embedded in these technologies.

The challenges posed by the evolving landscape, including interdisciplinary demands and the integration of AI, underscore the necessity for further fostering cross-domain synergy and collaborative approaches within the ESFRI RIs ecosystem.

> *The transformation of RIs towards interdisciplinary collaboration and the integration of AI is crucial for positioning RIs as effective contributors to crisis management, HEU missions, and the broader green and digital transition, aligning with the evolving needs of society.*