



PART1

# **ROADMAP & STRATEGY REPORT**

**ON RESEARCH INFRASTRUCTURES**

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# ROADMAP & STRATEGY REPORT

The European Strategy Forum on Research Infrastructures (ESFRI)<sup>1</sup>, established in 2002, brings together national governments, the scientific community and the European Commission (EC) to support a coherent, strategy-led approach to Research Infrastructures (RI) in Europe.

Equipping Europe with infrastructures for ground breaking research is at the heart of the ESFRI Roadmap<sup>2</sup>,

which identifies European investment priorities in RIs<sup>3</sup> and provides directions for their further development, analyses the main features of the RIs landscape in Europe to implement the European Research Area (ERA) Priority 2b<sup>4</sup>, and looks into the future challenges of Research Infrastructure policy.

The ESFRI Roadmap 2021 is the sixth edition of the document, which has been influencing the European and national RIs strategies, policies and funding since 2006. ESFRI periodically updates its Roadmap to provide a coherent and strategic vision ensuring that Europe has excellence RIs in all fields of science and innovation<sup>5,6,7</sup>. The key messages of the 2021 edition of the Roadmap, prepared during the COVID-19 pandemic, clearly underline the importance of world-class RIs in enabling cutting-edge research needed to address the pressing requests and challenges of our society. This Roadmap, with the highest total cost of needed investments since the first edition in 2006, also demonstrates the persisting willingness of national governments to substantially invest in improving the RIs capacities in Europe, as an important element of our long-term scientific sovereignty and crisis preparedness.

This Strategy Report consists of four interconnected parts. First, it describes the **MAIN FEATURES AND OUTCOMES OF THE ROADMAP 2021**. Secondly, it presents **WHAT IS NEW IN THE ROADMAP 2021** edition in comparison to its predecessor. In the third part, it analyses the **LESSONS LEARNT** from this Roadmap and from the work of ESFRI over the last three years. The final part provides a strategic outlook into the future, identifying the key challenges for the RI policy in the coming years, **CHALLENGES AND STRATEGY FOR THE FUTURE**. This strategic outlook is particularly important as the fast evolving RI ecosystem is challenged by changing external circumstances and ESFRI needs to react to those changes in order to be capable of maintaining its capability to provide timely and relevant strategic advice and to stimulate further development of the RI ecosystem in Europe.

1. In June 2001, the Research Council invited "the Commission, in close collaboration with the Member States, to explore the establishment of new arrangements to support policies related to research infrastructures". The first meeting of ESFRI took place in Brussels on 25 April 2002. Detailed mandate and rules governing ESFRI are laid out in ESFRI Procedural Guidelines, see: [www.esfri.eu](http://www.esfri.eu)
2. Conclusions of the Competitiveness Council, 25-26 November 2004 and 21-22 May 2007
3. Conclusions of the Competitiveness Council, 11 December 2012
4. Conclusions of the Competitiveness Council, 1 December 2015
5. Conclusions of the Council of the European Union of 26 May 2014 on Implementation of the roadmap for the European Strategy Forum on Research Infrastructures. Doc. 10257/14  
<http://register.consilium.europa.eu/doc/srv?l=EN&f=ST%2010257%202014%20INIT>
6. Conclusions of the Council of the European Union of 27 May 2016 on FP7 and Future Outlook: Research and innovation investments for growth, jobs and solutions to societal challenges. Doc. 9527/16  
<http://data.consilium.europa.eu/doc/document/ST-9527-2016-INIT/en/pdf>
7. Conclusions of the Council of the European Union of 29 May 2018 on Accelerating knowledge circulation in the EU. Doc 9507/18  
<http://data.consilium.europa.eu/doc/document/ST-9507-2018-INIT/en/pdf>

# MAIN FEATURES AND OUTCOMES OF THE ROADMAP 2021

ESFRI engages in a well-defined road-mapping process with comprehensive and transparent rules and procedures that are refined at every new roadmap update process. For the Roadmap 2021, ESFRI has adopted the definitions, models and methods detailed in the Roadmap 2021 Guide<sup>8</sup>.

ESFRI RIs are facilities, resources or services of a unique nature identified by European research communities to conduct and to support top-level research activities in their fields. They include: major scientific equipment (or sets of instruments), knowledge-based resources such as collections, archives and scientific data, e-Infrastructures, such as data and computing systems and communication networks and any other tools that are essential to achieve excellence in Research & Innovation (R&I).

The **ESFRI PROJECTS** are RIs in their Preparation Phase, which have been selected for the excellence of their scientific case and for their maturity, according to a sound expectation that the Project will reach the Implementation Phase within a ten-year period. They are included in the Roadmap in order to underline their strategic importance for the ERA and to support their timely implementation.

The **ESFRI LANDMARKS** are RIs that are implemented - reached an advanced implementation stage - and represent major elements of competitiveness of the ERA. The Landmarks can be already delivering science services and granting user access, or can be in an advanced stage of construction with a clear schedule for the start of operation. Landmarks need continuous support and advice for successful completion, operation and – when necessary – upgrade to ensure the provision of state-of-the-art services, optimal management and maximum return from the investment.

For the Roadmap 2021, ESFRI monitored the Projects that entered the Roadmap in 2010 and 2016 and evaluated New Proposals that would be included in the Roadmap 2021.

The Roadmap 2021 Guide describes the overall ESFRI lifecycle approach and explains in detail the procedure and objective of the monitoring of current ESFRI Projects and the evaluation of the New Proposals. The monitoring and evaluation of the scientific and implementation cases are conducted independently and in parallel by the ESFRI Strategy Working Groups (SWGs) and the Implementation Group (IG), according to the Implementation Group and Strategy Working Groups Manual<sup>9</sup>.

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8.

ESFRI Public Roadmap 2021 Guide, September 2019  
[https://www.esfri.eu/sites/default/files/ESFRI\\_Roadmap2021\\_Public\\_Guide.pdf](https://www.esfri.eu/sites/default/files/ESFRI_Roadmap2021_Public_Guide.pdf)

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9.

Implementation Group and Strategy Working Groups Manual – In complement to the Roadmap 2021 Guide, September 2019  
[https://www.esfri.eu/sites/default/files/ESFRI\\_Roadmap%202021\\_SWG%26IG\\_Manual.pdf](https://www.esfri.eu/sites/default/files/ESFRI_Roadmap%202021_SWG%26IG_Manual.pdf)

## MONITORING OF ESFRI PROJECTS 2010

The specific objective of the monitoring of the Projects 2010 is to check whether, after the ten-year term, they reached the Implementation Phase as described in the Roadmap 2021 Guide.

Among the six Projects that entered the Roadmap in 2010, ISBE and WindScanner renounced the monitoring process and were withdrawn from the ESFRI Roadmap. For the other Projects – AnaEE, EU-SOLARIS, MIRRI, MYRRHA – the monitoring determines whether they can stay on the ESFRI Roadmap as a Landmark. In addition, ACTRIS, which entered the Roadmap in 2016, was considered sufficiently advanced to undergo the monitoring together with the Projects 2010 and be evaluated with respect to the minimal key requirements for a Landmark.

Based on the final monitoring reports and taking into account that the Projects that have successfully reached the Implementation Phase may be upgraded to the Landmark status if they are also considered major elements of the competitiveness of the ERA, ESFRI awarded the status of Landmark to ACTRIS, AnaEE, EU-SOLARIS and MIRRI.

## MONITORING OF ESFRI PROJECTS 2016

The specific goal of the monitoring of the Projects 2016 is to check the overall progress towards implementation and report on whether the Projects have addressed the recommendations received in 2016.

There are six Projects 2016 on the ESFRI Roadmap: ACTRIS, DANUBIUS-RI, EMPHASIS, E-RIHS, EST and KM3NeT 2.0. The relevant SWGs and IG monitored all of them according to the set of criteria for the scientific and implementation case, as specified in the Roadmap 2021 Guide.

Following this analysis, it was concluded that all six projects made substantial progress since they entered the ESFRI Roadmap<sup>10</sup>, none of them can be considered implemented though. Nevertheless, there was a possibility that two projects – ACTRIS and KM3NeT 2.0 – would be meeting the minimal key requirements for the Implementation Phase. Therefore, these projects were offered the opportunity to undergo the full monitoring with external reviewers and a hearing, as foreseen for the Projects 2010. ACTRIS decided to accept this offer and, upon the approval of the ESFRI Forum, underwent the full monitoring (see 'Monitoring of ESFRI Projects 2010').

## EVALUATION AND ASSESSMENT OF NEW PROPOSALS

According to ESFRI rules, Member States (MS), Associated Countries (AC) and EIROforum members are eligible to submit proposals for the ESFRI Roadmap.

In order to identify projects with high degree of maturity and stakeholder support, ESFRI introduced two eligibility conditions. First, the proposals must have at least a funding commitment from the lead MS or AC, along with a proof of political support by at least two

10.

Report from the monitoring of Projects 2016, October 2021

[https://www.esfri.eu/sites/default/files/Public\\_report\\_from\\_monitoring\\_of\\_2016\\_ESFRI\\_Projects.pdf](https://www.esfri.eu/sites/default/files/Public_report_from_monitoring_of_2016_ESFRI_Projects.pdf)



additional MS/AC (or a resolution of the Council for EIROforum organisations). Second, an inter-institutional/multilateral agreement to implement the proposed RI must be signed by the partners involved in the consortium. These requirements strengthened the links between the governments involved and the research communities resulting in an increased likelihood of implementation within the ten-year term.

The deadline for submission of New Proposals was initially fixed on 5th May 2020. However, in the midst of the crisis caused by the coronavirus outbreak and the impact it had on the activity of research organisations, ESFRI decided to extend the deadline to 9th September 2020 while keeping the launch of the new ESFRI Roadmap in 2021.

The eighteen submitted proposals were all eligible and underwent the evaluation process as described in the Guide. Based on the results of the evaluation, eleven new Projects – EBRAINS, EIRENE RI, ET, EuPRAXIA, GGP, GUIDE, MARI-NERG-i, OPERAS, RESILIENCE, SLICES and SoBigData++ – have been included in the ESFRI Roadmap 2021.

# WHAT IS NEW IN THE ROADMAP 2021

The ESFRI Roadmap 2021 reflects the lifecycle of several ESFRI Projects that entered in 2010 and that, in most cases, reached an advanced degree of implementation moving therefore to the Landmark list and 'Strengthening the European RI ecosystem'. The 'Strategic Landscape Analysis as a key element' of ESFRI Methodology captures the most relevant Research Infrastructures that are available to European scientists. The 'New projects are filling gaps in European RI capacities' in the diverse thematic domains.

## STRENGTHENING THE EUROPEAN RI ECOSYSTEM

The Roadmap 2021 further highlights the Landmarks list as a core element representing the group of implemented RIs that emerged from the ESFRI process. They represent the most advanced undertakings at global level in their fields, strengthening the competitiveness of European science. The four new Landmarks reinforce the Energy, Environment, and Health & Food domains with strategic long-term investments in research capability and capacity.

The ensemble of ESFRI Landmarks is one of the essential pillars of the ERA. It complements – and intersects with – the EIROforum to form a full pan-European portfolio of long-term undertakings in excellent science and innovation, thus creating unique opportunities for further internationalization. In adopting the new Landmarks, ESFRI considered the specific merit of those projects, having successfully completed their incubation through the Roadmap.

Landmarks, which are in operation and accessible to users, offer not only excellent conditions for doing science today, but also provide unique environments for further long-term development of European excellence in Research & Innovation. The research demand develops strongly both at a disciplinary level, often requiring the acquisition of diverse data from different methods, and across disciplines when the complexity of science requires the use of data and merge analyses from different disciplines in order to reach the information which is needed to improve our understanding of the different phenomena. The ensemble of Landmarks, having developed through ESFRI unifying criteria of monitoring and requirements – e.g. on data analysis open-tools and FAIR data management and policy – are in a good position to foster advanced disciplinary as well as multidisciplinary research, thereby increasing the impact of scientific knowledge on society in terms of innovation and societal needs.

# STRATEGIC LANDSCAPE ANALYSIS AS A KEY ELEMENT

The Landscape Analysis (LA, see PART2) part of the Roadmap 2021 provides an advanced scrutiny of the scientific needs and existing Research Infrastructure gaps as well as directions for strategic investments in the future that would help maintain Europe's leadership in the global context.

As the renewed ERA envisions stronger contributions of Research & Innovation activities to Europe's wider policy objectives, the LA adopts a more service-driven and impact-oriented approach maintaining the principle of excellence in science at the heart of European RIs. This demonstrates the relevance of investments in RIs for the environmental, economic and social issues identified at European and International level.

The LA captures the most relevant RIs that are available to European scientists and developers of innovative technologies and methodologies through the international standard of peer-reviewed proposals. ESFRI performed a new exercise to explicitly render the relevant connections among the RIs. These connections are showcased by existing links. New linkage-needs appear as well.

Capitalizing on the common reflection done by ESFRI in the previous roadmaps, the LA 2021 consists of three sections.

**SECTION1** gives insight for each domain and indicates in which direction it should evolve and how it can be optimised by stronger collaboration of existing RIs and strategic investments in the future.

**SECTION2** gives a different picture and an effective contextual analysis of links and complementarities between the existing European RIs, including general scientific trends across domains.

**SECTION3** focuses on the RIs services and their broader impacts, describing what the landscape can do. In order to illustrate explicitly the relevant contributions of RIs to societal challenges, including the capacity to respond to emergencies, the following three areas are described:

- the analysis of the relevance of ESFRI RIs for Sustainable Development Goals (SDGs);
- the analysis of capacity of RIs to respond to emergencies, as for example in the case of the COVID-19 crisis;
- the contribution of ESFRI RIs to the digital transformation, including the European Open Science Cloud (EOSC).

The LA is the prerequisite for strategic priority setting at European and national level as any future investment in RIs must be evaluated against its impact on the Landscape. Consequently, the LA is a key reference for the understanding of the Roadmap, its content and its analysis. It also demonstrates the relevance of investments in RIs for the environmental, economic and social issues identified at European and International level. It is a decisive tool to promote European RIs and their services and to reach out to new international partners. This essential role of the LA of the European RIs was acknowledged in the Council conclusions of 30<sup>th</sup> November 2018<sup>11</sup>.

11. \_\_\_\_\_  
Conclusions of the Council of the European Union of 30 November 2018 on Governance of the European Research Area.  
Doc. 14989/18  
<https://data.consilium.europa.eu/doc/document/ST-14989-2018-INIT/en/pdf>

## NEW PROJECTS FILLING GAPS IN EUROPEAN RI CAPACITIES

The new entries in the Roadmap 2021 reinforce important areas of research in which insufficient capacities exist in Europe. They will also make essential contributions to fostering research relevant for some of the key EU priorities, such as health, the Green Deal, digital transition or strengthening the EU social pillar.

▶▶ The **European Brain ReseArch INfrastructureS (EBRAINS)** is unique worldwide in providing access to the most comprehensive set of brain data, along with tools to share, analyse and store data, and to run virtual experiments. It is also unique in making High Performance Computing available to brain research, which it does through the Fenix and PRACE networks, enabling data and compute-intensive research.

▶▶ The **Scientific Large-scale Infrastructure for Computing/Communication Experimental Studies (SLICES)** adds a unique and significant value to the existing European research capacity by delivering a reference large-scale RI under public initiatives, as a trusted platform for large-scale experimentation of novel Digital Infrastructure science and technology, possibly also supporting disruptive innovations.

▶▶ The **European Integrated Infrastructure for Social Mining and Big Data Analytics (SoBigData++)** responds to the rising demand for cross-disciplinary Research & Innovation on the multiple aspects of social complexity from combined data-driven and model-driven perspectives; it also responds to the rising importance of ethics and data scientists' responsibility as a pillar of trustworthy use of Big Data and analytical technology.

▶▶ The **Marine Renewable Energy Research Infrastructure (MARINERG-i)** will facilitate national and international collaboration, creating the critical mass of knowledge, skills and resources necessary to sustainably develop the ORE industry. It will provide access to the highest quality testing facilities with a common research agenda focused on the development of innovative, investable ORE technologies.

▶▶ The **Research Infrastructure for Environmental Exposure assessment in Europe (EIRENE RI)** addresses the gap and bridges the H&F, Environment and Social domains to develop necessary tools and services to accelerate European exposome research. Unique experimental and computing capacities for assessment of environmental exposures to toxic mixtures will address the research community needs currently not answered.

▶▶ The **Einstein Telescope (ET)** responds to the desire from a broad scientific community to observe signals from across the cosmos to understand the very origins of our Universe. Despite their success, in terms of distances explored, the current reach of 2G observatories such as LIGO and Virgo is limited to a region that, on cosmological scales, is still our local neighbourhood, leaving much of the curiosity of scientists unquenched.

▶▶ The **European Plasma Research Accelerator with Excellence in Applications (EuPRAXIA)** will address the demand for increased access to FEL facilities in Europe; offers unique features in time resolution, pump-probe capabilities, spatial resolution for X-ray imaging and penetration depth for material analysis; will be the first RI worldwide to realise an accelerator facility based on novel concepts that so far have only been used in experimental tests; provides unique opportunities for education and training in innovative technologies in the ERA and beyond.

▶▶ The **Generations and Gender Programme (GGP)** fills in a gap from a life course perspective with its focus on young adults and the child-rearing years. Substantively, it is positioned alongside SHARE ERIC with its focus on the older ages, and the emerging birth cohort study (GUIDE/EuroCohort) with its focus on children and adolescents. Moreover, the GGP aims at addressing societal challenges related to population and family dynamics, and is thus complementary to SHARE's expertise on health and ageing, and the GUIDE/EuroCohort on well-being.

▶▶ The **Growing Up in Digital Europe: EuroCohort (GUIDE)** will be able to give valuable information on how early life experiences have a clear effect on later life outcomes. Together, GUIDE/EuroCohort, GGP and SHARE can deliver a comprehensive picture of the European life course from early years until later life. They cover all the major phases of life and adapt the methods and content of their data collection to suit the target population.

▶▶ The **Open scholarly communication in the European Research Area for Social Sciences and Humanities (OPERAS)** fills a gap in the European landscape, between generic e-Infrastructures and RIs dedicated to research data in specific disciplines or topics. OPERAS deals with a neglected part of the research life-cycle, regarding the production and access to research outputs, and supports multilingual scholarly communication cultures in SSH.

▶▶ The **Religious Studies Infrastructure: toolS, Innovation, Experts, conNectiOns and Centres in Europe (RESILIENCE)** responds to the challenges of the European societal landscape and of dialogue with neighbouring countries, and also fills the gap in the RI landscape by giving physical and digital access to major relevant data archives for Religious Studies – which are not yet part of ERA, mostly for historical or geographical reasons; fostering the digitisation of collections of dead and rare languages both handwritten and in print; providing domain-specific ontologies as well as providing sophisticated communication platforms among researchers, social actors and decision makers.

The updated and complete list of **22 ESFRI PROJECTS** and **41 ESFRI LANDMARKS** is summarized in the following table reporting the main information on each ESFRI RI (see PART3 for details).

▶ ESFRI PROJECTS

|                                 | NAME                | FULL NAME  | TYPE         | LEGAL STATUS (Y) | ROADMAP ENTRY (Y) | OPERATION START (Y) | INVESTMENT COST (M€) | OPERATION COST (M€/Y) |
|---------------------------------|---------------------|--|--------------|------------------|-------------------|---------------------|----------------------|-----------------------|
| DIGIT                           | <b>EBRAINS</b>      | European Brain ReseArch INfrastructureS  | distributed  | AISBL, 2019      | 2021              | 2026*               | 323.8                | 19.8                  |
|                                 | <b>SLICES</b>       | Scientific Large-scale Infrastructure for Computing/Communication Experimental Studies                     | distributed  |                  | 2021              | 2024*               | 137.7                | 6.5                   |
|                                 | <b>SoBigData++</b>  | European Integrated Infrastructure for Social Mining and Big Data Analytics                                | distributed  |                  | 2021              | 2030*               | 130.5                | 5.0                   |
| ENERGY                          | <b>IFMIF-DONES</b>  | International Fusion Materials Irradiation Facility - DEMO Oriented NEutron Source                         | single-sited |                  | 2018              | 2033*               | 884.0                | 56.0                  |
|                                 | <b>MARINERG-i</b>   | Marine Renewable Energy Research Infrastructure  | distributed  |                  | 2021              | 2030*               | 8.9                  | 0.9                   |
| ENVIRONMENT                     | <b>DANUBIUS-RI</b>  | International Centre for Advanced Studies on River-Sea Systems   | distributed  | ERIC Step1       | 2016              | 2024*               | 202.5                | 23.9                  |
|                                 | <b>DiSSCo</b>       | Distributed System of Scientific Collections   | distributed  |                  | 2018              | 2025*               | 420.3                | 12.1                  |
|                                 | <b>eLTER RI</b>     | Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure | distributed  |                  | 2018              | 2026*               | 150.0                | 50.0                  |
| HEALTH & FOOD                   | <b>EIRENE RI</b>    | Research Infrastructure for EnvIRonmental Exposure assessmentNt in Europe                                  | distributed  |                  | 2021              | 2031*               | 202.0                | 42.2                  |
|                                 | <b>EMPHASIS</b>     | European Infrastructure for Multi-scale Plant Phenomics and Simulation                                     | distributed  |                  | 2016              | 2021                | 160.0                | 3.6                   |
|                                 | <b>EU-IBISBA</b>    | European Industrial Biotechnology Innovation and Synthetic Biology Accelerator                             | distributed  |                  | 2018              | 2025*               | 52.6                 | 65.1                  |
|                                 | <b>METROFOOD-RI</b> | Infrastructure for promoting Metrology in Food and Nutrition   | distributed  |                  | 2018              | 2020                | 102.4                | 31.0                  |
| PHYSICAL SCIENCES & ENGINEERING | <b>EST</b>          | European Solar Telescope   | single-sited |                  | 2016              | 2029*               | 200.0                | 12.0                  |
|                                 | <b>ET</b>           | Einstein Telescope   | single-sited |                  | 2021              | 2035*               | 1912.0               | 37.0                  |
|                                 | <b>EuPRAXIA</b>     | European Plasma Research Accelerator with Excellence in Applications                                       | distributed  |                  | 2021              | 2028*               | 569.0                | 30.0                  |
|                                 | <b>KM3NeT 2.0</b>   | KM3 Neutrino Telescope 2.0   | distributed  |                  | 2016              | 2020                | 196.0                | 3.0                   |
| SOCIAL & CULTURAL INNOVATION    | <b>E-RIHS</b>       | European Research Infrastructure for Heritage Science  | distributed  |                  | 2016              | 2025*               | 54.0                 | 5.0                   |
|                                 | <b>EHRI</b>         | European Holocaust Research Infrastructure   | distributed  |                  | 2018              | 2025*               | 15.0                 | 2.0                   |
|                                 | <b>GGP</b>          | The Generations and Gender Programme   | distributed  |                  | 2021              | 2028*               | 18.2                 | 1.1                   |
|                                 | <b>GUIDE</b>        | Growing Up in Digital Europe: EuroCohort   | distributed  |                  | 2021              | 2032*               | 580.6                | 17.8                  |
|                                 | <b>OPERAS</b>       | OPen scholarly communication in the European Research Area for Social Sciences and Humanities              | distributed  | AISBL, 2019      | 2021              | 2029*               | 15.0                 | 0.9                   |
|                                 | <b>RESILIENCE</b>   | RELigious Studies Infrastructure: tooLs, Innovation, Experts, conNections and Centres in Europe            | distributed  |                  | 2021              | 2034*               | 318.4                | 9.5                   |

| NAME                                   | FULL NAME  | TYPE         | LEGAL STATUS (Y) | ROADMAP ENTRY (Y) | OPERATION START (Y) | INVESTMENT COST (M€) | OPERATION COST (M€/Y) |
|--|--|--------------|------------------|-------------------|---------------------|----------------------|-----------------------|
| <b>PRACE</b>                           | Partnership for Advanced Computing in Europe   | distributed  | AISBL, 2010      | 2006              | 2010                | 712.8                | NA                    |
| <b>ECCSEL ERIC</b>                     | European Carbon Dioxide Capture and Storage Laboratory Infrastructure  | distributed  | ERIC, 2017       | 2008              | 2016                | 1,000.0              | 0.9                   |
| <b>EU-SOLARIS</b>                      | European Solar Research Infrastructure for Concentrated Solar Power  | distributed  | ERIC Step2       | 2010              | 2022*               | 7.0                  | 0.1                   |
| <b>JHR</b>                             | Jules Horowitz Reactor   | single-sited | JHR CA, 2007     | 2006              | 2030*               | 1,800.0              | NA                    |
| <b>ACTRIS</b>                          | Aerosol, Clouds and Trace Gases Research Infrastructure  | distributed  | ERIC Step2       | 2016              | 2025*               | 698.0                | 93.0                  |
| <b>EISCAT_3D</b>                       | Next generation European Incoherent Scatter radar system   | single-sited | EISCAT SA, 1975  | 2008              | 2023*               | 79.3                 | 4.9                   |
| <b>EMSO ERIC</b>                       | European Multidisciplinary Seafloor and water-column Observatory   | distributed  | ERIC, 2016       | 2006              | 2016                | 100.0                | 20.0                  |
| <b>EPOS ERIC</b>                       | European Plate Observing System  | distributed  | ERIC, 2018       | 2008              | 2023*               | 500.0                | 18.0                  |
| <b>EURO-ARGO ERIC</b>                  | European contribution to the international Argo Programme  | distributed  | ERIC, 2014       | 2006              | 2014                | 10.0                 | 8.0                   |
| <b>IAGOS</b>                           | In-service Aircraft for a Global Observing System  | distributed  | AISBL, 2014      | 2006              | 2014                | 9.2                  | 7.0                   |
| <b>ICOS ERIC</b>                       | Integrated Carbon Observation System   | distributed  | ERIC, 2015       | 2006              | 2016                | 116.0                | 24.2                  |
| <b>LifeWatch ERIC</b>                  | e-Infrastructure for Biodiversity and Ecosystem Research   | distributed  | ERIC, 2017       | 2006              | 2017                | 150.0                | 12.0                  |
| <b>AnaEE</b>                           | Analysis and Experimentation on Ecosystems   | distributed  | ERIC Step2       | 2010              | 2021                | 41.9                 | 11                    |
| <b>BBMRI ERIC</b>                      | Biobanking and BioMolecular Resources Research Infrastructure  | distributed  | ERIC, 2013       | 2006              | 2014                | NA                   | NA                    |
| <b>EATRIS ERIC</b>                     | European Advanced Translational Research Infrastructure in Medicine  | distributed  | ERIC, 2013       | 2006              | 2013                | 500.0                | 2.5                   |
| <b>ECRIN ERIC</b>                      | European Clinical Research Infrastructure Network  | distributed  | ERIC, 2013       | 2006              | 2014                | 5.0                  | 5.0                   |
| <b>ELIXIR</b>                          | A distributed infrastructure for life-science data   | distributed  | ELIXIR CA, 2013  | 2006              | 2014                | 47.6                 | 5.4                   |
| <b>EMBRC ERIC</b>                      | European Marine Biological Resource Centre   | distributed  | ERIC, 2018       | 2008              | 2017                | 164.4                | 11.2                  |
| <b>ERINHA</b>                          | European Research Infrastructure on Highly Pathogenic Agents   | distributed  | AISBL, 2017      | 2008              | 2018                | 5.8                  | 0.7                   |
| <b>EU-OPENSREEN ERIC</b>               | European Infrastructure of Open Screening Platforms for Chemical Biology   | distributed  | ERIC, 2018       | 2008              | 2021                | 82.3                 | 1.2                   |
| <b>Euro-Biolmaging ERIC</b>            | European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences                      | distributed  | ERIC 2019        | 2008              | 2016                | 270.0                | 1.6                   |
| <b>INFRAFRONTIER</b>                   | European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models | distributed  | GmbH, 2013       | 2006              | 2013                | 180.0                | 80.0                  |
| <b>INSTRUCT ERIC</b>                   | Integrated Structural Biology Infrastructure   | distributed  | ERIC, 2017       | 2006              | 2017                | 450.0                | 30.0                  |
| <b>MIRRI</b>                           | Microbial Resource Research Infrastructure   | distributed  | ERIC Step2       | 2010              | 2021                | NA                   | 0.7                   |
| <b>CTA</b>                             | Cherenkov Telescope Array  | single-sited | gGmbH, 2014      | 2008              | 2024*               | 400.0                | 20.0                  |
| <b>ELI ERIC</b>                        | Extreme Light Infrastructure   | single-sited | ERIC, 2021       | 2006              | 2018                | 850.0                | 80.0                  |
| <b>ELT</b>                             | Extremely Large Telescope  | single-sited | ESO#             | 2006              | 2027*               | 1,309.0              | 48.0                  |
| <b>EMFL</b>                            | European Magnetic Field Laboratory   | distributed  | AISBL, 2015      | 2008              | 2014                | 170.0                | 20.0                  |
| <b>ESRF EBS</b>                        | European Synchrotron Radiation Facility Extremely Brilliant Source   | single-sited | ESRF#            | 2016              | 2020                | 128.0                | 82.0                  |
| <b>European Spallation Source ERIC</b> | European Spallation Source   | single-sited | ERIC, 2015       | 2006              | 2026*               | 3,009.0              | 140.0                 |
| <b>European XFEL</b>                   | European X-Ray Free-Electron Laser Facility  | single-sited | European XFEL#   | 2006              | 2017                | 1,540.0              | 137.0                 |
| <b>FAIR</b>                            | Facility for Antiproton and Ion Research   | single-sited | GmbH, 2010       | 2006              | 2025*               | NA                   | NA                    |
| <b>HL-LHC</b>                          | High-Luminosity Large Hadron Collider  | single-sited | CERN#            | 2016              | 2027*               | 1,408.0              | 136.0                 |
| <b>ILL</b>                             | Institut Max von Laue - Paul Langevin  | single-sited | ILL#             | 2006              | 2012                | 188.0                | 100.0                 |
| <b>SKAO</b>                            | Square Kilometre Array Observatory   | single-sited | SKAO, 2011       | 2006              | 2027*               | 1,986.0              | 77.0                  |
| <b>SPIRAL2</b>                         | Système de Production d'Ions Radioactifs en Ligne de 2e génération   | single-sited | GANIL            | 2006              | 2019                | 307.3                | 5.2                   |
| <b>CESSDA ERIC</b>                     | Consortium of European Social Science Data Archives  | distributed  | ERIC, 2017       | 2006              | 2013                | 117.0                | 39.0                  |
| <b>CLARIN ERIC</b>                     | Common Language Resources and Technology Infrastructure  | distributed  | ERIC, 2012       | 2006              | 2012                | NA                   | 14.0                  |
| <b>DARIAH ERIC</b>                     | Digital Research Infrastructure for the Arts and Humanities  | distributed  | ERIC, 2014       | 2006              | 2019                | NA                   | 0.7                   |
| <b>ESS ERIC</b>                        | European Social Survey   | distributed  | ERIC, 2013       | 2006              | 2013                | 117.5                | 6.4                   |
| <b>SHARE ERIC</b>                      | Survey of Health, Ageing and Retirement in Europe  | distributed  | ERIC, 2011       | 2006              | 2011                | NA                   | 17.0                  |

# LESSONS LEARNT

The ESFRI Roadmap updates constitute an important strategic framework for the development of RIs of pan-European relevance and thus of the ERA as a whole. Continuous assessment and adjustment of its methodology enables ESFRI to fulfil its strategic role, especially in view of upcoming political needs, challenges facing RIs, such as Long-Term Sustainability and strengthening their impact, as well as new mandates that the Competitiveness Council entrusted with ESFRI.

Preserving and further developing ESFRI's strategic mission remains essential for full utilization of the ESFRI advisory capacity. As the portfolio of ESFRI RIs becomes richer and more comprehensive, it is important to capture evolving trends and focus on initiatives of strategic importance, with high added value and significant potential to develop unique resources and further improve services for European science and innovation.

To increase the strategic value of the Roadmap, ESFRI should consider prolonging its update cycle. This would facilitate the preparation of mature proposals based on comprehensive studies of the RI ecosystem and, thus, contribute to the Long-Term Sustainability of RIs and the most effective use of resources. A substantial effort during the next ESFRI Roadmap cycle should be made to identify the existing gaps in view of long-term scientific development and broader policy goals, as well as to identify the most effective ways to address these gaps.

At operational level, further emphasis should be put on further harmonization of the evaluation process at all evaluation stages (*ex ante*, *ad interim* as well as *ex post*). Particular attention must be paid to interdisciplinary projects that are by nature difficult to be appropriately assessed and require greater effort and engagement of a broader range of experts from different fields.

The current evaluation process was affected by the COVID-19 pandemic, not just in prolonging the submission period but also in using solely virtual platforms for evaluation meetings. In some cases, the latter was surprisingly beneficial, especially regarding the organization of the project hearings, which were very efficient and saved both time and costs. For the next Roadmap cycle, virtual platform meetings for project hearings and possibly Working Group meetings could be used again. However, using virtual platforms was not always appropriate for meetings involving intensive discussions.

The ESFRI Landscape Analysis is a key part of the Roadmap. The SWGs (including additional experts) have, with all the scientific competence and links to research communities, an increased participation in the drafting of the document. The direct exchange with the RIs is also a positive element of the drafting process and its potential could be further explored when designing the next Roadmap concept. The next LA will be decoupled from the Roadmap and its strategic role will be strengthened. It is clear that a specific and more detailed methodology based on a solid analytical framework must be developed. The process will also include interactions with main stakeholders including the main user communities.

Already the Roadmap 2016 was conceived with RI sustainability in mind: a higher level of maturity and official political support by MS/AC has been set as eligibility criterion, which

has been strengthened in the Roadmap 2018. The ten-year term limit of 'residency' for a Project on the Roadmap was introduced already in 2018 and we think that it is still valid considering that new Projects have better grounding. However, in case of projects entered in the roadmap before 2016 or for possible future projects as in case of very large RIs to be built, this limit could be very difficult to be met. ESFRI will therefore investigate those critical cases and, if necessary, will define specific guidelines when exceptions to this ten-year rule could be adopted.

## THE EVOLVING ROLE OF RIs

Pan-European RIs have become a pillar of the ERA. Both the ERA concept and the RI ecosystem vision intend to serve and interconnect research and researchers throughout Europe and globally. Investments in RIs have been seen mainly as support to research as they meet the demand of the scientific community for state-of-the-art resources, services and data. However, they are also centres of knowledge transfer to the society and the economy, as well as play an important role in training of researchers and fostering science literacy. RIs have now evolved into an interconnected and interoperable ecosystem, which goes beyond the area of the R&I domain. RIs are kernels of regional development in many domains of economy, they have significant impact on the cultural and societal environment of the region where they are built and show strong outreach to many sectoral policies and agendas.

Responding to the increased emphasis on environmental, social and economic challenges, Europe envisions stronger contributions of R&I activities to the EU's wider policy objectives. However, additional efforts to reinforce the capacity of European research are needed in order to develop



science-based solutions that can effectively lead the economic, social and environmental transitions and improve the everyday life of European citizens.

European RIs are a key element to make this happen. ESFRI presented its vision on how RIs can help meeting the challenges of the society, increase societal resilience and contribute to the new ERA in its *White Paper Making Science Happen, a new ambition for Research Infrastructures in the European Research Area*<sup>12</sup>.

## MAKING SCIENCE HAPPEN

Together and in parallel with the process to revitalize the ERA, ESFRI launched in 2018 a comprehensive reflection process on the future of RIs in the ERA. This included an internal reflection on a set of agreed topics as well as an exchange with RIs, thematic clusters and other stakeholders. This led to the publication of the ESFRI White Paper *Making Science Happen, a new ambition for Research Infrastructures in the European Research Area*<sup>12</sup> in 2020. The conception of the ESFRI White Paper, therefore, started a new way of ESFRI engagement with key stakeholders, including the scientific community at large. Thus, the White Paper represents ESFRI's contribution to a broader policy discussion on R&I in Europe and draws a new ambition for RIs, shared by governments and the scientific community.

Due to the COVID-19 outbreak, the White Paper was distributed only electronically and presented at the online conference of the Croatian Presidency *European Research Infrastructures for a smarter future*<sup>13</sup> on 15<sup>th</sup> May 2020. This event had an attendance of 600-850 participants throughout the day and hosted a broad range of stakeholders, including key policy makers at European and national level. The conference was live-streamed and the resulting videos are available in ESFRI YouTube channel<sup>14</sup>, while the official Conference Conclusions<sup>15</sup> were prepared by the Croatian Presidency.

Focusing on future orientation and perspective, ESFRI, with its White Paper, sends out important policy messages to policy actors, ESFRI RIs, and ESFRI itself. The implementation of the key messages and actions will be an important part of the ESFRI activities post-2021.

12. ESFRI White Paper: Making Science Happen, a new ambition for Research Infrastructures in the European Research Area. March, 2020  
<https://www.esfri.eu/esfri-white-paper>

13. European Research Infrastructures for a smarter future Conference, May 2020  
<https://www.esfri.eu/esfri-events/european-research-infrastructure-smarter-future-conference>

14. European Research Infrastructures for a smarter future Conference - Youtube channel, May 2020  
<https://www.youtube.com/playlist?list=PLjHsxBU5vVVRxAHrAxeJvaa25lFNApdYH>

15. European Research Infrastructures for a smarter future Conference - Conclusions, May 2020  
[https://www.esfri.eu/sites/default/files/Croatian\\_Presidency\\_Conference\\_European-Research-Infrastructures-for-a-Smarter-Future\\_Conclusions.pdf](https://www.esfri.eu/sites/default/files/Croatian_Presidency_Conference_European-Research-Infrastructures-for-a-Smarter-Future_Conclusions.pdf)

## THE RIs AND FAIR OPEN DATA

By providing services to a very broad variety of users, RIs create a shared and collaborative RI ecosystem, which has been shaping big science for decades. To facilitate this process, ESFRI fosters the definition, implementation and further development of advanced solutions for the effective provision and use of high-quality scientific data as practiced by ESFRI RIs and horizontal e-Infrastructures. A robust interdisciplinary data environment will be developed by using data analysis support services to exploit the most advanced and documented datasets.

On 20<sup>th</sup> February 2017, the Council of the EU approved ESFRI recommendation on coordination of Member States' investment strategies in e-Infrastructures recognizing ESFRI as a Strategy hub of funders<sup>16</sup>.

ESFRI RIs are unique in ensuring robust quality control on scientific data to be opened. ESFRI evaluates, selects, monitors and reviews its RIs with emphasis on their e-Infrastructure component as an element for excellent science and excellent data services to the broadest community. As a result, ESFRI RIs are the key pillars of research and at the forefront of establishing quality checks on FAIRness of data and data management plans accepted by the relevant user communities. In general, they already implemented FAIR and Reproducibility criteria for the Data and operate open access portals. Finally, they safeguard data quality in all domains of science, in monitoring their persistence and integrity and in releasing them according to the EOSC rules and standards as robust data products and services.

Therefore, thematic RIs are an indispensable and even a driving element of the EOSC data management chain. Five ESFRI science cluster projects, ENVRI-FAIR<sup>17</sup>, EOSC-Life<sup>18</sup>, ESCAPE<sup>19</sup>, PaNOSC<sup>20</sup>, and SSHOC<sup>21</sup> were launched in 2019, providing a focus for various ESFRI RIs to connect to the EOSC. The overarching goal is to advance the FAIRness of digital assets, in particular research data and related services, and to deliver an open access platform for interdisciplinary research data utilizing the EOSC. They also aim at developing links between the concerned ESFRI RIs and EOSC, creating an open, digital and collaborative space to manage and integrate diverse data and metadata.

16. Outcome of the 3519th Meeting of the Council of the European Union, 20 February 2017, Brussels.  
<https://www.consilium.europa.eu/media/22241/st0646gen17.pdf>

17. ENVRI-FAIR  
<https://envri.eu/home-envri-fair>

18. EOSC-Life  
<https://www.eosc-life.eu>

19. ESCAPE | The European Science Cluster of Astronomy  
<https://projectescape.eu>

20. The Photon and Neutron Open Science Cloud - PaNOSC  
<https://www.panosoc.eu>

21. Social Sciences & Humanities Open Cloud (SSHOC)  
<https://sshopencloud.eu>



In addition, some thematic consortia have in their remit the task to support the FAIRness of data and the establishment of links between EOSC and their users. For instance, the League of advanced European Neutron Sources (LENS)<sup>22</sup> and the League of European Accelerator-based Photon Sources (LEAPS)<sup>23</sup> aim to improve the cooperation of various communities and enhance user facilities in Europe. These diverse ESFRI RI communities lead efforts to increase reproducibility of the data and data quality management.

The ESFRI EOSC Task Force helps ESFRI tackle the EOSC issues, provide a platform for exchange of information and organise exchanges between ESFRI and EOSC on topics of mutual interest. These exchanges, taking form of three dedicated workshops in 2019<sup>24,25</sup> and 2020<sup>26</sup> pointed to the need for improving the exchange between ESFRI, RIs and EOSC stakeholders while actively and effectively engaging with EOSC governance bodies as well as highlighted the need to define a position, which reflects the unique perspective of this important sector of the research community and to develop a long-term view of ESFRI's role in engaging with the EOSC post-implementation.

They also effectively demonstrated that the RI community has been contributing to high-quality data and to an open science culture change and therefore its involvement is key for EOSC development and its strong participation in the EOSC governance is required.

## RI'S AND THE COVID-19 RESPONSE

COVID-19 represents the greatest threat to global public health and economies in the 21<sup>st</sup> century. The pandemic has been having a growing economic and social impact and highlighted global interdependence on many different levels. To achieve a new normal requires a coordinated, coherent and cohesive, effective and sustainable response. The opportunities provided by European RIs, which have the capacity to act in a coordinated manner, are crucial in battling the pandemics, as coordination is an important prerequisite for stepping up global cooperation, which is essential to tackle COVID-19 related issues.

22. League of advanced European Neutron Sources (LENS)  
<https://www.lens-initiative.org/>

23. League of European Accelerator-based Photon (LEAPS)  
<https://leaps-initiative.eu/>

24. 1<sup>st</sup> ESFRI RIs and EOSC Workshop – London, January 2019  
<https://www.esfri.eu/esfri-events/esfri-ris-eosc-liason-workshop>

25. ESFRI Workshop on the Future of Research Infrastructures in the European Research Area – La Palma, November 2019  
<https://www.esfri.eu/esfri-eoe-workshops/esfri-workshop-future-research-infrastructures-european-research-area?qt-event-0#qt-event>

26. 2<sup>nd</sup> ESFRI RIs-EOSC Workshop "Research Infrastructures shaping EOSC" goes digital, October 2020  
<https://www.esfri.eu/esfri-events/znd-esfri-ris-eosc-workshop-research-infrastructures-shaping-eosc>

ESFRI encourages European scientists and health professionals to work together to accelerate the research and development process to fight the COVID-19 pandemic as well as to shape the post-COVID-19 health recovery and lay the foundations for a more resilient landscape to achieve the goals of sustainable development. It is important to highlight that investments in adequate and comprehensive pandemic preparedness are essential in the field of health research as well as environment, energy, social-economic, and other future critical issues.

ESFRI believes that the opportunities provided by European RIs to support the science-led response to the COVID-19 outbreak are extremely important. ESFRI is helping the scientific community by aggregating information about dedicated services offered by RIs and communicating all relevant actions as broadly as possible. To this end, ESFRI has created a dedicated webpage *RIs against COVID-19 pandemic*<sup>27</sup> that lists and provides quick links to the information gathered. The many initiatives presented there illustrate the huge mobilisation and capacities of the European RIs. As an example, three medical RIs: the European Research Infrastructure for Translational Medicine (EATRIS ERIC), the European Clinical Research Infrastructure Network (ECRIN ERIC), and the European Research Infrastructure for biobanking (BBMRI ERIC) joined forces under the umbrella of the Alliance of Medical Research Infrastructures (AMRI)<sup>28</sup> to provide joint COVID-19 targeted services. Raising public awareness about the RIs working on COVID response has also been very important to promote the use of existing opportunities. Croatian Presidency Conference *European Research Infrastructures for a smarter future*<sup>13</sup> in May 2020 was the first and quick response to the current crisis and provided an opportunity to discuss the contribution of RIs in fighting the COVID-19 pandemic. ESFRI took an active part in this conference, as well as in other international events, which followed during 2020-2021, like the ICRI conference or OECD workshops. The first ESFRI Open Session held during the ESFRI Forum in March 2021 also had a particular focus on the response to the COVID-19 of selected RIs.

All these initiatives supported by ESFRI since the beginning of the pandemic feed into a larger set of coordinated R&I actions at EU level presented in the ERAVsCorona Action Plan<sup>29</sup>. The Action Plan sets out ten key measures to coordinate, share, and increase support for R&I, in line with the objectives and tools of the ERA. In particular, for RIs, funds<sup>30</sup> were added and re-oriented to support RI projects providing services and activities in response to the Coronavirus outbreak.

Two priority actions out of the ten are addressing directly RIs and are strongly supported by ESFRI.

27. RIs against COVID-19 pandemic  
[www.esfri.eu/covid-19](http://www.esfri.eu/covid-19)

28. Alliance of Medical Research Infrastructures  
<https://eatris.eu/insights/bbmri-ecrin-and-eatris-join-forces-to-offer-covid-19-fast-response-service/>

29. ERAVsCorona Action Plan, April 2020  
[https://ec.europa.eu/info/sites/default/files/covid-firsteravscorona\\_actions.pdf](https://ec.europa.eu/info/sites/default/files/covid-firsteravscorona_actions.pdf)

30. European Research Area corona platform  
<https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/covid-19>

**Access to Research Infrastructures.** The availability of the services provided by RIs and of the data they hold is vital for researchers working on the coronavirus. New services – including High-Performance Computing and Artificial Intelligence – and datasets are being brought on stream and it is important to match supply and demand across borders.

**Research data sharing platform.** This action aimed to establish a European COVID-19 Data Platform for SARS-CoV-2<sup>31</sup> and coronavirus-related information exchange, connected to the European Open Science Cloud<sup>32</sup>. It allows quick sharing of research data and results to accelerate discovery.

The COVID-19 pandemic increased the demand for access to timely, relevant, and quality data. This demand has been driven by several needs: taking informed policy actions quickly, improving communication on the current state of play, carrying out scientific analysis of a dynamic threat, understanding its social and economic impact, and enabling civil society oversight and reporting. The COVID-19 Fast Response Service procedure was established to coordinate and accelerate the access to academic facilities, services, and resources.

EMBL-EBI, which hosts the ELIXIR RI, is an example of the RI gathering and sharing data resources as they become available<sup>33</sup>. The relevant data hosted at EMBL-EBI on the Pathogen Portal are available for further research activities. This includes sequences of outbreak isolates and records relating to coronavirus biology. Furthermore, data submitted to the European Nucleotide Archive (ENA) are available as well. ELIXIR, the ESFRI RIs for life science data, provides a range of services and resources, that can be used by researchers and consortia working on SARS-CoV-2 research via ELIXIR Nodes<sup>34</sup>. ELIXIR has also initiated new community-driven initiatives (e.g. Hackathons) that help to open up and link COVID-19 data.

ESFRI Roadmap 2021 dedicates an important part of the Landscape Analysis to the role of RIs in COVID crisis, their resilience and capacities in addressing future challenges. RIs have faced severe difficulties from the COVID crisis: they had difficulties working in the traditional way and had to adapt rapidly in providing access to users. In the face of the pandemic, RIs fast-tracked access for urgent health projects and had to put many other experiments on hold. As travel restrictions and lockdowns hit, RIs had to invent new ways of carrying out essential work safely, largely introduced remote access schemes and allowed researchers to send in samples for those projects that do not require their physical presence in the infrastructure. Acknowledging that these new ways of working give

31. Covid-19 Data Portal  
<https://www.covid19dataportal.org/>

32. European COVID-19 Data Platform  
<https://www.covid19dataportal.org/the-european-covid-19-data-platform>

33. EMBL-EBI launches COVID-19 Data Portal  
<https://www.ebi.ac.uk/about/news/press-releases/embl-ebi-launches-covid-19-data-portal>

34. ELIXIR support to COVID-19 research  
<https://elixir-europe.org/services/covid-19>

the RIs and scientists more flexibility, these new methods could be extended beyond the pandemic.

# CHALLENGES AND STRATEGY FOR THE FUTURE

There is a growing need for new types of Research Infrastructures linked with specific challenges, like climate change and environmental sustainability, cutting across scientific disciplines. These RIs require multiple sites and mobile or virtual capacities. They need to be conceived and deployed not only in the EU but at a global scale that matches the scope of the targeted problems.

At the same time, RIs in traditional disciplines are becoming larger, requiring a growing number of participant countries and more significant financial resources. This is happening both within the EU and at global scale.

There are also growing expectations for Research & Innovation to effectively contribute to broader political goals. RIs are therefore increasingly expected to produce socio-economic impact beyond scientific knowledge, such as defined by the Sustainable Development Goals.

RIs, individually and collectively, therefore play an ever increasing role in the implementation of R&I priorities especially in the context of the renewed ERA. It is now important to stimulate the impact of the rising number of interconnected RIs that are forming a new RI ecosystem, which serves not only research but also leads to stronger integration of RIs into the innovation ecosystem and many other areas.

## RIs IN THE RENEWED ERA

Since its launch in 2000, the ERA is envisioned as a unified space open to the world, in which research, innovation, technology and the people carrying out these activities circulate freely. After a progress review, an ERA Roadmap 2015-2020, was agreed by the Member States, Associated Countries and European Commission, setting out several priority actions likely to have significant impact on completing the construction of ERA. National Action Plans, developed by individual MS and AC, have reinforced the European-level Roadmap. RIs have been an integral part of ERA since its conception. The work of ESFRI, which has mobilised close to € 20 billion in investments, has been recognized as one of the major achievements of ERA<sup>35</sup>.

At the time of the preparation of the report, the Competitiveness Council is defining the renewed approach to the delivery of ERA, including the new approach to its governance. This new approach is largely based on the Commission's Communication, the Competitiveness Council Conclusions<sup>36</sup> and the Commission's Proposal for a Council Recommendation on a Pact for Research & Innovation in Europe (the Pact)<sup>37</sup>. The document, proposes the course of the renewed ERA over the next decade. It is built on common EU principles and values for Research & Innovation, and proposes shared priority areas for action, to be implemented over the next decade.

<sup>35</sup> A new ERA for Research and Innovation, COM(2020) 628 final, September 2020  
<https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0628&from=EN>

<sup>36</sup> Conclusions of the Council of the European Union of 1 December 2020 on the New European Research Area. Doc. 13567/20  
<https://data.consilium.europa.eu/doc/document/ST-13567-2020-INIT/en/pdf>

<sup>37</sup> Proposal for a COUNCIL RECOMMENDATION on a Pact for Research and Innovation in Europe, COM(2021) 407 final  
[https://ec.europa.eu/info/sites/default/files/research\\_and\\_innovation/strategy\\_on\\_research\\_and\\_innovation/documents/ec\\_rtd\\_pact-for-research-and-innovation.pdf](https://ec.europa.eu/info/sites/default/files/research_and_innovation/strategy_on_research_and_innovation/documents/ec_rtd_pact-for-research-and-innovation.pdf)

ESFRI has increased evidence that effective interconnection among the RIs contributes to an integrated ecosystem that is a significant element of the renewed ERA. It allows coherence between European, national and regional priorities and RI policies, contributes, through ESFRI, to better integration of research in Europe and to better alignment of the national systems of the RIs support – national roadmaps, good practices of national road-mapping processes including financial consideration – and long-term sustainability of RIs.

An interconnected RIs ecosystem attracts frontier research and contributes to pursue excellent, curiosity-driven inter/multidisciplinary research pushing the current limits of knowledge and addressing many technological, scientific and organizational issues.

The impact of an interconnected RIs ecosystem is visible also in the field of education and human resource development. The various mobility schemes, exchange of experience activities, and training programs, including life-long learning operated by the RIs together with national administrations and the EC are increasing the attractiveness of the research and RI operators/managers career path.

Such an ecosystem creates a creative environment where science based solutions are born and contribute to EU's strategic agendas as well as being part of a broader international cooperation framework. RIs form global networks, have links to their international counterparts and play a role in science diplomacy.

Finally, a structured RIs ecosystem contributes to EU sustainable growth and competitiveness and represents an element of regional cohesion.

## ESFRI AND ITS CONTRIBUTION TO ERA

ESFRI acts as an inspiration and good practice example in terms of research policy governance at EU level. ESFRI was set-up in 2002 as an informal Forum (with the formal status of an expert group of the EC) combining a broad variety of expertise and following the original mandate of the Competitiveness Council of the European Union<sup>1</sup> of June 2001 – and reaffirmed in November 2004 and May 2007<sup>2</sup>, December 2012<sup>3</sup> and December 2015<sup>4</sup>.

ESFRI has been a part of the ERA since its conception and will be involved in the future overall ERA governance to meet the new ERA objectives. ESFRI was considered as one of the so-called ERA-related groups and engaged in the setting of broader European policy agendas<sup>38</sup>. The Chair of ESFRI is an ex-officio member of the ERAC Steering board and participated in all the ERAC plenaries. Thus,

<sup>38.</sup> ESFRI as a body responsible for the ERA priority 2b-Research infrastructures has been contributing ERA monitoring by providing ERAC the information on the progress made by the MS/AC while following the ERA National action plans to support implementation of the Council Conclusions from 30 November 2018 on the governance of the ERA (14989/18) and the Recommendations of the ERAC Opinion on the 2018 review of the ERA advisory structure (1209/18).

ESFRI as part of the ERA Governance structure and one of the ERA Related Groups is right in the middle of the process to revitalise ERA that began in 2018, entailing a fresh look at the ERA priorities and at the advisory structure required to support these priorities. ESFRI is a structure that has proven not only its advisory, but also executive capabilities and serves as a role model for parts of the future ERA governance. Clear success of the ESFRI governance approach is well documented in the past ESFRI Roadmaps, in the policy advice resulting from the co-creation process in ESFRI, and in the impact of ESFRI in inspiring the national processes. The effectiveness of the ESFRI governance model materialized in almost € 20 billion investment (around € 2 billion/year operational costs) committed by the MS, AC and the EC for funding of the 63 ESFRI RIs. Taking also into account, the national contributions to international organisations operating Research Infrastructures, such as CERN or the European Southern Observatory for example, the current national public R&D funding for pan-European Research Infrastructures reaches around € 3 billion per year.

In addition, ESFRI was also instrumental for synergies between the various national and the EU funding. ESFRI Roadmap became an ex-ante condition for the use of European Structural and Investment Funds (ESIF) for RI investments and reference to the presence in the ESFRI Roadmap is often a requirement for obtaining national or European funding.

While the Competitiveness Council currently discusses the renewed ERA governance, ESFRI expresses its continuous commitment to contribute to the advancement of ERA. It will continue enabling science and supporting the structuring of the ERA through road-mapping, while continuing to improve the roadmap process, including the landscape and gap analysis. Through the roadmaps, it will continue to pool resources towards the joint objectives, across different funds and countries, to support the ESFRI RIs selected through a competitive process. To ensure the continuous excellence of these RIs, an ambitious monitoring process will be put in place.

In the renewed ERA, ESFRI will strive to contribute to various R&I policy objectives and will support the implementation of relevant actions in the ERA policy agenda 2022-2024 in coordination with the ERA Forum and ERAC. It will focus on delivering a true open science culture across the EU, including by mainstreaming open access to scholarly publications and research data, where RIs should play a relevant role. It will support the RIs to develop their integrating role in the ERA, through enhanced cooperation with higher education and research institutions, businesses and other ERA actors, such as research partnerships. Looking beyond the R&I policies, ESFRI and the RIs will contribute to higher policy objectives across various ERA activities, contributing to the well-being of citizens and the environment. It will also support its RIs in their further integration in the global research ecosystem.

In doing so, it will develop its activities in collaboration with stakeholders. Due to its relevance to ERA, ESFRI's engagement with stakeholders, the landmark monitoring ambition, the innovation challenge and the global approach are addressed in more detail.

# STAKEHOLDER ENGAGEMENT AND COMMUNICATION

ESFRI RIs always worked based on cross-fertilisation and dialogue, which was particularly reflected in the Roadmap 2018 and further developed in important events such as the *ESFRI RIs and EOOSC Workshop* in London in January 2019<sup>24</sup>, followed by the *ESFRI Workshop on the Future of RIs in the ERA* in La Palma in November 2019<sup>25</sup>. One of the results of these consultations was that RIs face different challenges from the early stage to the Operational Phase of their lifecycle. ESFRI increasingly fosters communication among RIs by facilitating exchange of experience and dialogue on key topics identified by them.

Contributing to the twin priorities of strengthening Europe's capacities to carry out cutting-edge science and of providing the conditions in which science can help to solve the major socio-economic and environmental challenges facing the world, ESFRI initiated in 2020 a number of engagement activities, such as *Open sessions and Stakeholder meetings*. These new activities, along with the existing ones – i.e. ESFRI website, YouTube channel, Twitter notifications, impact dedicated events or contributions to EU Presidency conferences, ESFRI representation at international and European fora, taking part in policy discussions on ERA future, etc. – will further help ESFRI to implement its mission. The objective of these new ESFRI initiatives is to support the self-organisation and consolidation of RIs within the same domain and across domains, in order to better address users' needs in replying to societal challenges and to promote sharing of good practices on the different RI related agendas.

**Open Sessions.** The Open Sessions are organised twice a year. They are intended to serve both the ESFRI Delegates and the external participants, in particular the representatives of the ESFRI RIs, and to facilitate exchange of information.

As stated by the Council conclusions on the *New European Research Area*<sup>36</sup> of 1<sup>st</sup> December 2020, the renewed ERA should be based on shared responsibilities, stakeholders, and citizens' participation. To be successful, the participatory element should be applied across ERA and should therefore include ESFRI and RIs. The ESFRI White Paper *Making Science Happen, a new ambition for Research Infrastructures in the European Research Area*<sup>12</sup> already prepared the ground for a broader approach by stating "ESFRI will investigate the possibility of organising a platform for regular discussion among the different European RI stakeholders, e.g. an ESFRI Stakeholder Forum". In this way, ESFRI and RIs will position themselves at the heart of the Research & Innovation ecosystem, closely interlinked with different actors – business, research, education, policy, citizens and others.

**ESFRI Stakeholder Forum.** The ESFRI Stakeholder Forums will attract stakeholders and raise their awareness across the whole Research & Innovation ecosystem such as research organisations and higher education institutions with scientific communities which are participating in the ERA activities and which are potential users of RIs, decision and policymakers, municipalities, citizens, socio-economic actors, etc. The objective is to look beyond the traditional

RI communities. All these stakeholder engagement and communication activities are crucial not only to exchange of knowledge, experience and good practices, but also to promote a broader use of European RIs, to engage in a dialogue with stakeholders and to foster the interplay between regional (smart specialization), national and European strategies on RIs.

These are the effective tools, which will allow ESFRI to strengthen the links of the Roadmap to the R&I agenda at national and European levels and to develop international standards in strategic priority setting for RIs, supporting the development of the global RI ecosystem.

## MONITORING OF LANDMARKS

ESFRI Landmarks were introduced in the ESFRI Roadmap 2016 as reference RIs and are pillars in the ERA landscape offering not only services to academic research, but also supporting development and innovation, and they are specifically important for regional scientific and economic development. ESFRI is aware that the inclusions of Landmarks in its Roadmap often are conditional on (eligibility for) regional, national and European funding and underlines that these inclusions are a result of the robust and transparent methodology. Guaranteeing the excellence of the Landmark label, ESFRI has a responsibility for the quality of the RIs listed in the ESFRI Roadmap as Landmarks. With the adoption of the internal and external guides for the ESFRI Roadmaps 2018 and 2021<sup>8,9</sup>, ESFRI consolidated its definitions, models and methods. In follow-up of the Competitiveness Council conclusions of May 2018<sup>7</sup>, and the pilot review of four Landmarks assessing the scientific status and their implementation, ESFRI has set up an *ad hoc* Working Group on *Monitoring of Research Infrastructures Performance*<sup>39</sup>. The *ad hoc* Working Group recommended a quality standard for Key Performance Indicators (KPIs) – the *RACER-Criteria* – and a dialogue process between the RIs and the evaluating organisations to define the most appropriate KPIs that would at the same time fulfil the objectives of the assessment. It prepared a final report containing general criteria for Landmark and RI assessment, and it came with considerations for implementing an appropriate methodology in the future. This report addressed various aspects of Landmarks and developed a set of specific KPIs. The report was approved and published by ESFRI in December 2019<sup>40</sup>.

While discussing the future of ESFRI monitoring and in order to prepare and implement a fully consistent procedure for ESFRI Landmarks, ESFRI has set up another Working Group, the *Monitoring Implementation Group*, with the mandate to propose a methodol-

39. Ad hoc Working Group on Monitoring, June 2018  
<https://www.esfri.eu/working-groups/monitoring>

40. Monitoring of Research Infrastructures Performance – ESFRI ad hoc Working Group Report, December 2019  
[https://www.esfri.eu/sites/default/files/ESFRI\\_WG\\_Monitoring\\_Report.pdf](https://www.esfri.eu/sites/default/files/ESFRI_WG_Monitoring_Report.pdf)



ogy for the monitoring of Landmarks on the ESFRI Roadmap. The Working Group has prepared a report, which, taking into account the progress made by ESFRI towards developing a framework for monitoring of RI performance, identified options for implementation of Landmark monitoring at ESFRI and provided directions for further development of the ESFRI monitoring framework and for uptake of the ESFRI monitoring approach beyond the Landmarks.

For the purpose of this monitoring, the Landmarks shall use KPIs as outlined in the ESFRI Working Group Report, which may be adjusted to the specific needs of the Landmarks and thus are capable of capturing the specificities of individual infrastructures. Although the uptake of KPIs is voluntary, Landmarks who do not wish to apply KPIs matching the ESFRI standards will not be eligible for Landmark monitoring.

The Landmark monitoring will use questionnaires, hearings and the other established methods of monitoring. KPIs will complement the information for the monitoring panels.

- The monitoring shall demonstrate the high quality of each individual Landmark.
- It shall also identify possible problems and support the Landmarks to take appropriate actions.
- Each Landmark shall be monitored at regular intervals of about five years. Specific ESFRI panels for each Landmark, complemented by external experts, shall conduct the monitoring.
- A detailed report on the rationale and the procedures of Landmark monitoring with guidelines on the methodology will be available by the end of 2021.

ESFRI is going to contact the Landmarks and jointly elaborate with them a schedule for the monitoring activity. The monitoring of the first Landmarks should start in 2022. By 2024, the first round of monitoring covering a substantial part of the Landmarks listed in the Roadmap 2018 should be concluded. ESFRI will then evaluate the monitoring system and procedures.

## CONSOLIDATION OF THE EUROPEAN RI LANDSCAPE

In the last 20 years, the European RI landscape has been evolving towards a consolidated ecosystem. Amongst the activities and trends that have been promoting this development are cooperation between RIs – scientific collaborations, partnerships, associations and organizations –, growing interdependence, clustering within scientific domains, interdisciplinarity and interoperability.

We can find examples in:

- Thematic ESFRI clusters established through EU-funded projects to address common issues, exchange experience as well

as develop and share good practices related to RI development and operation, and most recently to strengthen their capacity of linking to the European Open Science Cloud<sup>17,18,19,20,21</sup>.

- The Alliance of Medical Research Infrastructures<sup>28</sup> where close collaboration of three ERICs ESFRI Landmarks – EATRIS, ECRIN and BBMRI – with highly complementary methods created significant synergies and new added value, allowing the research community to reach more complex and comprehensive goals, among others on COVID-19.
- Two initiatives of European analytical facilities, the League of Advanced European Neutron Sources<sup>22</sup> and the League of European Accelerator-based Photon Sources<sup>23</sup> are bringing together a critical mass of European analytical facilities in their respective areas to identify synergies and opportunities for closer collaboration, for example around Green Deal, Horizon Europe Missions or COVID-19, as well as develop joint positions on issues of common interest.
- The ENRIITC Consortium<sup>41</sup>, which brings together eleven actors among which the ESFRI Landmarks EMSO ERIC, EATRIS ERIC, ESRF and ESS ERIC, and CLARIN ERIC. This consortium brings together actors from industry and RIs and can have important socio-economic impacts.
- The GÉANT Association, an organization for European collaboration in research networks with 38 National Research and Education Network (NREN) partners, and the largest and most advanced R&E network in the world.
- The collaboration between CERN, SKAO, GÉANT and PRACE aiming at realizing the full potential of the coming new generation of High-Performance Computing (HPC) technology.
- The many interconnections between the different fields that are identified, and analyzed in detail, in the Landscape Analysis chapter of this Roadmap.

However, many aspects remain to be improved to further consolidate the European RI landscape. For instance, there is still a need for an interoperable data system that fully complies with the FAIR principles and is well integrated into a functioning EOSC ecosystem serving the needs of the European research communities. Significant potential remains in further enhanced collaboration among Research Infrastructures at structural and operational level, further exploring synergies between facilities. It is important to create favorable conditions for the development of joint service pipelines, shared resources and capacities, as well as strengthening data interoperability, and the use of new digital tools/technologies, among others.

<sup>41.</sup> ENRIITC Consortium  
<https://enriitc.eu/project/consortium/>

## STRENGTHENING RIs SERVICES

Integrated RI services are a key element of a functioning Research & Innovation system. Since its inception, over twenty years ago, the European Research Area has contributed to unprecedented accessibility of state-of-the-art RI services to users from across Europe. The establishment of pan-European Research Infrastructures through the ESFRI Roadmap and of targeted measures via the R&I Framework Programmes has integrated, interconnected and opened up the national RIs. Moreover, broad accessibility of these services, based on the principle of excellence-based open access, is also an important element of bridging the research gap, levelling up the opportunities for scientists from all corners of Europe.

The maturity of the RI landscape coupled with the challenge of the twin transitions and lessons learned from the pandemic illustrate that we are at the crossroads of a different paradigm. Indeed, an operational, robust ecosystem of RIs requires strengthened coordination of activities of European and national facilities, effectively complementing each other in providing services tailored to the specific needs of different types of users by design.

Therefore, building on the existing European Research Infrastructures, established through the ESFRI Roadmap and the ERIC Framework, the structuring of the European RI landscape needs to be complemented by a service-level approach to better address the evolving needs, both policy-driven and curiosity-driven. Developing system-level services means setting up a user-driven European architecture involving different types of facilities, in different locations and across disciplines, providing the capacities to tackle the most challenging scientific problems, enabling discoveries leading to science-based solutions for the most pressing societal challenges.

A rich landscape of world-leading RIs puts Europe in a favourable position to lead the green and digital transformations. COVID-19 has demonstrated the capability of European RIs to quickly react to urgent societal needs, as described in the Landscape Analysis (see PART2) of the Roadmap. Facilitating an effective, science-led response to other societal challenges will require similar measures, where targeted services of individual RIs and groups of RIs are mobilised focusing on specific objectives. The new Horizon Europe Missions<sup>42</sup> will provide further opportunity for European RIs to design, develop and deploy services responding to user needs and identified objectives within the five specific challenges – climate change, cancer, restoring oceans and waters, smart cities and healthy soil.

In order to better serve the R&I priorities in support of European policies, the joint, or complementary, development of services together with the needed technological developments by relevant Research Infrastructures requires strategic guidance. Such coordinated, targeted efforts need to be supported at European level to

create spill-overs across the RI ecosystem. This will also help to first identify and then fill in the existing gaps in RI services, both at the level of individual facilities and the European RI ecosystem overall.

The ESFRI road-mapping and monitoring process in coordination with the ERIC Framework can be instrumental in addressing the way forward for the setting up of system-level services. Accordingly, measures can be piloted through European and national programmes consistently with this process.

## THE INNOVATION CHALLENGE

World-class RIs, improving their performance by pushing the frontiers of science and technology, constitute very particular innovation ecosystems where scientists need to work hand in hand with high-tech companies that supply them with manufacturing capacity as well as state-of-the-art services and technologies. These collaborations have significant potential to incubate innovative spin-offs exploiting the applications of technologies developed for RIs in the broader economic and social context.

RIs are often associated with curiosity-driven research and the creation of new fundamental knowledge. However, there has always been close interaction with industry and SMEs. Industrial users in search for innovative solutions using innovative methods are attracted with tailor-made services or services that build on well-established analytical techniques.

The creation of new services, that include data analysis, data interpretation, and consultancy, have led to a continuous increase of industrial and SME users of RIs. It is estimated that approximately 5% of user time is devoted to industry; however, in some cases it may reach even 20%. Where the services provided by RIs target medium to high technology readiness levels, they can be assimilated to those of Technology Infrastructures<sup>43</sup>. A better linking of services provided by both Research and Technology Infrastructures is needed to increase the attractiveness and efficiency for industrial users. The aim is to provide a continuum of services along the knowledge creation and innovation chain that respond to R&I needs in technology areas relevant for the European Union, boosting innovation in the internal market.

42. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on European Missions, September 2021.  
[https://ec.europa.eu/info/sites/default/files/research\\_and\\_innovation/funding/documents/ec\\_com\\_heu\\_randi\\_missions\\_29092021.pdf](https://ec.europa.eu/info/sites/default/files/research_and_innovation/funding/documents/ec_com_heu_randi_missions_29092021.pdf)

43. Technology Infrastructures' means facilities and resources, such as test beds, pilot lines, demonstrators, testing facilities or living labs, and related services, that are used predominantly by undertakings to develop, test and upscale technology up to higher Technology Readiness Levels prior to competitive market entry; access to these infrastructures is open to users from the European Economic Area on a transparent and non-discriminatory basis.

In that respect, the Commission Communication *A New ERA for Research and Innovation*<sup>35</sup> has formulated specific key actions such as number 10, which is targeted to the support for developing an integrated ecosystem of RIs in Europe and to a European strategy and governance structure for Technology Infrastructures. Moreover, as pointed out in the EU updated Industrial Strategy<sup>44</sup>, R&I play a central role in the green and digital transition and in the recovery of our economy. Fourteen industrial ecosystems were identified which are of highest relevance for Europe. These industrial ecosystems<sup>45</sup>, as well as the industrial alliances and Horizon Europe partnerships, are the starting point to develop roadmaps and prioritise actions for Technology Infrastructures.

RIs are clearly linked to industrial ecosystems such as *Agri-Food*, *Health* and *Energy-Renewables* and to partnerships and industrial alliances such as the battery alliance or the clean hydrogen partnership. However, there is still potential to reinforce and structure these links and to strengthen the role of RIs in other areas by:

- developing more standardised techniques, a stronger modularity and interoperability across platforms, and services, using multi-messenger science;
- strengthening industrial R&I and the long-term sustainability of laboratories;
- developing new Research Infrastructure services tailored to industrial needs, in particular in areas linked to key EU policy priorities;
- reinforcing the role of industry liaison officers at RIs.

Ultimately, the challenge of European innovation also involves a better and optimized relationship between RIs, Technology Infrastructures and industrial players that would allow the EU to keep its global leadership role.

## SOCIO-ECONOMIC IMPACT OF RIs

Research Infrastructures are key enablers of scientific and technology discoveries as well as of incremental accumulation of knowledge. At the same time, they often have considerable socio-economic impact beyond science itself. Understanding these impacts, and the capacity of Research Infrastructures to achieve them, is necessary for public authorities to make informed investment decisions aligned with broader political goals.

44. Updating the 2020 New Industrial Strategy. COM(2021) 350  
<https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0350&from=EN>

45. Aerospace and Defence; Agri-Food; Construction; Cultural and Creative Industries; Digital; Electronics; Energy-Intensive Industries; Energy – Renewables; Health; Mobility – Transport – Automotive; Proximity, Social Economy and Civil Security; Retail; Textile; Tourism

Some socio-economic impact studies of Research Infrastructures, notably in physics, have been available since the 1980s. However, significant progress in identification and analysis of the different dimensions of impact that Research Infrastructures make on the broader socio-economic ecosystem in which they function has only been made in recent years. This development was linked to the changing policy context envisioning stronger contributions of Research & Innovation activities to Europe's wider policy objectives emphasizing environmental, social and economic challenges.

At the level of ESFRI, socio-economic impact has become one of important considerations in the road-mapping process that identifies European investment priorities in Research Infrastructures, as it has been formally considered as one of the evaluation criteria since ESFRI Roadmap 2016. At the same time, consideration of the socio-economic impact has also increasingly entered into discussions on funding priorities at national and regional levels.

Numerous impact studies of individual Research Infrastructures have shown significant direct and indirect benefits not only to users of these infrastructures but also more broadly to the economy and society through human capital formation, technological spillovers, boosting local employment and development, as well as supporting medical treatments or even creation of cultural goods.

Conceptualisation of socio-economic impacts is progressing rapidly, including through the development of impact pathways models, however consensus on what these impacts are and how they can be measured and described still needs to be developed. At the same time, as the methodology for monitoring of Research Infrastructure performance is developed, questions arise on the relationship between performance and impact, and the respective indicators. This requires reaching a common understanding among Research Infrastructures and their key stakeholders on how to proceed with monitoring, evaluation and impact assessments, both at European and national level.

The concepts of different impacts and impact pathways also need to be further investigated and developed, together with better understanding of what indicators are used and how. It is important to develop and share good practices on impact assessments in order to foster their alignment among Research Infrastructures, across countries and at European level.

## EUROPEAN RIs AT THE GLOBAL STAGE

Scientific research is a global endeavour that knows no political, governmental, national, or geographic boundaries. Pooling resources and sharing knowledge is an integral part of scientific development. No matter where science is produced, who funds it and who conducts it, the results benefit all of humanity and the entire planet. Science does not exist in isolation, and this is now truer than ever. Human ingenuity requires comparison, social sciences surveys are designed to be comparable with others around the world,



knowledge multiplies when all the bits and pieces are put together. As enablers of scientific work, Research Infrastructures live in this global space of science, and their impact extends largely beyond their main physical and administrative confines.

ESFRI RIs are no exception to this and play a significant role at the global stage of science. In fact, the ESFRI ecosystem of RIs is unique in the world and serves as a reference point for other regions, not only scientifically but also methodologically, demonstrating the leadership of Europe in the area. Global uniqueness characterises many individual ESFRI RIs as well, which benefit from strong inter-governmental agreements that allow them to provide unique opportunities for studying fundamental scientific problems, performing cutting-edge research, and stimulating technology developments on a global scale, thereby strengthening their sustainability.

The global range and scale of ESFRI RIs is evident on several independent dimensions of a RI's environment/universe.

**Scientific Contribution.** Several ESFRI RIs in various sectors are used in collaborative scientific efforts that are global by nature, e.g. environmental sciences, social sciences, high-energy particle physics, and others.

**Scientists/Users.** Many ESFRI RIs offer physical access or virtual access to data and services to scientists and engineers from countries outside the EU or even Europe at large, with some of them having up to 50% of their users coming from outside Europe.

**Data.** Numerous ESFRI RIs collect and offer data on a global scale, with some of them having done that for a rather long time, thereby creating opportunities for obtaining significant research outcomes.

**Location.** There are ESFRI RIs that are deployed in countries other than MS/AC, in all corners of the globe. In fact, some of them are exclusively outside the European region.

These are elaborated further below.

The European RI ecosystem is facing new challenges that require revised strategic orientations. The demands for Research Infrastructure are increasing rapidly within most research fields. Technical progress, ever more complex scientific questions, and the need to tackle global emergencies, such as pandemics or climate change, demand a reinforcement of international collaboration, where global cooperation and data sharing are essential to offer solutions. In this sense, The ESFRI White Paper *Making Science Happen*<sup>12</sup> establishes the promotion of international cooperation as one of the actions for fostering the development, increasing the operational capacity, and securing the sustainability of the entire Research Infrastructure ecosystem.

46. European Virus Archive  
<https://www.european-virus-archive.com/>

47. Global Ecosystem Research Infrastructure (GERI)  
<https://meetingorganizer.copernicus.org/EGU21/EGU21-16541.html>

48. Group of Senior Officials (GSO) on global Research Infrastructures  
<https://www.gsogri.org/>

The COVID-19 pandemic has reaffirmed the importance of international cooperation in science and the relevant role of Research Infrastructures: the European COVID-19 Data Platform, established jointly by the European Commission<sup>34,32</sup>, EMBL<sup>33</sup> and ELIXIR<sup>34</sup>, in collaboration with Member States and other partners, offers tools for variant genomic surveillance and access to viral genomes from national sequencing efforts. In addition, the European Virus Archive<sup>46</sup>, a network of facilities also funded by the EU, is supplying materials globally for the detection and molecular diagnostics of the new virus variants.

Climate change is another clear example of the need for international cooperation, as global environmental monitoring is essential: EURO-ARGO ERIC serves as the EU contribution to the global ARGO; EMSO ERIC, the deep sea observatories, is linked to international partners in the US, Canada, Australia and Japan; and ICOS ERIC, the CO<sub>2</sub> observation infrastructure, supplies data to the UN Framework Convention on Climate Change. Furthermore, the ongoing initiative for a Global Ecosystem Research Infrastructure (GERI)<sup>47</sup> brings together partners in the EU, the US, Australia, China and South Africa.

The Group of Senior Officials (GSO) on Global Research Infrastructures (GRIs) is a body within the G7<sup>48</sup> that has developed a set of criteria for defining GRIs, which allows new facilities around the world to understand access mechanisms and to join global knowledge networks (e.g. it has acknowledged GERI). In the future, the GSO should have an important role in articulating global governance models for international Research Infrastructures. The organizational structures for international RIs can range from highly structured and centralized, like CERN, to very decentralized and loose, like the LIGO Collaboration. Some of these facilities will be game changers, like CERN was over 60 years ago. For example, ITER was born with this objective and has 35 nations trying to prove the feasibility of fusion as a carbon-free source of energy.

Appropriate governance models must be developed for each case, depending on the scientific needs and the relevant stakeholders. In collaboration with scientists, policy makers must build on earlier achievements and supply mechanisms for coming together globally, as was done quite recently with UNESCO facilitating the set-up of SESAME<sup>49</sup>, the synchrotron in Jordan. The EU can contribute the experience it has acquired through the years with the ESFRI Roadmap, offering expertise and leadership in Global Research Infrastructure projects. EU cooperation with priority countries and regions can be extended by explicitly including Research Infrastructures in the relevant strategy agendas, as in the cooperation with Latin America and the Caribbean region. ESFRI and its Research Infrastructures – LifeWatch ERIC, INSTRUMENT ERIC and E-RIHS, among others – play an important role in the implementation of the EU-CELAC<sup>50</sup> strategic roadmap for science, technology

49. Synchrotron-Light for Experimental Science And Applications in the Middle East (SESAME)  
<https://www.sesame.org.jo/>

50. EU-CELAC  
[https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/europe-world/international-cooperation/latin-america-and-caribbean\\_en](https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/europe-world/international-cooperation/latin-america-and-caribbean_en)

and innovation, being examples and drivers for the implementation of its third pillar, the cooperation on research infrastructures.

The fields of Physics and Astrophysics offer classical examples of big international facilities. They require Infrastructures of a size and cost that can only be built through international cooperation. Experiments are conceived as international projects from the start, and Europe, North America, and Japan, among others, cooperate very closely to implement them. For example, laboratories, such as the European XFEL, and ongoing projects, such as FAIR, advance with substantial Russian participation. Especially the nature of astrophysics and the need for particular geographical locations has forced this field to be truly global, with very important projects being in the works, notably the Square Kilometre Array Observatory (SKAO) in Australia and South Africa, the Extremely Large Telescope (ELT) in Chile, the Cherenkov Telescope Array (CTA) in Europe and Chile.

Regarding users, a large number of ESFRI RIs using open access policies are granting access to international users with some of them having up to 40-50% of their users be non-European. A case in point are the big Particle Physics laboratories and the great observatories, which serve very integrated, truly global scientific communities and offer access to international users using different modalities and supporting them through different funding mechanisms.

Finally, Research Infrastructures are an essential tool for the international deployment of the open science paradigm. The recent Commission Communication on a *Global approach to Research and Innovation – Europe's strategy for international cooperation in a changing world*<sup>51</sup> calls for "deepened cooperation on the basis of openness, a level playing field and respect of fundamental rights and values and supporting EU's open strategic autonomy". The related Council conclusions<sup>52</sup>:

- underline the importance of international cooperation in RIs for the advancement of science, science diplomacy, tackling the global challenges and increasing access to excellence;
- recognise the need for further development and implementation of the Global Research Infrastructure framework; and
- encourage the European Strategy Forum on Research Infrastructures and the Commission to support activities of Research Infrastructures to this end.

The rollout of the renewed ERA policy agenda and of the Horizon Europe Programme will provide new opportunities for European Research Infrastructures to strengthen their international collaboration and influence the shaping of the global RI landscape.

<sup>51.</sup> Europe's global approach to cooperation in research and innovation: strategic, open, and reciprocal, 18 May 2021  
[https://ec.europa.eu/commission/presscorner/detail/en/ip\\_21\\_2465](https://ec.europa.eu/commission/presscorner/detail/en/ip_21_2465)

<sup>52.</sup> Conclusions of the Council of the European Union of 28 September 2021 on Global approach to Research and Innovation - Europe's strategy for international cooperation in a changing world Governance of the European Research Area. Doc. 12301/21  
<https://data.consilium.europa.eu/doc/document/ST-12301-2021-INIT/en/pdf>