



PART1

ROADMAP & STRATEGY REPORT

ON RESEARCH INFRASTRUCTURES

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ROADMAP & STRATEGY REPORT

The European Strategy Forum on Research Infrastructures (ESFRI) periodically updates its Roadmap as mandated by the Competitiveness Council of the European Union to provide a coherent and strategic vision ensuring that Europe has excellent Research Infrastructures (RIs) in all fields of science and innovation^{1,2,3}.

This ESFRI Roadmap 2018 is an update of the previous ESFRI Roadmap 2016, accounting for the results of the end of the ten-year cycle of those ESFRI Projects that entered in 2008 and the outcomes of the selection of new proposals. It also suggests a vision on the future evolution of ESFRI activities and methods.

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 domains. They include: major scientific equipment – or sets of instruments; knowledge-based resources like 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 and innovation.

RIs are implemented with different organisation models: *single-sited* Research Infrastructures – namely large research plants in a single or a few fully dedicated sites as astronomy and astrophysics telescopes, accelerator based sources, nuclear reactor sources, extreme laser sources; or *distributed* Research Infrastructures – e.g. networks of observatories of the earth, oceans, biodiversity; multiple operational sites in the health and food domain; surveys and longitudinal studies of the European population; collections of physical or digital information; innovation in heritage and culture; very large computational resources. In all cases, RIs offer physical access to the researchers and/or remote use (see **BOX 1**).

ESFRI selects proposals of RIs that become ESFRI Projects and have up to ten years to reach implementation, and identifies successfully implemented RIs in the class of ESFRI Landmarks (see **BOX 2**).

1. 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://data.consilium.europa.eu/doc/document/ST-10257-2014-INIT/en/pdf>

2. 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>

3. 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>

SINGLE-SITED RESEARCH INFRASTRUCTURES

Single-sited RIs are central facilities geographically localised in a single site or in a few dedicated complementary sites designed for user access, whose governance is European or international. A single-sited RI needs to: i) have a legal status and a governance structure with clear responsibilities and reporting lines, including international supervisory and relevant external advisory bodies; ii) have an access policy¹ and access point for external users facilitating the submission of proposals and a user programme absorbing a considerable fraction of the total capacity of the RI; iii) have a user support structure to optimise access to the relevant site, such as users office, ancillary laboratories, accommodation arrangements and logistics; iv) have a data management system providing metadata and data storage, retrieval tools and on-line/in situ/remote data reduction and analysis; v) identify relevant and measurable Key Performance Indicators (KPI) addressing both excellence of scientific services and sustainability; vi) enforce a human resources policy guaranteeing the necessary competences for its operation, users support, education and training by equal opportunity hiring and secondments.

DISTRIBUTED RESEARCH INFRASTRUCTURES

A distributed RI consists of a Central Hub and interlinked National Nodes. A distributed RI particularly needs to: i) have a unique specific name, legal status and a governance structure with clear responsibilities and reporting lines, including international supervisory and relevant external advisory bodies; ii) have legally binding attributions of coordination competences and resources to the Central Hub; iii) have a unique access policy¹ and provide for a single point of access for all users with a support structure dedicated to optimise the access for the proposed research; iv) have a user programme absorbing a relevant fraction of the total capacity of the RI; v) identify and adopt measurable Key Performance Indicators addressing both excellence of scientific services and sustainability; vi) have a human resources policy adequate to guarantee the effective operation of the Central Hub supporting the research, users programme, education and training by equal opportunity hiring and secondments; vii) define a joint investment strategy aimed at strengthening the RI through the Nodes and the common/shared facilities. These features mark the difference of a RI with respect to a coordinated research network (international collaborations of fully independent research performing organizations). Nodes may be absorbed partially by the distributed RI while maintaining their national or institutional programmes, but the capacity and amount of resources engaged in the RI must be coordinated and managed by the Central Hub according to agreed statutes and common rules and procedures of the legal RI consortium.

1. European Charter for Access to Research Infrastructures
https://ec.europa.eu/research/infrastructures/pdf/2016_charterforaccessto-ris.pdf

BOX 1.

Single-sited and distributed RIs

ESFRI PROJECTS

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 enter the Implementation Phase within the ten-year term. They are included in the Roadmap to point out the strategic importance they represent for the European Research Area (ERA) and to support their timely implementation as new RIs or major updates* of existing RIs. The Projects can be at different stages of their development towards implementation according to their respective date of inclusion in the Roadmap.

* A major upgrade is a transformative change of an operational RI as required to maintain leadership in science and increase research capacity, implying a substantial new investment.

ESFRI LANDMARKS

The ESFRI Landmarks are RIs that were implemented or reached an advanced Implementation Phase under the Roadmap and that represent major elements of competitiveness of the ERA. The Landmarks can be already delivering science services and granting user access, or can be in advanced stage of construction with a clear schedule for the start of the Operation Phase. The Landmarks need continuous support and advice for successful completion, operation and – if necessary – upgrade to achieve optimal management and maximum return on investment.

BOX 2.

ESFRI Projects and ESFRI Landmarks

WHAT IS NEW IN THE ESFRI ROADMAP 2018

The ESFRI Roadmap 2018 reflects the lifecycle of several ESFRI Projects that entered in 2008 and that, in most cases, reached an advanced degree of implementation moving therefore to the Landmark list and **STRENGTHENING THE ESFRI LANDMARKS PORTFOLIO** in all areas of research. The **LANDSCAPE ANALYSIS AS A KEY INGREDIENT** of ESFRI Methodology captures the most relevant Research Infrastructures that are available to European scientists. The **NEW ESFRI PROJECTS ARE FILLING GAPS** in the diverse thematic domains. The updated and complete lists of 18 ESFRI Projects and 37 ESFRI Landmarks is summarized in a table reporting the main information of each ESFRI RI.

STRENGTHENING THE LANDMARKS PORTFOLIO

The Roadmap 2018 consolidates the Landmarks list as a core element representing the ensemble of implemented Research Infrastructures that emerged from the ESFRI process. ESFRI Landmarks are delivering science and science services – or have a well-defined, forthcoming plan for starting the Operation Phase – and represent in their field the most advanced undertakings, often at global level, overall strengthening the competitiveness of European research. The eight new Landmarks reinforce the Energy, Environment, Health & Food, and Physical Sciences & Engineering domains with strategic long-term investments in research capability and capacity. The ensemble of ESFRI Landmarks is an important contribution to the European Research Area; it complements – and intersects with – the EIROforum⁴ to form a full pan-European portfolio of long-term undertakings in excellent science and innovation, thus also creating unique opportunities for further internationalization. In adopting the new Landmarks, ESFRI considered the specific merit of those projects having successfully completed their ten-year incubation.

The research needs are demanding both at disciplinary level – requiring more and more often the acquisition of diverse complementary data from different methods and instruments – and also across disciplines – as the study of complex phenomena demands to jointly analyse data obtained from Research Infrastructures belonging to different scientific domains. The ensemble of Landmarks, having developed through ESFRI unifying criteria and commons – e.g. on data analysis open-tools and FAIR data management and policy – are in a good position to support advanced interdisciplinary research therefore providing unique resources to address the frontiers of knowledge, innovation and societal needs.

4. EIROforum
<https://www.eiroforum.org>

LANDSCAPE ANALYSIS AS A KEY INGREDIENT

The updated Landscape Analysis (LA, see **PART2**) is a key ingredient to the ESFRI Methodology. It captures the most relevant Research Infrastructures that are available to European scientists and to technology developers, and allows to appreciate the unique contribution brought by the ESFRI RIs.

The Landscape Analysis is an indicative reference document and does not represent, in any way, the view and prioritisation of ESFRI, nor any national financial and political commitment.

The Landscape Analysis is organized in three Sections.

Section1 consists of six chapters – one per scientific domain – and describes the state of play of all RIs in the corresponding thematic area, their contributions to support frontier research and to provide key-data necessary to address the *Grand Challenges*. Each domain is structured in areas or subdomains of research, when appropriate, and the interfaces of the RIs belonging to the same disciplinary area are captured also by plots against relevant dimensions. The gaps, challenges and future needs are analysed for each group of thematic RIs and summarised. Research develops both within disciplinary domains and across disciplinary borders, so that the needs for competitive research imply to enable a smooth access to more and diverse RIs.

Section2 is an all-new analysis effort to render explicit the relevant connections that already exist among the ESFRI RIs, and to identify the critical needs for new links and new research practices. The results in Section2 give evidence of the implications of research generated by ESFRI RIs in each domain onto the other fields of research. There exist links and a high potential for advanced synergies among most ESFRI RIs. ESFRI can play an important strategic role in supporting interdisciplinary and multidisciplinary research and realising the conditions for an approach that is conceptually equivalent to the *multi-messenger* method established for Astronomy. The concept of *multi-messenger* research relies on exploiting diverse sources of information from different research methodologies to yield an integrated complementary ensemble of data that becomes the true insight on the phenomenon studied. Generalizing to all fields of research, we can recognize that a *multi-messenger* approach is already at work in domains like environmental sciences and life sciences, and that there is a high potential to address complex phenomena like grand societal and scientific challenges – e.g. climate change, population increase and differential ageing, food and energy sustainability – by using synergistically RIs from all fields.

Section3 is about cross-cutting aspects of the ensemble of RIs – i.e. the *transversal issues* like education and training, needs for digital infrastructure, contribution to innovation; and the *horizontal analyses* like socio-economic impact, territorial impact, pan-European and global dimensions that are carried out by all RIs. The contributions of different areas are merged to capture an aspect of the overall landscape of RIs that directly shapes European research and its societal role.

The LA is the prerequisite for the ESFRI strategy exercise, as any new Project or Landmark 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.

NEW PROJECTS FILLING GAPS

The new ESFRI Projects in the Roadmap 2018 reinforce important areas of research.

The **International Fusion Materials Irradiation Facility - DEMO Oriented NEutron Source (IFMIF-DONES)** will play a strategic role in the Energy (ENE) domain for the implementation of nuclear fusion solutions to the massive production of energy, as well as for the role of Europe as an active actor in the development of nuclear fusion technologies. The consolidation of the technical design of IFMIF-DONES will take place during the Preparation Phase as well as the potential internationalization of the project that will play an important role in the global effort for fusion technologies.

The **Distributed System of Scientific Collections (DiSSCo)** will play a strategic role in the Environment (ENV) domain aiming at unifying European natural science collections, effectively transforming the currently dispersed and fragmented access to the resources into an integrated data-driven pan-European Research Infrastructure of broad international interest.

The **Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure (eLTER)** is filling a major gap in the Environment (ENV) domain for a pan-European Infrastructure addressing long-term multi-disciplinary ecosystem studies integrating observatories that individually provide and manage time serial observations and offering physical access to sites for ecological experiments.

The **Industrial Biotechnology Innovation and Synthetic Biology Accelerator (EU-IBISBA)** will play a strategic role in the Health & Food (H&F) domain as a distributed RI supporting research on several bio-economy areas: energy (liquid biofuels), chemicals (organic acids), materials (bio-plastics) and ingredients for the food, feed, cosmetics and pharma sectors (enzymes, antioxidants, antibiotics).

The **Infrastructure for promoting Metrology in Food and Nutrition (METROFOOD-RI)** clearly fills a gap in the Health & Food (H&F) domain by proposing a distributed RI aiming at providing high quality metrology services in food and nutrition. It comprises an important cross-section of highly interdisciplinary and interconnected fields throughout the food value chain, including agro-food, sustainable development, food safety/quality/traceability/authenticity, environmental safety, and human health.

The **European Holocaust Research Infrastructure (EHRI)** will play a strategic role in the Social & Cultural Innovation (SCI) domain as it represents a unique access point to the historical documents and human resources for research on the Holocaust. The project will represent a unique asset for international research.

THE ESFRI RESEARCH INFRASTRUCTURES LIST

The following table lists the ESFRI Projects and the ESFRI Landmarks of the Roadmap 2018 – grouped in the six thematic domains – reporting on acronym, full name, type of RI, legal status, Roadmap entry year, expected Operation start year, and estimated costs. The left page identifies the Research Infrastructures that are currently in their ten-year period as ESFRI Project, while the right page lists the RIs having successfully attained the Landmark status.

The detailed description and information of each ESFRI Project and ESFRI Landmark, as well as validated data on the *political support* expressed by Governments of Member States (MS) and Associated Countries (AC), the timeline for construction/operation and estimated costs data are provided in **PART3**.



NAME	FULL NAME	TYPE	LEGAL STATUS (Y)	ROADMAP ENTRY (Y)	OPERATION START (Y)	CONSTRUCTION COSTS (M€)	OPERATION COSTS (M€/Y)
EU-SOLARIS	European Solar Research Infrastructure for Concentrated Solar Power	distributed		2010	2020*	6	0.2
IFMIF-DONES	International Fusion Materials Irradiation Facility - DEMO Oriented NEutron Source	single-sited		2018	2029*	420	50
MYRRHA	Multi-purpose hYbrid Research Reactor for High-tech Applications	single-sited		2010	2027*	1.352	74
WindScanner	European WindScanner Facility	distributed		2010	2021*	6.1	2
ACTRIS	Aerosols, Clouds and Trace gases Research Infrastructure	distributed		2016	2025*	190	50
DANUBIUS-RI	International Centre for Advanced Studies on River-Sea Systems	distributed		2016	2022*	222	28
DiSSCo	Distributed System of Scientific Collections	distributed		2018	2025*	69.4	12.1
eLTER	Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure	distributed		2018	2026*	94	35
AnaEE	Infrastructure for Analysis and Experimentation on Ecosystems	distributed	ERIC Step1, 2018	2010	2019*	1.1	0.8
EMPHASIS	European Infrastructure for Multi-scale Plant Phenomics and Simulation	distributed		2016	2021*	73	3.6
EU-IBISBA	Industrial Biotechnology Innovation and Synthetic Biology Accelerator	distributed		2018	2025*	11	65.1
ISBE	Infrastructure for System Biology Europe	distributed		2010	2019*	10	5.2
METROFOOD-RI	Infrastructure for promoting Metrology in Food and Nutrition	distributed		2018	2019*	78.8	31
MIRRI	Microbial Resource Research Infrastructure	distributed		2010	2021*	0.8	0.7
EST	European Solar Telescope	single-sited		2016	2029*	200	12
KM3NeT 2.0	KM3 Neutrino Telescope 2.0	distributed		2016	2020*	151	3
E-RIHS	European Research Infrastructure for Heritage Science	distributed		2016	2025*	20	5
EHRI	European Holocaust Research Infrastructure	distributed		2018	2022*	0.8	2

NA=Not Available

*expected

NAME	FULL NAME	TYPE	LEGAL STATUS (Y)	ROADMAP ENTRY (Y)	OPERATION START (Y)	CAPITAL VALUE (M€)	OPERATION COSTS (M€/Y)
ECCSEL ERIC	European Carbon Dioxide Capture and Storage Laboratory Infrastructure	distributed	ERIC, 2017	2008	2016	1.000	0.85
JHR	Jules Horowitz Reactor	single-sited		2006	2022*	1.800	NA
EISCAT_3D	Next generation European Incoherent Scatter radar system	single-sited	EISCAT Scientific Association, 1975	2008	2022*	123	5.1
EMSO ERIC	European Multidisciplinary Seafloor and water-column Observatory	distributed	ERIC, 2016	2006	2016	100	20
EPOS	European Plate Observing System	distributed	ERIC Step2, 2018	2008	2020*	500	18
EURO-ARGO ERIC	European contribution to the international Argo Programme	distributed	ERIC, 2014	2006	2014	10	8
IAGOS	In-service Aircraft for a Global Observing System	distributed	AISBL, 2014	2006	2014	9.2	7
ICOS ERIC	Integrated Carbon Observation System	distributed	ERIC, 2015	2006	2016	116	24.2
LifeWatch ERIC	e-Infrastructure for Biodiversity and Ecosystem Research	distributed	ERIC, 2017	2006	2017	150	12
BBMRI ERIC	Biobanking and BioMolecular Resources Research Infrastructure	distributed	ERIC, 2013	2006	2014	195	3.5
EATRIS ERIC	European Advanced Translational Research Infrastructure in Medicine	distributed	ERIC, 2013	2006	2013	500	2.5
ECRIN ERIC	European Clinical Research Infrastructure Network	distributed	ERIC, 2013	2006	2014	5	5
ELIXIR	A distributed infrastructure for life-science information	distributed	ELIXIR Consortium Agreement, 2013	2006	2014	125	95
EMBRC ERIC	European Marine Biological Resource Centre	distributed	ERIC, 2018	2008	2017	164.4	11.2
ERINHA	European Research Infrastructure on Highly Pathogenic Agents	distributed	AISBL, 2017	2008	2018	5.8	0.7
EU-OPENSREEN ERIC	European Infrastructure of Open Screening Platforms for Chemical Biology	distributed	ERIC, 2018	2008	2019*	82.3	1.2
Euro-Biolmaging	European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences	distributed	ERIC Step2, 2018	2008	2016	90	1.6
INFRAFRONTIER	European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models	distributed	GmbH, 2013	2006	2013	180	80
INSTRUCT ERIC	Integrated Structural Biology Infrastructure	distributed	ERIC, 2017	2006	2017	400	30
CTA	Cherenkov Telescope Array	single-sited	gGmbH, 2014	2008	2024*	400	20
ELI	Extreme Light Infrastructure	distributed	AISBL, 2013	2006	2018	850	80
ELT	Extremely Large Telescope	single-sited	ESO#	2006	2024*	1.120	45
EMFL	European Magnetic Field Laboratory	distributed	AISBL, 2015	2008	2014	170	20
ESRF EBS	European Synchrotron Radiation Facility Extremely Brilliant Source	single-sited	ESRF#	2016	2023*	128	82
European Spallation Source ERIC	European Spallation Source	single-sited	ERIC, 2015	2006	2025*	1.843	140
European XFEL	European X-Ray Free-Electron Laser Facility	single-sited	European XFEL#	2006	2017	1.490	118
FAIR	Facility for Antiproton and Ion Research	single-sited	GmbH, 2010	2006	2025*	NA	234
HL-LHC	High-Luminosity Large Hadron Collider	single-sited	CERN#	2016	2026*	1.408	136
ILL	Institut Max von Laue-Paul Langevin	single-sited	ILL#	2006	2020*	188	97
SKA	Square Kilometre Array	single-sited		2006	2027*	1.000	77
SPIRAL2	Système de Production d'Ions Radioactifs en Ligne de 2e génération	single-sited	GANIL	2006	2019*	281	6
CESSDA ERIC	Consortium of European Social Science Data Archives	distributed	ERIC, 2017	2006	2013	117	39
CLARIN ERIC	Common Language Resources and Technology Infrastructure	distributed	ERIC, 2012	2006	2012	NA	14
DARIAH ERIC	Digital Research Infrastructure for the Arts and Humanities	distributed	ERIC, 2014	2006	2019*	NA	0.7
ESS ERIC	European Social Survey	distributed	ERIC, 2013	2006	2013	NA	2.5
SHARE ERIC	Survey of Health, Ageing and Retirement in Europe	distributed	ERIC, 2011	2006	2011	250	18
PRACE	Partnership for Advanced Computing in Europe	distributed	AISBL, 2010	2006	2010	500	60

NA=Not Available

*expected

EIROforum member

THE EVOLVING ROLE OF RESEARCH INFRASTRUCTURES

The role of RIs is evolving as originally stand-alone undertakings are becoming more and more part of a connected ecosystem forming a unique resource for advanced research and interdisciplinary analysis of complex scientific problems.

The initiative to develop an open research data system has grown from a need within a given discipline or thematic area to an overarching project of Europe – the European Open Science Cloud (EOSC)⁵ – that will make possible a much higher level of interdisciplinarity and potentially a higher impact of solid scientific evidence into decision-making, planning and strategy at societal level. ESFRI RIs have been pioneering advanced data management and e-Infrastructure tools. Responding to specific mandates, ESFRI is developing a strategy that is based on the e-needs and advanced solutions implemented by the RIs. The RI ecosystem yields a high return on investment under conditions that finances and human resources are assured through the full lifecycle. The question of Long-Term Sustainability has been at the core of the work of ESFRI, upon a specific mandate, in close dialogue with the European Commission (EC) and national roadmapping exercises. The aspect of open innovation and knowledge exchange between economic activities and research at RIs is also a subject that required an analysis by ESFRI.

The Research Infrastructures are key investments in research in all areas as they meet both the demand of the scientific community for state-of-the-art resources for supporting excellent science, and the demand of knowledge transfer for innovation at social and economic level. The RIs are often generators of large volumes of data that have prompted technical and policy solutions to curate, document, preserve and make available these data upon request by other scientists or developers. These *vertical* e-Infrastructures represent a relevant fraction of the effort carried out by RIs both in terms of human resources, technology and finance. The RIs accordingly are generators of FAIR and Reproducible data, with an intrinsically built-in quality check of the data sets that are considered by the users' community to be worth the full effort of making them FAIR-ready and accessible through their own portals or, perhaps in the future, through the EOSC. The interface of the RIs with the horizontal e-Infrastructures via the e-needs analysis of ESFRI and the definition of *Commons*⁶ by the e-IRG, represent key elements for designing the EOSC and the European Data Infrastructure (EDI).

The **Section2** of the Landscape Analysis addresses the interfaces and complementarities of the ESFRI Projects and Landmarks that are key elements, as identified by the Strategy Working Groups (SWGs), for defining the future strategy of ESFRI. Further fostering such links will increase interoperability between excellent disciplinary research in the ERA, and thus enable multidisciplinary approaches to new research needs.

5. European Open Science Cloud – EOSC
<http://ec.europa.eu/research/openscience/index.cfm?pg=open-science-cloud>

6. e-Infrastructure Commons
<http://e-irg.eu/commons>

ESFRI RIs AND FAIR DATA

ESFRI fosters the definition, implementation and further development of advanced solutions for the effective provision and use of high-quality scientific data, with effective descriptors, ease of access, interoperability and reusability, fully implementing the FAIR principles. It also develops and promotes *Data Commons* as practised by ESFRI Research Infrastructures and *horizontal e-Infrastructures*. These efforts contribute to shaping the EOSC, including its governance model, fully reflecting the engagement and responsibility on open science that the Member States and Associated Countries strategically play through ESFRI. Data are an explicit part of the more general mandate of the EU Council of 29 May 2015 that "INVITES ESFRI to explore mechanisms for better coordination of Member States' investment strategies in e-infrastructures, covering also HPC, distributed computing, scientific data and networks"⁷. ESFRI elaborated, with the help of an *ad hoc* Working Group on e-Infrastructures, the recommendation transmitted to the EU Council (see **BOX 3**).

On 20 February 2017, the EU Council approved the ESFRI recommendation on coordination of Member States' investment strategies in e-Infrastructures recognizing ESFRI as a Strategy hub of funders⁸. ESFRI RIs, along with the many other RIs that are internationally open, are unique in assuring a robust quality control on the scientific data to be managed accordingly to the FAIR principles and on the related data services. ESFRI Landmarks and Projects are Research Infrastructures producing scientific data that are used by highly competitive and broad research communities covering most areas of research. ESFRI RIs are evaluated, selected, monitored and reviewed with much emphasis on their e-In-

7. _____
Conclusions of the Council of the European Union of 29 May 2015 on Open, data-intensive and networked research as a driver for faster and wider innovation. Doc. 9360/15
<http://data.consilium.europa.eu/doc/document/ST-9360-2015-INIT/en/pdf>

8. _____
Outcome of the 3519th Meeting of the Council of the European Union, 20 February 2017, Brussels.
<https://www.consilium.europa.eu/media/22241/sto646gen17.pdf>

ESFRI RECOMMENDATION ON COORDINATION OF MEMBER STATES' INVESTMENT STRATEGIES IN e-INFRASTRUCTURES

- ESFRI aims to contribute to an *effective and efficient approach to e-Infrastructures and services* (vertical and horizontal) for European science and its competitiveness in the global scene building on existing Research Infrastructures and electronic Infrastructures.
- ESFRI advises to establish urgently a *convergent policy of funding mechanisms* for e-Infrastructures at the various levels (institutional, regional, national, European). Such policy could include *support and financing of e-Infrastructures* for scientific users, providing incentives to researchers to generate *FAIR¹ and reproducible (+R) data*, as well as the development of enabling e-tools/e-technologies and the mainstreaming of support actions addressing e-needs of all levels of intervention.
- ESFRI suggests to act as *STRATEGY FORUM OF FUNDERS* of the e-Infrastructures for European science as a key element of support of a coherent approach to policy-making on research infrastructure in Europe.
- ESFRI could be effective in facilitating the *coordination of national and European efforts in e-Infrastructures* for research and innovation, following the model that has been put in place for Research Infrastructures. The global dimension of e-Infrastructures shall also be addressed in a coherent way.
- ESFRI advises to proceed by *building on the EOSC HLEG vision²* and by *strengthening the data FAIR+R generator role of Research Infrastructures* and the coordination of science and innovation communities also at broad international level as described by the e-IRG roadmap³.
- ESFRI advises that *urgent actions* must be taken to support the *training and hiring of e-Infrastructures experts/scientists* and to expand the *data literacy* at all levels of education and innovation activities to enable the return on investment in e-Infrastructures and Research Infrastructures and maximize societal benefits.
- ESFRI advises that *deploying strategic joint e-services*, including standardization and assisted open access, can be *most efficiently done at least at European level*.
- ESFRI recognizes that the capacity of distributed High Performance and High Throughput Computing, of communication networks for scientific data, and of transversal e-services, should be *strengthened by building on national resources* and adding an effective coordination and a possible additional funding to realize a full European-scale impact.
- ESFRI recognizes that the funding approach to *HPC Tier-Zero facilities* bears challenges similar to more centralised large-scale Research Infrastructure facilities⁴ with direct industrial policy implications and should be dealt with accordingly.

1. Findable, Accessible, Interoperable, and Re-usable
2. Realising the European Open Science Cloud Report 2016
3. e-IRG Roadmap 2016
4. ESFRI Strategy document and Roadmap 2016

BOX 3.

ESFRI recommendation on coordination of Member States' investment strategies in e-Infrastructures

infrastructure component that is considered a basis for excellent science and excellent data services to the broadest community. ESFRI RIs, in general, already implement FAIR and Reproducibility criteria of the data and operate open access portals and Data Management Plans (DMPs) in tune with their user communities. ESFRI RIs of all domains can engage in providing data quality check and in monitoring the persistence of data integrity in a way that will give to the EOSC the necessary robustness in terms of high-quality data products and services. Furthermore, ESFRI RIs can help to cover hitherto unstructured areas and contribute towards the development of European Open Science (Data) Commons. By favouring the exploitation of the most advanced and well documented data sets - metadata and data analysis support services developed by ESFRI RIs - a robust environment favouring interdisciplinarity shall be developed. RIs can contribute to make DMPs more homogeneous in each domain and to address near-neighbour domains. On this background and through extensive discussion, ESFRI formulated a position on EOSC that has been communicated to the EC in January 2018 (see **BOX 4**).

The EU Council Conclusions of 29 May 2018 on European Open Science Cloud "[...] CALLS ON the Commission to make optimal use of ongoing projects, existing expertise and knowledge available via existing initiatives, such as ESFRI, eIRG, GO FAIR and others; and [...] RECOMMENDS (EOSC) that effective coordination is established with ESFRI"⁹.

ESFRI POSITION ON EOSC

ESFRI welcomes the EOSC initiative that identifies an ambitious and very important goal with structuring impact on European science and beyond.

1. ESFRI IS A STRATEGY HUB OF FUNDERS

The ESFRI Forum has been created by the European Council to develop and support a coherent and strategy-led approach to policy-making on Research Infrastructures in Europe. It represents 28 MS and 12 AC. It acts upon mandates by the Council as STRATEGY HUB OF FUNDERS of Research Infrastructures of pan-European interest and elaborates a Roadmap of the RIs to be funded as new initiatives (ESFRI Projects) or as consolidated strategic undertakings (ESFRI Landmarks). It has received in 2015 the mandate to "explore mechanisms of better coordination of Member States' investment strategies in e-Infrastructures, covering also HPC, distributed computing, scientific data and networks". Also with respect to this specific broad mandate ESFRI acts as STRATEGY HUB OF FUNDERS for the e-Infrastructures of pan-European strategic interest.

ESFRI considers that ensuring convergence of strategies and implementation actions with EOSC is a priority.

A close and effective collaboration between EOSC and ESFRI Forum is needed and must be structured at the proper level.

ESFRI has responsibility regarding FAIR, Reproducibility and Openness of Data of the Research Infrastructures (Landmarks and Projects, inspiring also other national/international RIs) that absorbs a sizeable fraction of the whole European effort in RIs. EOSC will mobilize important resources and will federate national data systems also enabling new actors to foster the data interoperability and multi-/interdisciplinary research.

A continuous dialogue between ESFRI and EOSC at the strategy level as well as further collaboration at all levels of implementation will ensure and enhance synergies and will effectively promote convergence to advanced Commons.

2. ESFRI – AND OTHER INTERNATIONALLY OPEN – RIs ARE UNIQUE IN ASSURING A ROBUST QUALITY CONTROL ON SCIENTIFIC DATA TO BE OPENED

ESFRI Landmarks and Projects are Research Infrastructures producing scientific data that are operated by highly competitive and broad research communities covering most areas of research. ESFRI RIs are evaluated, selected, monitored and reviewed with much emphasis on their e-Infrastructure as an element for excellent science and excellent data services to the broadest community. ESFRI RIs are amongst the key pillars of research that already perform quality check on the open access data and have data management plans agreed by the users.

ESFRI RIs of all domains can engage in providing data quality check and in monitoring the persistence of data quality and integrity to release to the EOSC the necessary robustness of data products and services.

9. Conclusions of the Council of the European Union of 29 May 2018 on European Open Science Cloud (EOSC). Doc. 9291/18
https://www.era.gva.at/object/document/4013/attach/CC_EOSC_final.PDF

3. EOSC SHOULD ADOPT A SUBSIDIARITY AND PARTICIPATORY PRINCIPLE

EOSC should recognize and take full advantage from the well performing Data Management Plans (DMPs)¹ and practices developed by ESFRI RIs that already implement FAIR and Reproducibility criteria of the Data and operate open access portals. EOSC should favour the participation of the RIs to the elaboration of *Commons* to serve as key elements of the EOSC. The acronym should actually become, or be generally understood as, European Open Science (Data) Commons.

4. EOSC SHOULD FILL THE GAPS OF UNSTRUCTURED AREAS

EOSC should play a significant role in raising to the most advanced level the science domains that have unsatisfied e-needs. EOSC should transparently display which and where services already exist, and help to develop metadata standards for overall progressive alignment of different domains and their increasing integration.

5. EOSC SHOULD ENABLE HIGH LEVEL INTERDISCIPLINARITY

EOSC should contribute to develop a robust environment to promote INTERDISCIPLINARITY by favouring the exploitation of the most advanced and documented data sets by advanced metadata and data analysis support services.

6. EOSC SHOULD MAKE HIGH LEVEL INTEROPERABILITY POSSIBLE AND WORKABLE

The great goal of INTEROPERABILITY is the most EOSC specific of all. RIs can contribute to make Data Management Plans (DMPs) more homogeneous in each domain and to address near-neighbour domains, but the general picture of cross-domain interoperability needs the EOSC action at European/international level. In this respect, the role of EOSC in facilitating and improving interoperability of existing well-developed data systems – including those of RIs – and guiding development of interoperable data systems in unstructured areas is crucial and irreplaceable. The INTEROPERABILITY is a long-term goal to which the existing sectorial best practises can contribute, but should not be perturbed as far as they are the operational best existing model and system.

1. Guidelines on FAIR Data Management in Horizon 2020

http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-oa-data-mgt_en.pdf

THE LONG-TERM SUSTAINABILITY OF RIs

A robust long-term vision is essential to successfully and sustainably develop, construct and operate Research Infrastructures. ESFRI has addressed RIs sustainability since its creation, but a systemic approach was taken up in response to the Competitiveness Council request of 27 May 2016². ESFRI set up an *ad hoc* Working Group with the mandate to provide a set of recommendations that would help to strengthen the Long-Term Sustainability of RIs, and to provide ESFRI's input to the dedicated Action Plan to be prepared by the European Commission.

Long-Term Sustainability of RIs is a very complex challenge requiring an adequate framework which is embedded in a supportive policy-driven environment. RIs must be recognized as long-term strategic investments at all levels, deeply rooted in society, and indispensable both for enabling excellent research in their scientific domains, and for contributing to overall competitiveness. Sufficient time and continuous support must be given to the RIs to fully unfold, develop and maintain their potential as they are typically operational for several decades. Such support should be founded on a strong strategic vision, at national and EU levels, as it implies long term financial and human resources investments.

For RIs to remain relevant throughout the entire lifecycle, scientific excellence is the condition *sine qua non*, which becomes crucial when it comes to the long-term persistence in the Operational Phase. Building on this primary condition, the key elements for ensuring Long-Term Sustainability of Research Infrastructures – as detailed in the ESFRI Scripta Vol.2¹⁰ – are:

1. ESTABLISH AND MAINTAIN EXCELLENCE. Research excellence requires state-of-the-art instrumentation and cutting-edge methodology, high-quality staff, services and support, and leading users who bring the most challenging or significant problems. To achieve and maintain all of these factors a number of conditions must be met: strong in-house research and/or technical development; effective engagement with the user community; access mechanisms that encourage and facilitate the very best researchers to the RI. All of these activities need to be underpinned with a funding framework that provides adequate support and long-term planning ensuring reliable high-quality science services therefore establishing the RI as the supplier of choice for the users, as well as an employer of choice for competitive staff.

2. ENSURE THAT RIs HAVE THE RIGHT PEOPLE IN THE RIGHT PLACE AT THE RIGHT TIME. The most important resource for a RI is, arguably, its human capital. This includes its own staff, who play many roles – designing, building, operating, using, supporting and managing – as well as the user community who exploits it for research and innovation. Most of these roles require specialised skills and experience to be effective. Moreover, the set of skills required by a RI may change markedly during its lifecycle in particular when transiting from construction to operation. RIs also operate across disciplinary domains, requiring, for instance scientists with experi-

ence in handling large and complex data sets, or in working with engineers to design bespoke and often highly innovative equipment and services. They also need managers who understand the field in which a RI operates. Users, in academia or industry, generally need some degree of training to be able to exploit the potential of RIs for their research.

3. HARMONIZE AND INTEGRATE A VISION FOR CONVERGENT OPERATION OF RIs AND e-INFRASTRUCTURES. RIs must generate and exploit documented digital data, products and services in a sustainable way, on the long term. The rapidly increasing amounts of data of RIs – e.g. ESFRI RIs, need to be made open and easily available to researchers from different fields. To enable this, the data need to be managed, stored and preserved adopting cost-efficient e-science solutions, with appropriate quality and safety assurances, fostering access across borders. Data infrastructure therefore is a central part of the research ecosystem, which enables researchers and other stakeholders from research, education, society and business to use, re-use and exploit data for the benefit of science and society.

4. FULLY EXPLOIT THE POTENTIAL OF RIs AS INNOVATION HUBS. RIs, as enablers of high-quality research, providers of advanced services and data as well as prescribers of leading-edge technologies, have an innovation potential that needs to be fully exploited to ensure maximum return and therefore financial and societal long-term sustainability and acceptance. There are, however, many significant challenges to fulfil this potential: imperfect communication, lack of awareness of the needs of economic actors and opportunities of RIs, entry barriers for access, as well as insufficient human resources at the interface between RIs and the commercial sector. Some of these challenges can be met by creating a more efficient integrated and coordinated ecosystem for RIs and Industry in which every player in the socio-economic value chain is involved, including public authorities at local, regional, national and European level, as appropriate.

5. DEMONSTRATE THE ECONOMIC AND WIDER SOCIAL VALUE OF RIs. There is increasing pressure at all levels for RIs to demonstrate the positive contribution they make to society in general, including the impact on regional and national economies, and the benefits they offer to our citizens through the science they deliver. Both the definition and measurement of socio-economic impact present considerable challenges, not least due to the difficulty of establishing causality between the activities or research, enabled by a RI, and its impact or value to society, quite possibly with a very long time delay or induction period.

6. ESTABLISH EFFECTIVE GOVERNANCE AND SUSTAINABLE LONG-TERM FUNDING FOR RIs AT EVERY STAGE IN THEIR LIFECYCLE. Although RIs may have different needs according to their configuration and their activities, it is vital that the common elements of their governance, their funding and their management guarantee long-term sustainability. Governance models for RIs should define the roles and commitments of all the different stakeholders (International, European, Member States or Associated

10. Long-Term Sustainability of Research Infrastructures, ESFRI Scripta Vol.2, October 2017 http://www.esfri.eu/sites/default/files/u4/ESFRI_SCRIPTA_TWO_PAGES_19102017_1.pdf

Countries, Regions, Research performing organisations, Research hosting institutions etc.) with respect to a coherent and consistent funding landscape throughout the RI lifecycle.

7. FOSTER BROADER COORDINATION AT NATIONAL AND EUROPEAN LEVELS. Cutting edge science and technology are international – policies should reflect this and be coordinated at a national and European level. European countries have a richness of creative Research & Innovation (R&I) systems and cultures. These should be shared with each other through mutual learning exercises to strengthen the European region as a whole but still leave space for smart specialization strategies to strengthen the regions. Furthermore, joint investments in European Research Infrastructures need to be well coordinated and aligned in terms of priority setting and funding decisions.

Experience from several well established ESFRI Landmarks shows the significant long-term benefits of RIs to society at large. In particular, large-scale RIs, or clusters of RIs, intrinsically

shape the economy and society of the region where they are located contributing to competitiveness, but also to cohesion and integration. RIs also have a broad impact on skills and education agendas. Increasing the competences of staff, researchers and academic users, and through outreach to pupils and students, as well as the general public, they steadily improve the perception and understanding of science and technology in society. Investment in excellent RIs is an instrument for increasing regional competitiveness, and thus a key component of European cohesion policy. RIs are boosting the generation of scientific knowledge, accelerating technology development, and enhancing both technological and social innovation. The effective investment in RIs and their exploitation are among the key priorities for realising the European Research Area. Thus, sustainability of RIs is an important prerequisite for contributing to continuous economic growth at national and European levels.

THE INNOVATION-ORIENTED APPROACH

Also the innovation-oriented approach of RIs was addressed by ESFRI since the beginning and tackled by setting an *ad hoc* Working Group with the mandate to propose to the Forum the broad lines of a strategic plan in response to the Council Conclusion of 31 May 2011¹¹.

The open innovation model includes Research Infrastructures at the supply side of new knowledge and as effective testbeds of innovative technologies. The cutting-edge knowledge developed in the Research Infrastructures pave the way to new, innovative components, instruments and services, providing unique contributions complementary to application scoped research and development. For example:

- ultrafast, low-noise electronics for detectors of particles, X-rays and neutrons, are developed and then qualified for use in Research Infrastructures, yielding direct innovation in broad fields of application – e.g. medical and environmental sector, information technologies, energy, material development and manufacturing;
- RIs make available samples, images and protocols in the bio-medical sector for open innovation to flourish;
- in the broad-band communication of data and high power / high throughput computing, as well as in environmental observation and modelling, or in societal studies, the RIs provide advanced testbeds for innovation;
- in the social behaviour, ageing, multi-lingual communication, access to heritage and acceptance of environmental issues and technology changes, the RIs provide unique tools for cultural, socio-political and socio-economic innovation.

¹¹ Conclusions of the Council of the European Union of 31 May 2011 on Development of the European Research Area (ERA) through ERA related groups. Doc. 11032/11 <http://register.consilium.europa.eu/doc/srv?l=EN&f=ST%2011032%202011%20NIT>

Research Infrastructures engage with industry in many different ways including procurement, direct support with services, testing and proving technology, as well as collaborating with industry on pre-competitive research. In recent years, we observe the continuous increase in usage by industry of, in particular, analytical and life sciences RIs, yielding impact on innovation activities. A key role of Research Infrastructures in innovation is also in the training of scientists and research engineers, as well as by creating opportunities of their mobility to and from science and industry or services. In fact, the enabling technologies for the Industry 4.0 *smart factory* paradigm are at work or have been pioneered at RIs. A great impact on innovation is also expected from the openness of well documented high-quality research data supported by reliable and effective data services.

Nevertheless, the impact of Research Infrastructures on industry and society is still underexploited. First, there is a high potential of *multi-messenger* science, understood as taking information about the same complex phenomena from different sources. Research Infrastructures are a key element here, as by developing complementary and interoperable services they can produce and analyse data going across disciplines. Second, integrated Research Infrastructure campuses provide significant opportunities to establish close links with the actors in regional innovation ecosystems, such as local Research Infrastructures, incubators, technology parks, universities and businesses, as well as to be proactively integrated into local planning and smart specialisation strategies. Third, co-creation, understood as two-way seeding of scientific excellence to generate new knowledge between Research Infrastructures and industry, can also stimulate innovation-driven research on pre-competitive challenges.

The emergence and growth of hubs of science and innovation around European RIs will amplify their impact on society by attracting economic activities and generating value in the open-innovation model. This is a culture change that specifically requires:

- Industry to be aware of opportunities provided by RIs and RIs to be responsive to business-oriented needs. All stakeholders to be aware of the existing potential for cooperation and of its significant socio-economic impact.
- Raising awareness on RI opportunities and services in all directions: towards RIs themselves, to industry and to a wider audience, including policy decision makers, and the general public.
- New initiatives to be taken to increase the attractiveness of RIs for industry.
- To proactively practice the concept of "industry as a full partner" of RIs, both as a supplier and as a user. This implies promoting partnerships on joint R&D projects and cooperative programmes, e.g. the development of advanced technologies and innovation, the training and exchange programmes. RIs can offer industrial companies to be immersed in active ecosystems of innovation based on their broad range of complementary competences and skills.
- Innovation to be considered in all its aspects. RIs serve research and technology but also policy-making and society. Research data also represent significant financial assets and business opportunities. Such approach needs to be an in-built part of an organisation's business strategy and strategic vision, where conditions are created to facilitate innovative thinking and creative problem solving.

Optimal collaboration between industry, policy-makers and Research Infrastructures, can be pursued so to ensure greater impact of our research and innovation system, as a whole, on the economy and society, helping us to effectively address the challenges of the modern world. The ESFRI Scripta Vol.3, published in January 2018, reflects the updated analysis of the *ad hoc* Working Group on Innovation¹².

12. Innovation-oriented cooperation of Research Infrastructures, ESFRI Scripta Vol.3, January 2018
http://www.esfri.eu/sites/default/files/u4/ESFRI_SCRIPTA_VOL3_INNO_single_page.pdf

CHALLENGES AND STRATEGY FOR THE FUTURE

Important interconnections are being established among the RIs as reported in **Section2** of the Landscape Analysis. ESFRI identifies these clear facts.

- RIs attract and support frontier research and contribute to pursue excellence through curiosity-driven research efforts that push the current limits of knowledge in a discipline. In doing so, RIs address and solve many technological, scientific and organizational issues that create additional value and knowledge at *non primary levels in the disciplinary paradigm*.

- Excellent research is becoming more and more *multi-messenger* – i.e. based on diverse data sources oriented to study the same phenomena – which requires to enforce the coordination among infrastructures, their internationalization, and advanced, even *real-time*, data management and analysis tools.

- Research often occurs at the interfaces among RIs domains, which fact is conventionally defined *ex ante* interdisciplinarity or multidisciplinary, indicating that new knowledge is pursued beyond disciplinary methods and limits.

- High-quality research data sets are produced at RIs, which are documented by advanced-level metadata to potentially enable interoperability, i.e. the *ex post* interdisciplinary use of the data.

- Internationalization of RIs must be advanced through the development of compatible access modes to resources and data and through international strategy for Global Research Infrastructures.

An outstanding paradigmatic example of *multi-messenger* research is given by the extraordinary developments in the field of Astronomy, following the recent observations of Gravitational Waves (GW) by three large RIs (interferometers), located in Europe (VIRGO) and in the USA (the two LIGOs), that jointly enable to identify the direc-

tion of the gravitational signal source, and consequently trigger, at world scale, the fast pointing of optical and radiowave telescopes. The implementation of this method has already allowed to collect critically valuable data on the hitherto few observed GW events. CTA, a new ESFRI Landmark, is defined as one of the *magnificent seven* observatories that promise to contribute to establishing the *multi-messenger* paradigm as the new avenue unifying Astronomy and Astroparticle Physics. Notably, *multi-messenger* can become a general paradigm, being also developed in ENV and H&F RIs as it is described in the LA. We expect that it will further expand in many other fields of research.

RIs belonging to the same domain are already developing more and more efficient interfaces and are natural facilitators of the *multi-messenger* approach, enabling interdisciplinary research. The **Section2** of the Landscape Analysis gives evidence of the interconnections among the RIs contributing new knowledge in a complementary way. The RIs, while maintaining their own disciplinary-rich diversity portfolio, have a high potential to horizontally coordinate on science topics that can be addressed only by adopting multiple diverse complementary techniques.

Different research needs stimulate the RIs to develop new tools which then become available to all other research fields as well. The development of *Commons* in data format and management as represented by the European initiatives PaNdata¹³ and EUDAT¹⁴, and by the international Research Data Alliance (RDA)¹⁵, has prompted a convergence on standards at RIs that, through the users, spread also to universities and national re-

13. _____
PaNdata initiative
<http://pan-data.eu>

14. _____
EUDAT
<https://www.eudateu>

15. _____
Research Data Alliance (RDA)
<https://www.rd-alliance.org>

search laboratories. Data reduction, analysis and tools are developed or shared at RIs, outreaching a broad scientific community, overall improving communication and efficient research programmes.

At the organizational and coordination level some successful Integrating Activities of H2020 as well as bottom-up initiatives – like the League of European Accelerator-based Photon Sources (LEAPS) engaged in a proto-federation attempt – demonstrate the need to implement a higher efficiency in integrating research resources in Europe. Integrating Activities, as those supported by the EC Framework Programmes, have a high potential to optimise the investments and to exploit overall synergies of national, European and international RIs, sharing the most advanced technologies rather than duplicating efforts, expanding the offer to the users' communities, and increasing the overall return on investment, without jeopardizing the healthy scientific competition among partner RIs.

The ESFRI strategy for the future Roadmap system will be developed recognising that:

- ESFRI Projects and Landmarks, as well as other important RIs of pan-European dimension and scope, like the EIROforum and others – represented for example by the European Research Facilities (ERF)¹⁶ – are reference instruments and centres of competences in the disciplinary research, enabling the most competitive proposals and most original ideas to develop and prove their full potential;

- however, most of the compelling problems of society, the so called *Grand Challenges* like climate changes, energy needs, food resources, demography and ageing of population, peace and migratory phenomena, are of interdisciplinary nature and this is true also for the knowledge needs of civil services and industry.

16. _____
ERF AISBL
<http://www.erf-aisbl.eu>

The implication of the above points is that RIs, while often being disciplinary oriented – astroparticle physics, mouse genomics, language, ocean observation, etc. – must be capable to integrate with near-neighbouring RIs contributing to enforcing interdisciplinary research.

A further implication is that the demand for new knowledge coming from society can hardly be addressed by single RIs of disciplinary, or even multidisciplinary scope. The moderate success of all efforts made to translate new disciplinary knowledge in useful skills and hints towards economic activities shows that the current approach is not sufficient.

On the other hand, the increased capability of RIs to talk to each other at near-neighbour level – e.g. within and between H&F and ENV, ENV and ENE, ENE and PSE, PSE and DIGIT and all other combinations that also include SCI – has created the basis for the RI system as a whole to become capable to generate new knowledge when and where it is needed. A well interfaced RI system will be an important contribution to European research competitiveness by enabling research to yield responses to issues such as the *Grand Challenges* and industrial and social needs.

Part of the effort towards a more efficient *knowledge-based society* and economy is being addressed by the open data concept. The broad debate and high expectations about the EOSC demonstrated that there is a widely shared aim to make the overall information contained in (high) quality-controlled data – FAIR and Reproducible – readily accessible also to users working in different disciplinary domains with respect to the researchers who originated the data. ESFRI plays and will play a substantial reference role in supplying the EOSC with original high quality data from the RIs and to strategically orient the investments in RIs to cover the whole data cycle. EOSC will enable *ex post* multidisciplinary research and analysis of complex questions based on the available data of disciplinary origin. This is just one part of the data issue for the *knowledge-based society*.

There is a second, complementary, part of the same effort that requires to build a system capable to generate knowledge when and where it is needed to address complex, multifaceted problems (society, industry) and *Grand Challenges* (climate, food, energy).

Industrial needs are a familiar example of a complex problem: there is typically a technical aspect connected with a product or production process, but also an environmental impact aspect, an energy efficiency aspect, and a social acceptance aspect that require integrated knowledge to be produced and transferred at the proper level of complexity in order to satisfy the industrial need and generate innovation. Asking the individual RIs to generally improve their interface with industry encounters a bottleneck in the fact that disciplinary research can give very valuable, but only sector-limited answers, often not ready to be implemented by industry. On the other hand, a robust RI ecosystem, as an interconnected ensemble, could develop the capability to provide answers by generating the pieces of new knowledge in the most efficient way: employing the best tools on each relevant aspect of the complex problem. This will enable *ex ante* multidisciplinary and provide a powerful and timely instrument for the *knowledge-based society*.

One new strategic direction for ESFRI will therefore be to take into account – within the fulfilment of its mandate – the contribution of RIs towards a novel, *open-integrated research environment* capable of mobilizing the necessary disciplinary resources at the proper level, and of combining the new data to formulate answers to complex issues.

The Landscape Analysis of this Roadmap 2018 contains for the first time an analysis of the implications that research at a given ESFRI RI has on the research needs of other disciplinary areas. It is quite evident that active interdisciplinary interfaces exist – also with non-ESFRI RIs of course – and provide a baseline for more potential liaisons and combinations of the available resources. ESFRI aims at fostering the disciplinary excellence and at encouraging the ESFRI Projects and the ESFRI Landmarks to produce the necessary mix of data that are needed to formulate answers to complex demands. This development will impact the overall landscape and it is important that the dialogue between ESFRI and the national strategies and roadmaps is further strengthened, aiming at better coordination and higher efficiency within the RI ecosystem, with added scientific value and rationalized efforts.

Another challenge for RIs is their internationalisation. ESFRI is involved in this process with some Projects and Landmarks having a

broad international constituency and scope, like the astronomy and astrophysics observatories CTA, ELT, KM3NeT 2.0 and SKA. Special cases – like CERN, ITER-Broader Approach and some space science missions – involve directly many Governments as well as scientists from all over the world, but several more are taking shape – e.g. the Gravitational Wave Detectors, the Underground Laboratories, the International Mouse Phenotyping Consortium.

The globalisation of RIs is addressed by the Group of Senior Official G8+5 (GSO)¹⁷ who has identified case studies for Global Research Infrastructures (GRIs) that comply with the GSO Framework for GRIs approved in 2014 and continuously updated¹⁸ (see **BOX 5**).

GLOBAL RESEARCH INFRASTRUCTURES

Global Research Infrastructures represent those Research Infrastructures with a full international dimension to serve common needs of the world scientific community, or the advanced collaboration among existing RIs that share common needs and efforts to pursue challenging upgrades needed for top research.

The GSO Members can propose GRI candidates seeking for international partnership. ESFRI does not put forward proposals to the GSO, but GSO Members can propose ESFRI RIs as potential GRIs.

BOX 5.
Global Research Infrastructures

17. Group of Senior Official (GSO)
<https://ec.europa.eu/research/infrastructures/?pg-gso>

18. GSO Progress Report 2017
https://ec.europa.eu/research/infrastructures/pdf/gso_progress_report_2017.pdf

THE ESFRI METHODOLOGY

ESFRI engages in well-defined roadmapping processes with publicly available rules and procedures. In order to prepare the Roadmap 2018, ESFRI refined the definitions, models and methods building on those adopted for the Roadmap 2016, and that are fully detailed in the Roadmap 2018 Guide¹⁹. The main elements of the updated ESFRI Methodology are summarised in the following pages.

19. ESFRI Public Roadmap 2018 Guide
https://ec.europa.eu/research/infrastructures/pdf/esfri/esfri_roadmap/esfri_rd2018_guide_for_applicants.pdf

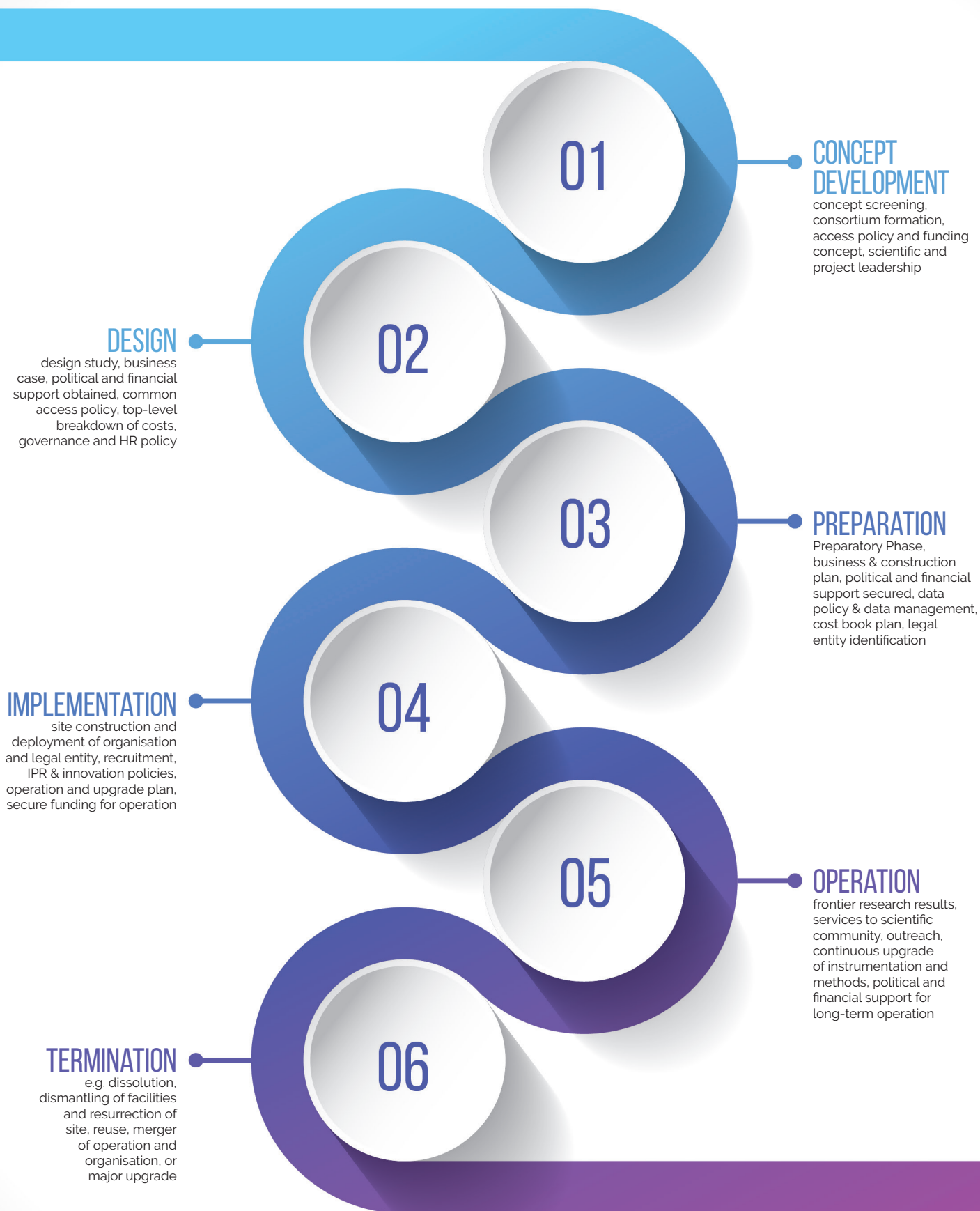


FIGURE 1.
Lifecycle approach

LIFECYCLE APPROACH

The dynamics of ESFRI Projects and ESFRI Landmarks and the needs and targets of the implementation are understood within an overall **LIFECYCLE APPROACH**, as depicted in **Figure 1**.

The **CONCEPT** of a new RI typically emerges bottom-up from the scientific communities clustering around well-identified scientific needs and goals. Such a concept can originate from completely novel approaches to answer scientific questions or to respond to the need of enhanced capacity at pan-European level as well as from new insights in existing RI – e.g. resulting in a plan for major upgrade or merger.

The **DESIGN** covers the proof of the scientific concept and technical feasibility of the RI, the analysis of the potential user community – both science and innovation oriented; the outline of a business case and the rationale for the international consortium. The feasibility study can be carried out with institutional, national or international support – e.g. Framework Programme (FP) Design Study grants. The design also includes an initial analysis of its position in the RI landscape, e-Infrastructure requirements and (open)-data management and policy. Importantly, the RI also foresees the financial and political support from governments and funding agencies necessary for the Preparatory Phase.

The **PREPARATION** – carried out at institutional, national, European or international level – is directed towards developing the RI as a fully-fledged organisation. Completion of preparation for the RIs in the Roadmap is often carried out through a Preparatory Phase contract under FP resulting in a business plan, a legal entity, an agreed role for the RI also in the context of the landscape of existing RIs at European and global level, and secured funding safeguarding the financial sustainability for the Implementation Phase and extending also for the Operation Phase. Some projects face a gap of

funding between the end of their Preparatory Phase contract and the final decisions for implementation – legal, funding and construction – which can lead to the establishment of ad hoc interim legal entities and governance to assure appropriate funding to complete the preparation and start construction.

The **IMPLEMENTATION** is different for single-sited and distributed RIs. In the first case it corresponds to an intense investment period of several years for construction engaging human and financial resources with big impact on the market – suppliers of goods and technologies. Longer-term benefits are generated to the hosting territory: employment, upgrade of services, internationalisation and up-skilling of the population, increased demand on high level services – schools, communication, financial services for international employees – and joint development of novel technologies that remain as a competitiveness legacy to the procuring firms. In case of distributed RIs, the implementation implies intense negotiations as both the Central Hub and the national nodes require specific commitments. The development of a successful governance and management structure may be of higher complexity than for single-sited RIs. Nevertheless, in several cases distributed RIs have been quite efficient at establishing their legal entities and launching services to the user community.

During their **OPERATION**, RIs produce frontier research and deliver advanced services for excellent science satisfying the users' demand, boosting brain circulation of early career scientists and trainees, therefore improving the ranking of their academic and research institutions. RIs can create spin-offs and start-ups and attract corporate partners generating a high potential for innovation. The operational costs of RIs range from 8 to 12% of the initial capital investment per year. A twenty-year operation cycle may develop

before major upgrades, requiring new substantial capital investment, are needed. The upgrade cycles in case of HPC and e-Infrastructure are typically much shorter.

The **TERMINATION** may encompass dissolution of the organisation, dismantling of facilities and related safety aspects and resurrection of the original site but it does not apply in these identical terms in all research domains. The Termination Phase could also result in a new infrastructure development as part of the evolution of the field. Re-orientation of RI sites has already occurred, e.g. in nuclear research or high-energy physics, where outdated RI have been transformed into analytical facilities with new science missions built upon the presence of technological infrastructure, logistics, human resources and organisation.

According to the lifecycle model, the ESFRI Roadmap Dynamics implies the **MONITORING OF ESFRI PROJECTS**. The ESFRI Projects that entered the Roadmap in 2008 and 2010 underwent monitoring in 2017-2018. In addition, ESFRI carried out a pilot exercise – **PILOT PERIODIC REVIEW OF ESFRI LANDMARKS** – for collecting elements to build a methodology to be applied in the future for the periodic updating of the ESFRI Landmarks' state of play.

Both processes were performed in parallel by the Strategy Working Groups (SWGs) in the Energy (ENE), Environment (ENV), Health & Food (H&F), Physical Sciences & Engineering (PSE), Social & Cultural Innovation (SCI) and Data, Computing and Digital Research Infrastructures (DIGIT) domains for the evaluation of the scientific case, and by the Implementation Group (IG) for the assessment of the maturity aspects.

The scheme of the ESFRI Roadmap Dynamics is represented in **Figure 2**.

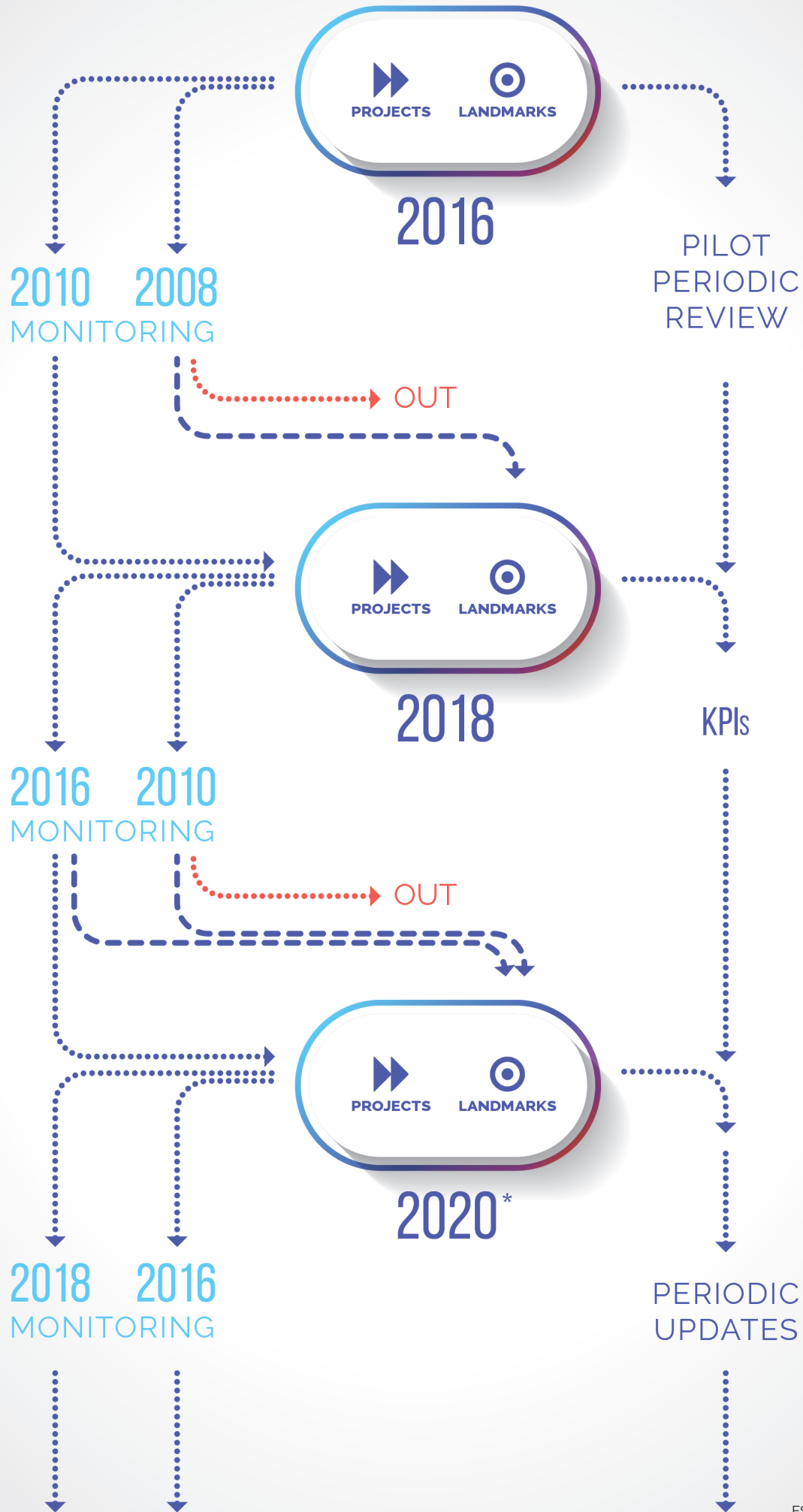


FIGURE 2.
ESFRI Roadmap Dynamics

* according to the ten-year rule the ESFRI Projects 2010 will be monitored in view of next Roadmap update that will be carried out in 2020.

MONITORING OF ESFRI PROJECTS

The specific goals of the **MONITORING OF THE ESFRI PROJECTS** is to check the overall progress towards implementation according to the fulfilment of minimal key requirements as defined in the ESFRI Roadmap Guide. The monitoring process leads to conclusions, advices to the Projects and recommendations to the Forum, including the possible promotion of Projects to the status of Landmark. The ten-year rule introduced with the Roadmap 2016 stipulates that Projects have ten years of residency on the Roadmap to reach implementation: those that do not meet this goal are removed from the Roadmap, albeit they can decide to re-apply in full competition with all new proposals. Projects that successfully reach the Implementation Phase can be further considered for the Landmark status.

The **MONITORING OF SIX ESFRI PROJECTS 2010** – EU-SOLARIS, MYRRHA, WindScanner (ENE); AnaEE, ISBE, MIR-RI (H&F) – was carried out with questionnaires addressing generic and specific aspects of the scientific case and progress towards implementation. The outcomes were presented to the Forum which took note of most common bottlenecks concerning legal and financial issues encountered by the projects.


The **MONITORING OF NINE ESFRI PROJECTS 2008** – ECCSEL ERIC (ENE); EISCAT_3D, EPOS, SIOS (ENV); EMBRC ERIC, ERINHA, EU-OPENSREEN ERIC, Euro-Biolmaging (H&F); CTA (PSE) – was meant to verify the achievement of the Implementation Phase as expected by the end of their ten years in the Roadmap. Specific questionnaires were addressed to each of the nine ESFRI Projects 2008, followed by invitation to formal hearing sessions. The SWG and IG Chairs harmonised the results of the monitoring, and the Executive Board (EB) formulated the recommendation to the Forum to award the status of ESFRI Landmark to eight of the 2008 Projects. One project – SIOS – did not reach the pan-European dimension that is required to be an ESFRI Landmark. SIOS is described in the Landscape Analysis but it is not listed anymore as ESFRI RI.

PILOT PERIODIC REVIEW OF ESFRI LANDMARKS

The **PILOT PERIODIC REVIEW OF ESFRI LANDMARKS** has been carried out to develop and test a methodology for the periodic update of the state of play of the ESFRI Landmarks. Four Landmarks volunteered to be part of the pilot exercise, upon invitation. They were: ELIXIR (H&F), as a distributed RI example dealing with high data-intensiveness and e-needs; SPIRAL2 (PSE), as a single site RI with special implementation conditions; the ESS ERIC (SCI), as a distributed RI with issues connected to the management of social sciences data and e-needs; ICOS ERIC (ENV) as a RI with global outreach. The lessons learnt from the pilot exercise were presented to the EB and to the Forum. The inputs to the future methodology are sketched below.

LANDSCAPE ANALYSIS

With the Roadmap 2016, ESFRI performed a broad **LANDSCAPE ANALYSIS** of the Research Infrastructures accessible to European scientists and industry to structure an overview of the European RI ecosystem in all fields of research. This includes national, regional and international facilities, as well as consortia that offer integrated services and transnational access to state-of-the-art resources for research.

 **The Landscape Analysis is an indicative reference document and does not represent, in any way, the view and prioritisation of ESFRI, nor any national financial and political commitment.**

The goals of the Landscape Analysis are to:

- provide a survey on major transnational RIs offering open access to researchers, students, teachers, support staff, education and research institutions, business, industries and public services in all domains;
- keep track of the developments and trends from thematic roadmaps and strategy papers;
- understand the complementarity and effectiveness of interfaces between RI, also across areas;
- provide an overview of the European RI ecosystem enabling ESFRI to fulfil its strategic and incubator roles;
- enable ESFRI to identify gaps in the European RI landscape and promote inter- and cross- disciplinary aspects;
- update evidence on the overall value and sustainability issues of the operational RIs.

In 2018, the SWGs updated the Landscape Analysis in the ENE, ENV, H&F, PSE, SCI scientific domains and the e-IRG updated the analysis on Data, Computing and Digital Research Infrastructures, with contributions from the DIGIT SWG. The thorough knowledge of the RIs Landscape and of its dynamics is a prerequisite for developing optimal strategies in the field of RIs aimed at strengthening the competitiveness and value – excellence and impact – of European research. The Landscape Analysis is a key ingredient of the ESFRI Methodology.

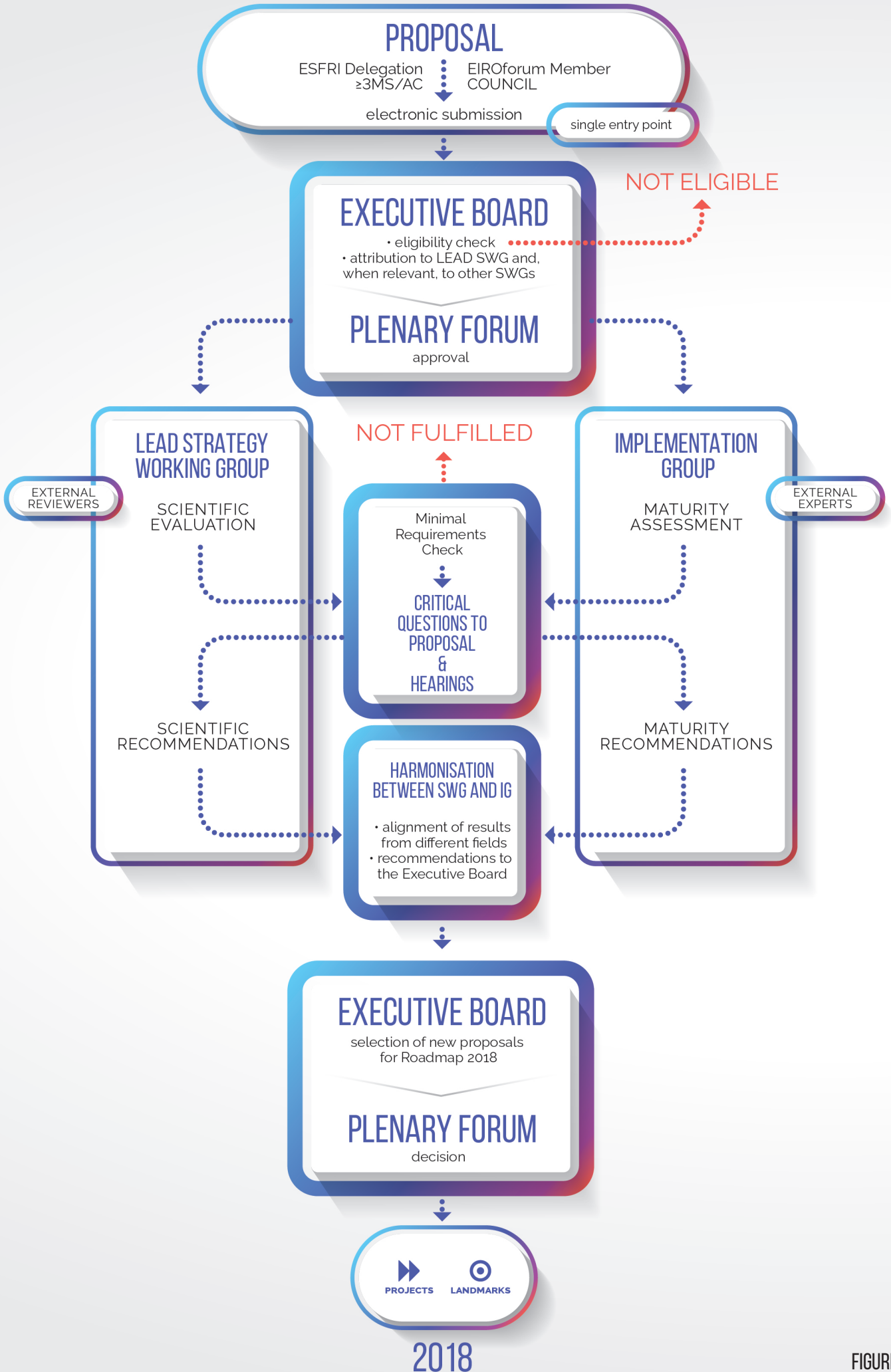


FIGURE 3. ESFRI Methodology for the selection of new proposals

EVALUATION AND ASSESSMENT OF NEW PROPOSALS

The selection of new proposals was carried out according to the well established procedure introduced for the Roadmap 2016, whose flow-chart is given in **Figure 3**.

Member States, Associated Countries and EIROforum members were eligible to submit proposals for the ESFRI Roadmap 2018. Since Roadmap 2016, in order to identify a limited number of projects with a high degree of maturity to ensure maximum likelihood to reach implementation within the ten-year deadline, ESFRI introduced important eligibility conditions: the expression of funding commitment by the lead Member State or Associated Country or a resolution of the Council for EIROforum organisations; the proof of political support by at least two additional MS/AC or EIROforum organisations; and the inter-institutional and multi-lateral agreement signed by the core partners formally involved in the consortium. These requirements strengthened both links with the Governments involved and the research communities, encouraged a closer dialogue among them and support from the very beginning of the RI project resulting in increased likelihood of successful implementation.

The deadline for online submission of new proposals expired on 31 August 2017. In September, the EB checked each proposal for eligibility and proposed attribution to the leading SWG. Proposals carrying a prominent impact across multiple domains were attributed also to a second SWG. In addition, as projects with dominant, or substantial, digital Research Infrastructure character were submitted, ESFRI decided to establish a new Strategy Working Group on Data, Computing and Digital Research Infrastructures – the DIGIT SWG.

The twelve submitted proposals were all eligible and underwent the two parallel and independent evaluation processes run by SWGs and IG, also involving independent external experts. Based on their analysis, the SWGs and IG identified several critical questions about each proposal, and then liaised to achieve a common list of issues. In one case the conclusions were that the proposal did not meet the minimal requirements to be considered as potential candidate for the Roadmap 2018. Eleven proposals were invited to dedicated hearing sessions during which the Coordinators addressed and discussed the issues. After the hearings, the SWGs and IG reached their conclusions and drafted a joint evaluation report for each project.

The harmonisation of the results on scientific excellence and maturity required three dedicated meetings of WG Chairs and EB. According to the ESFRI Roadmap Guide 2018, a threshold score High on both scientific excellence and maturity is needed for considering inclusion in the Roadmap 2018. Nine proposals were harmonized: four passed the criteria for inclusion and five did not meet the minimal requirements. Two projects could not be harmonised as the concerned SWGs and the IG could not reach a conclusive common position on the fate of the proposals. Based on these inputs the EB assessed the strategic value of the four proposals evaluated for inclusion, considering their role in filling gaps and overall reinforcing the Roadmap. The EB also discussed the two non-harmonised

proposals, as both met the scientific excellence criterion and bear a high strategic potential value for a timely inclusion in the Roadmap. This led to the recommendation of the six new entries in the ESFRI Projects list that was adopted on 28 June 2018 during the 65th ESFRI Forum Meeting in Corfu.

Ample discussion in the Forum also led to identifying the *high strategic potential areas of research in the field of Social & Cultural Innovation*: the area of *religious studies* and that of *digital services for open science*, as described in a dedicated page in the Landscape Analysis.

NEXT DEVELOPMENTS

The ESFRI Methodology is continuously adapted to better serve the scope of the Roadmap, as well as to integrate the new mandates that ESFRI receives from the EU Council. In particular, the forthcoming refinements that will be discussed by the Forum will take into account the EU Council Conclusions of 29 May 2018 on Accelerating knowledge circulation in the EU³ that "Stresses the importance of human resources and training skills as key factors in the success for Research Infrastructures and ACKNOWLEDGES the need for Research Infrastructures to strengthen a service-driven approach; INVITES Member States and the Commission within the framework of ESFRI to develop a common approach for monitoring of their performance and INVITES the Pan-European Research Infrastructures, on a voluntary basis, to include it in their governance and explore options to support this through the use of Key Performance Indicators". These recommendations inspire the formulation of **PERIODIC UPDATES OF LANDMARKS**, and the work **TOWARDS A FEW GENERIC KEY PERFORMANCE INDICATORS**.

The concept of ESFRI Landmarks implies periodic updating of their state of play throughout all the lifecycle phases. 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. ESFRI will be responsive to the possible requests for guidance indicated by the Research Infrastructures, and will take note of all the internal and external evaluations performed by their stakeholders and users communities, in order to be effectively updated on the state of play of the Landmarks.

The goal of future *periodic reviews of ESFRI Landmarks* – henceforth referred to as *Periodic Updates of ESFRI Landmarks* – is to understand the scientific status of each Landmark, considering its specific position in its lifecycle, and enabling ESFRI to fully deploy its strategic role and support the Landmarks. Moreover, periodic updates on ESFRI Landmarks will facilitate meaningful interaction between ESFRI and its Delegations to address the gaps and areas of strategic importance highlighted in the Landscape analyses.

The periodic update of ESFRI Landmarks differs fundamentally from the evaluation and assessment of proposals and from the monitoring of Projects along the following lines.

- It is independent from the ESFRI Roadmap updates and each Landmark is addressed for update periodically, taking into account the specific context of each RI.
- The periodic updates primarily take stock of external and internal evaluations provided by the Landmarks themselves and carried out by their internal bodies, funders and stakeholders. Importantly, the periodic review is directed towards providing a basis for dialogue between ESFRI, Landmarks and other stakeholders, taking into account also national roadmap processes.
- ESFRI will identify a combination of generic KPIs and specific KPIs – suggested by the RI itself – for updating the state of play of the Landmarks. It is important that each KPI is set against certain targets or metrics in terms of self-assessment and quality assurance.
- The updates of the Landmarks are meant to establish a lasting dialogue between ESFRI and the ESFRI Landmarks – and their research communities – and with the involved countries.
- A non-bureaucratic, evidence based, periodic update of Landmarks will reinforce the strategic role and position of ESFRI in supporting these RIs when referring to the EU Council, as well as in allowing for the maintenance of the Landmarks' list.

TOWARDS A FEW GENERIC KEY PERFORMANCE INDICATORS

To help address the unique aspects of each RI, Landmarks will develop specific KPIs and report on the few generic ones chosen by ESFRI, therefore updating their profile and capturing their own peculiarities. Avoiding *one-size-fits-all* shortcomings, indicative elements for developing flexible KPIs include:

- scientific excellence outcomes, output and delivery of talent;
- reference role in the disciplinary field (uniqueness in capabilities, in capacity) at European and international level;
- progress in achieving the RI's milestones along its lifecycle;
- impact, innovation, entrepreneurship;
- establishment and development of the RIs' user community;
- scientific data management policy, metadata catalogue interfacing EOSC and similar open science initiatives, advanced data services for scientific analysis and for innovation developments;
- enforcement of quality control of access (peer review), data (FAIR and reproducible), and services to research and innovation.

Another important development will concern the **ADVANCED COSTS ANALYSIS** of the RIs through their lifecycle.

The ESFRI Roadmap quotes indicative costs of the Projects and, since 2016 of the Landmarks, under the categories of Capital Value, Construction Cost, Operational Cost, Termination Cost as they are described in the guidelines and obtained from the Coordinators of the Research Infrastructures. These cost values are indicative, but overall turn out to be not accurate as they are interpreted differently by different types of RIs, or quoted inconsistently through the years. As a consequence, ESFRI has taken the initiative to start a study and discussion to improve the economic information on RIs and to facilitate both the RIs to produce reliable data and the users of the Roadmap to retrieve consistent information.

LESSONS LEARNT

The ESFRI process with its Roadmap updates constitutes an important strategic framework for the development of Research Infrastructures of pan-European relevance and thus for the European Research Area as a whole. The continuous assessment and adjustment of its methodology enables ESFRI to fulfil its strategic role, especially in view of upcoming political needs and challenges such as the Long-Term Sustainability of Research Infrastructures as well as the new mandates ESFRI was entrusted with by the Competitiveness Council. In order to preserve and further develop the strengths ESFRI has built up over time, a constant focus on ESFRI's strategic mission is essential. As the landscape of ESFRI Research Infrastructures becomes richer and more comprehensive, it is important to focus on initiatives of strategic importance, with high added-value and significant potential to develop unique resources and services for European research and innovation.

ESFRI's experience shows that the primary element for success and effective implementation is sustained scientific excellence and impact. Particular attention needs to be paid from the beginning to the maturity of projects. Evidence gained in the course of the ESFRI process clearly demonstrates that a strong scientific case together with stakeholder commitments and professional project planning secure RI implementation at a steady pace. Conversely, weaknesses in any of these key aspects have proven to hamper the RI implementation over time, incrementing the risks. Clear feedback on gaps and weaknesses observed by ESFRI at an early stage can substantially support the projects in overcoming such difficulties.

Stakeholder commitments are mostly based on proposals which have been developed over years. For the Roadmap 2016, ESFRI for the first time asked for reliable commitments – e. g. regarding financial support – from at least one Member State or Associated Country. This approach was extended for the Roadmap 2018, requiring proposals not only to prove political or financial support from MS/AC, but also to provide consortium agreements signed by the participating institutions. All commitments had to be submitted right from the beginning as an eligibility criterion. These requirements have proven important ele-

ments of ESFRI's methodology, representing a focus on the robustness of financial planning which should be further strengthened.

Another challenge identified in the discussion on Long-Term Sustainability of Research Infrastructures is to find ways to improve the alignment of ESFRI and national roadmap processes while bearing in mind their different goals and scopes. To achieve this objective, a common understanding of key evaluation criteria based on improved communication and exchange of experience would be of great advantage. This would help to build efficiently upon already existing quality assurance mechanisms established by the Research Infrastructures and their funders avoiding duplication of evaluation activities whilst enabling an effective update of the state of play of the RIs through their lifecycle. In view of the considerable amount of time required to reach stakeholder commitments and agreements between different institutions or MS/AC, ESFRI could consider Roadmap updates longer than the current two-year pace. This would facilitate the preparation of mature proposals and thus contribute to the Long-Term Sustainability of Research Infrastructure development.

The creation of the European Research Infrastructure Consortium (ERIC) as a legal entity model for European Research Infrastructures has helped to develop solid RI-governance in many cases, but has proven to be a bottleneck for the progress of initiatives in some others, making evident the need of flexibility.

With the new EU Council mandate of 29 May 2018³ that invites Member States and the Commission within the framework of ESFRI to develop a common approach for monitoring the RIs' performance, ESFRI is facing a challenging task. ESFRI's role and tasks in this context need to be defined in detail, taking into account the fact that ESFRI is an informal strategy forum and that ESFRI Research Infrastructures are funded by MS/AC in variable geometry. Providing for comprehensive evaluations should thus be the task of the funding members. However, ESFRI could recommend evaluation criteria with key requirements along the dimensions of the lifecycle.

Exploring options for the development and use of Key Performance Indicators is another action needed for the further development of ESFRI's methodology. KPIs are expected to increase effectiveness, complementarity and transparency of the ESFRI

monitoring and evaluation activities, avoiding *one-size-fits-all* approaches and calibrating a sustainable workload for ESFRI.

The developments in the field of data access and data management also need to be reflected in the ESFRI Methodology. This holds particularly true for the European Open Science Cloud/European Open Science Data Commons. Major contributions by ESFRI Research Infrastructures are a key ingredient for the advancement of the EOSC which need to be fully reflected in procedures and governance. ESFRI has a prime role in taking care that the standards for FAIR data – as developed within the EOSC framework – and the Data Reproducibility requirement are implemented within the whole range of ESFRI Research Infrastructures and beyond.

The evaluation process for new ESFRI proposals is also an important part of ESFRI Methodology, as it determines which initiatives enter the ESFRI Roadmap. In this context, the ESFRI Roadmap 2018 update demonstrated that a balanced approach is needed with regard to criteria for evaluation of the scientific case and implementation. The minimal key requirements against which the proposals are evaluated worked well. Nevertheless, they could be further streamlined allowing the simplification of the submission form with a focus on the most essential information. The role of the ESFRI Working Groups involved in the evaluation will remain central in the whole process. The independent advice provided by the external experts, under transparent conditions of absence of conflict of interest, helped the WGs to develop a fully informed analysis of the proposals. It must be stressed also that the full responsibility of the ESFRI Forum for strategic advice on the European RIs policy is engaged both at EB level, when recommendations are formulated, and at plenary level, when the final decisions are taken. This may include the decision to give evidence, in the Landscape Analysis, to special research areas of high strategic potential that emerged through the evaluation process and Forum discussion.

The European Strategy Forum on Research Infrastructures (ESFRI) was set-up in 2002 as an informal Forum – composed of representatives of national authorities of the Member States (MS) and Associated Countries (AC) of the European Union and the European Commission (EC) – following the original mandate¹ of the Competitiveness Council of the European Union of June 2001 – and reaffirmed in November 2004, May 2007, December 2012, May 2014, December 2015 – in order:

- to support a coherent and strategy-led approach to policy making on Research Infrastructures in Europe;
- to facilitate multilateral initiatives leading to a better use and development of Research Infrastructures acting as an incubator for pan-European and Global Research Infrastructures;
- to establish a European Roadmap for Research Infrastructures – new and major upgrades, of pan-European interest – for the coming 10-20 years, stimulate the implementation of these facilities, and update the Roadmap as the need arises²;
- to ensure the follow-up of implementation of already ongoing ESFRI Projects after a comprehensive assessment, as well as the prioritisation of the infrastructure projects listed in the ESFRI Roadmap³;
- to implement the ERA Priority 2b: Research Infrastructures⁴;

The EU Council has asked to prepare the ESFRI Roadmap update in 2018 as well as to closely monitor the implementation of the listed ESFRI Projects and to periodically update the scientific status of ESFRI Landmarks⁵; recently, it has invited to develop with Member States and the European Commission a common approach for monitoring Research Infrastructures⁶.

In this context, the Forum is responsible for the strate-

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

2. Conclusions of the Competitiveness Council, 25-26 November 2004, 21-22 May 2007, 26 May 2014

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 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>

6. 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>

gic planning of Research Infrastructures, to elaborate recommendations on issues raised by one or more country Delegations and/or on specific mandates of the Competitiveness Council of the European Union (BOX 6).

THE ESFRI FORUM

The ESFRI Forum is composed of representatives – the Delegates – of the EU Member States and Associated Countries, plus the European Commission. ESFRI Forum Meetings are held on a regular basis, typically four times a year, as convened by its elected Chair who holds a non-renewable two-year mandate, with a possible extension of up to a third year. An Executive Board (EB) – formed by seven members chosen among the Forum Delegates and the EC representative – supports the Chair in preparing the agenda items of the EB and the Forum meetings, and formulating recommendations to the Forum in a transparent way. A Secretariat is provided by the EC. ESFRI does not have its own budget: Delegates and experts forming the ESFRI Working Groups are expected to be supported by their Governments. Specific activities of ESFRI – assistance to the Chair, realisation of the Roadmap update, publication of relevant documents, communication and dissemination, organisation of workshops and exchanges of experience for the sharing of good practices – are partially supported by dedicated EU-funded projects: CoPoRI FP7 (2011-2014)¹ and StR-ESFRI H2020 (2015-2019)².

1. Communication and Policy development for Research Infrastructures in Europe – CoPoRI https://cordis.europa.eu/project/rcn/100343_en.html

2. Support to Reinforce the European Strategy Forum for Research Infrastructures – StR-ESFRI https://cordis.europa.eu/project/rcn/194950_en.html

BOX 6.
The ESFRI Forum

ESFRI has established permanent Strategy Working Groups (SWGs), whose members are experts identified by the Delegations – plus EC representatives and one e-IRG expert – and the Implementation Group (IG), whose members are ESFRI Delegates,

BACKGROUND AND HISTORY

ensuring complementary expertise and realising an adequate and fair balance in science and science management. The SWGs cover the scientific fields of Energy (ENE), Environment (ENV), Health & Food (H&F), Physical Sciences & Engineering (PSE), Social & Cultural Innovation (SCI), and – since 2017 – Data, Computing and Digital Research Infrastructures (DIGIT). The SWGs assess the scientific case of the ESFRI Projects and ESFRI Landmarks – according to excellence, pan-European relevance, socio-economic impact, e-needs – and carry out the Landscape Analysis (LA). The LA provides an updated overview of the European ecosystem consisting of major RIs operating transnational access and of major ongoing projects; it allows recognising gaps and challenges with an outlook to the global landscape. The Implementation Group assesses the maturity aspects of the ESFRI Projects and ESFRI Landmarks – according to stakeholder commitment, user strategy & access policy, preparatory work, planning, governance & management, human resources policy, finances, and risks. ESFRI benefits from a close collaboration with the e-IRG whose representatives in all SWGs help in evaluating the specific e-Infrastructure needs (e-needs) of each RI and their interface with the *horizontal* e-Infrastructure services.

ESFRI has developed a methodology to identify those Research Infrastructures needed for European's competitiveness in research and innovation, being all new undertakings that fill an existing gap in research capability or capacity at the frontiers of knowledge, or being major upgrades of existing operational pan-European Research Infrastructures. The first European Strategy Report on Research Infrastructures was published in 2006⁷; the Roadmap was then updated in 2008⁸, 2010⁹, 2016¹⁰.

After the Roadmap 2010, ESFRI focused on the implementation issues of the Research Infrastructures taking into consideration the specificities related with their organisation and research domain. In 2011, ESFRI was mandated to meet the goals of the Innovation Union Flagship Initiative that "by 2015, Member States together with the European Commission should have completed or

launched the construction of 60% of the priority European Research Infrastructures currently identified by ESFRI"¹¹. In 2013, the EC – in consultation with ESFRI – established a group of independent experts, the Assessment Expert Group (AEG)¹² to assess the status of all Roadmap projects and their readiness to start implementation. Moreover, upon request by the EC, ESFRI carried out the analysis of the projects that could most effectively take advantage of the special support measures within Horizon 2020 for meeting the Innovation Union Flagship Initiative goal.

ESFRI – upon the EU Council mandate of 26 May 2014 which welcomed ESFRI plans "to update its Roadmap and called on ESFRI to continue the prioritisation of all the Research Infrastructure projects of the ESFRI Roadmap"¹³ – designed a largely updated methodology for the new Roadmap to be published in 2016. ESFRI established a parallel process: the evaluation of the scientific case was carried out by the Strategy Working Groups covering five thematic areas, and the assessment of implementation was addressed, independently, by the Implementation Group. All Working Groups made use of independent external experts – who declared absence of conflict of interest – to formulate a comprehensive assessment of the project, based on its scientific excellence, its pan-European relevance, and its maturity to engage in the ESFRI process. The outcomes of this procedure were presented to the EU Council with the publication of the Roadmap 2016.

The Roadmap 2016 was conceived having sustainability in mind: higher level of maturity, officially expressed political support by Member States and Associated Countries, as well as funding commitment, were set as eligibility criteria. This was coherent with the introduction of a ten-year maximum permanence time for a RI project on the Roadmap list, a timeframe that was considered adequate to carry out the full implementation process, developing from a concept to a sustainable legal entity. The concept of ESFRI Landmark – along with the definition of ESFRI Project (**BOX 2**) – was introduced to identify those ESFRI RIs that, having reached full implementation or an advanced construction stage, with a stable legal status acknowledged by MS and AC, and a sustainability plan, currently represent a reference in their field. The

7. ESFRI Roadmap 2006
https://ec.europa.eu/research/infrastructures/pdf/esfri/esfri_roadmap/roadmap_2006/esfri_roadmap_2006_en.pdf

8. ESFRI Roadmap 2008
https://ec.europa.eu/research/infrastructures/pdf/esfri/esfri_roadmap/roadmap_2008/esfri_roadmap_update_2008.pdf

9. ESFRI Roadmap 2010
https://ec.europa.eu/research/infrastructures/pdf/esfri-strategy-report_and_roadmap.pdf

10. ESFRI Roadmap 2016
<http://www.esfri.eu/roadmap-2016>

11. Europe 2020 Flagship Initiative Innovation Union
https://ec.europa.eu/research/innovation-union/pdf/innovation-union-communication-brochure_en.pdf

12. Assessment Expert Group (AEG)
https://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/esfri.pdf

13. 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://data.consilium.europa.eu/doc/document/ST-10257-2014-INIT/en/pdf>

ESFRI Landmarks are successful scientific achievements and major assets for the competitiveness of the European Research Area. The ESFRI Roadmap 2016 listed a total of 21 Projects and 29 Landmarks.

The ten-year rule for the Projects and the concept of Landmarks as reference RIs imply a monitoring and periodic updating on the status of the RIs to provide ESFRI with the informed state of play of the ensemble of the Roadmap Infrastructures. This complies with the recommendations of the EU Council of May 2016⁵ who invited ESFRI to "closely monitor the implementation of ESFRI Projects and to periodically assess the scientific status of ESFRI Landmarks, as well as to prepare the ESFRI Roadmap update in 2018", and further confirmed such mandate in May 2018⁶. Consequently, ESFRI has refined its evaluation approach for the new proposals, and developed a methodology for the monitoring of the ESFRI Projects, namely when approaching the ten-year time limit. ESFRI has also carried out a first pilot periodic review of four Landmarks in order to test the elements for a future dedicated methodology.

ESFRI activities encompass response to specific additional mandates of the EU Council: i) to contribute to a strategic plan for an industry-oriented cooperation of the Research Infrastructure¹⁴; ii) to explore mechanisms for better coordination of Member States' investment strategies in e-Infrastructures, covering also HPC, distributed computing, scientific data and networks¹⁵; iii) to contribute to the debate on ensuring the long-term sustainability of Research Infrastructures⁵; iv) to develop a common approach for monitoring of Research Infrastructures' performance, inviting the pan-European Research Infrastructures, on a voluntary basis, to include it in their governance and explore options to support this through the use of Key Performance Indicators⁶; v) to establish effective coordination between EOSC and ESFRI¹⁶. ESFRI addresses the mandates by performing in-depth analyses and studies, in some cases creating *ad hoc* Working Groups to inform the Forum on emerging needs and requirements dictated by the evolutions of the RIs ecosystem and their implications.

ESFRI has activated four *ad hoc* Working Groups

14. Conclusions of the Council of the European Union of 31 May 2011 on Development of the European Research Area (ERA) through ERA related groups. Doc. 11032/11
<http://register.consilium.europa.eu/doc/srv?l=EN&f=ST%2011032%202011%20INIT>

15. Conclusions of the Council of the European Union of 29 May 2015 on Open, data-intensive and networked research as a driver for faster and wider innovation. Doc. 9360/15
<http://data.consilium.europa.eu/doc/document/ST-9360-2015-INIT/en/pdf>

16. Conclusions of the Council of the European Union of 29 May 2018 on European Open Science Cloud (EOSC). Doc. 9291/18
https://www.wera.gva.t/objct/document/4013/attach/CC_EOSC_final.PDF

in the period 2013-2017. The Working Group on Innovation – INNO WG, 2013 – was set-up to fulfil the Council mandate to contribute to a strategic plan for an industry-oriented cooperation of the Research Infrastructures¹⁴. The Neutron Landscape Group – NLG, 2014 – was mandated by the PSE SWG to analyse the European and international landscape of Neutron Scattering facilities, and its evolution over the next decades with the expected shutting-down of research reactors and starting operation of new spallation sources. The Working Group on Investment Strategies in e-Infrastructures – e-INFRA WG, 2015 – was set-up integrating competences from the e-IRG to respond to the Council mandate on coordination of Member States' investment strategies in e-Infrastructures¹⁵ and formulated recommendations that were adopted by ESFRI in December 2017. The Working Group on Long-Term Sustainability – LTS WG, 2016 – was setup to comprehensively respond to the Council mandate on Long-Term Sustainability of Research Infrastructures⁵.

The results of the analysis produced by the *ad hoc* WGs can be of general interest and impact, in which case they deserve publication: ESFRI has created the ESFRI Scripta series and published three volumes. The first one was released in September 2016 with the title "Neutron scattering facilities in Europe: present status and future perspectives" based on the NLG report¹⁷. The second ESFRI Scripta was published in October 2017, entitled "Long-Term Sustainability of Research Infrastructures", based on the conclusions of the LTS WG¹⁸. The third volume was published with the title "Innovation-oriented cooperation of Research Infrastructures" in January 2018, based on the results of the INNO WG¹⁹.

ESFRI has resumed the publication of periodic reports with the Annual Report 2016²⁰ and it will publish a Biannual Report for the years 2017-2018.

All reports are available electronically through www.esfri.eu.

17. Neutron scattering facilities in Europe: Present status and future perspectives, ESFRI Scripta Vol.1, September 2016
http://www.esfri.eu/sites/default/files/u4/NGL_CombinedReport_230816_Complete%20document_0209-1.pdf

18. Long-Term Sustainability of Research Infrastructures, ESFRI Scripta Vol.2, October 2017
http://www.esfri.eu/sites/default/files/u4/ESFRI_SCRIPTA_TWO_PAGES_19102017_1.pdf

19. Innovation-oriented cooperation of Research Infrastructures, ESFRI Scripta Vol.3, January 2018
http://www.esfri.eu/sites/default/files/u4/ESFRI_SCRIPTA_VOL3_INNO_SINGLE_PAGE.PDF

20. ESFRI Annual Report 2016
http://www.esfri.eu/sites/default/files/docs/ESFRI%20Annual%20report%2016_web.pdf