

European Strategy Forum
on Research Infrastructures

ESFRI

ROADMAP 2018

STRATEGY REPORT ON RESEARCH INFRASTRUCTURES



Strategy Report on Research Infrastructures

ROADMAP 2018

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Designed by Promoscience srl

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FOREWORD



ESFRI CHAIR

Prof. Giorgio ROSSI

Dear Ministers,

Dear Commissioners,

the European Strategy Forum on Research Infrastructures presents to you the updated Strategy Report and Roadmap 2018 that identifies eight scientifically leading Projects from previous Roadmaps which, after ten years of incubation, have reached the operational phase, or are well advanced in their construction, and deserved the ESFRI Landmark status, as well as six new Projects that were selected, among the collected proposals, for their strategic potential and impact for strengthening European research.

The strategy report addresses also all the key issues that were raised by you, through the subsequent mandates that the Council gave to ESFRI, ranging from sustainability of Research Infrastructures to innovation and to the role of hub of funders that ESFRI must play in the e-Infrastructure for European scientific competitiveness, including the challenging contribution to the construction of Open Science.

ESFRI has engaged in all these issues by deploying the expertise of the Forum, the Strategy Working Groups, the Implementation Group and the *ad hoc* Working Groups that were created on specific themes, putting at work together competences at the highest level and reaching a common vision.

The Roadmap is a collective work: as many as 100 individuals from all over Europe were involved in the writing if we count all Working Groups providing analysis and knowledge, the whole Forum extensively involved in discussing and refining the drafts along with the European Commission Officers and Secretariat, and the editorial team who managed the production of this document that represents the state-of-the-art of ESFRI: a collective vision for European Research Infrastructures to inspire European policy for maximizing competitiveness.

In fact, the impact of this work goes beyond the achieved technical and strategy report: it is a vivid demonstration of the high merit and potential of European collaboration in developing visions and sustainable perspectives for progress, in the spirit of freedom, of the rich culture that derives from the specialities that all of us represent and that we knew how to bring together, for reaching a synthesis and a pleasant perspective.

A handwritten signature in blue ink, appearing to be 'G. Rossi', written in a cursive style.

The Strategy Report on Research Infrastructures includes the Roadmap with ESFRI Projects and ESFRI Landmarks and the ESFRI vision of the evolution of Research Infrastructures in Europe, addressing the mandates of the European Council, and identifying strategy goals.

The Strategy Report is composed of three parts.

PART 1

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presents the features of the ESFRI Roadmap 2018 with emphasis on: i) the reinforced strategic role of the Landmarks portfolio of long-term engagements carrying out the completion and the operation of reference Research Infrastructures in all domains of research; ii) the new entries in the list of the ESFRI Projects, reinforcing critical areas of competitiveness of European research. The list of **18 ESFRI Projects** and **37 ESFRI Landmarks** is presented: each RI is identified by acronym, full name, type of RI, legal status, year of entry in the Roadmap, year of expected start of operation and estimated costs. This part also includes an analysis of the evolving role of the RIs, which reflects the specific mandates from the European Council to address the FAIR – Findable, Accessible, Interoperable, Reusable – data principles and e-Infrastructure, the Long-Term Sustainability and the benefits for innovation. We summarise the applied ESFRI Methodology and introduce the challenges for its future refinement based on the lessons learnt during this Roadmap exercise. The background of ESFRI and its history over the last 16 years complete PART1.

PART 2

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is the Landscape Analysis that provides the current context of the most relevant Research Infrastructures that are available to European scientists and to technology developers typically through peer review of competitive proposals. The unique contribution played by the ESFRI RIs in all scientific domains is analysed along with the interconnections and cross-cutting aspects of the whole European RIs ecosystem.



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

The Landscape Analysis is organised in three sections.

SECTION 1 consists of six chapters – one per scientific domain – and describes the state of play of all Research Infrastructures in the corresponding thematic area, their contributions to support frontier research and to provide key data necessary to address the *Grand Challenges*.

SECTION 2 is an all-new analysis effort to render explicit the relevant connections that already exist among different thematic areas by means of the ESFRI RIs, and to identify the critical needs and opportunities for new links and new research practices.

SECTION 3 describes the state of play of Research Infrastructures in addressing *transversal issues* like education and training, needs for digital infrastructure, contribution to innovation along with the *horizontal analyses* like socio-economic impact, territorial impact, pan-European and global dimensions that are carried out by all RIs.

The LA indicates also *high strategic potential areas of research in the field of Social & Cultural Innovation* that resulted from the Roadmap preparation work.

PART 3

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describes – through dedicated cards – each ESFRI Project and each ESFRI Landmark. A short description of the RI is given as well as updated information on the legal status, the timeline for construction/operation, and the estimated costs. The information on the political support to ESFRI RIs, expressed by Governments of Member States and Associated Countries – e. g. Lead country, Member country or Prospective Member country – is validated by the corresponding ESFRI Delegations.

ANNEX

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ESFRI Working Groups
ESFRI Forum





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/st06469en17.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

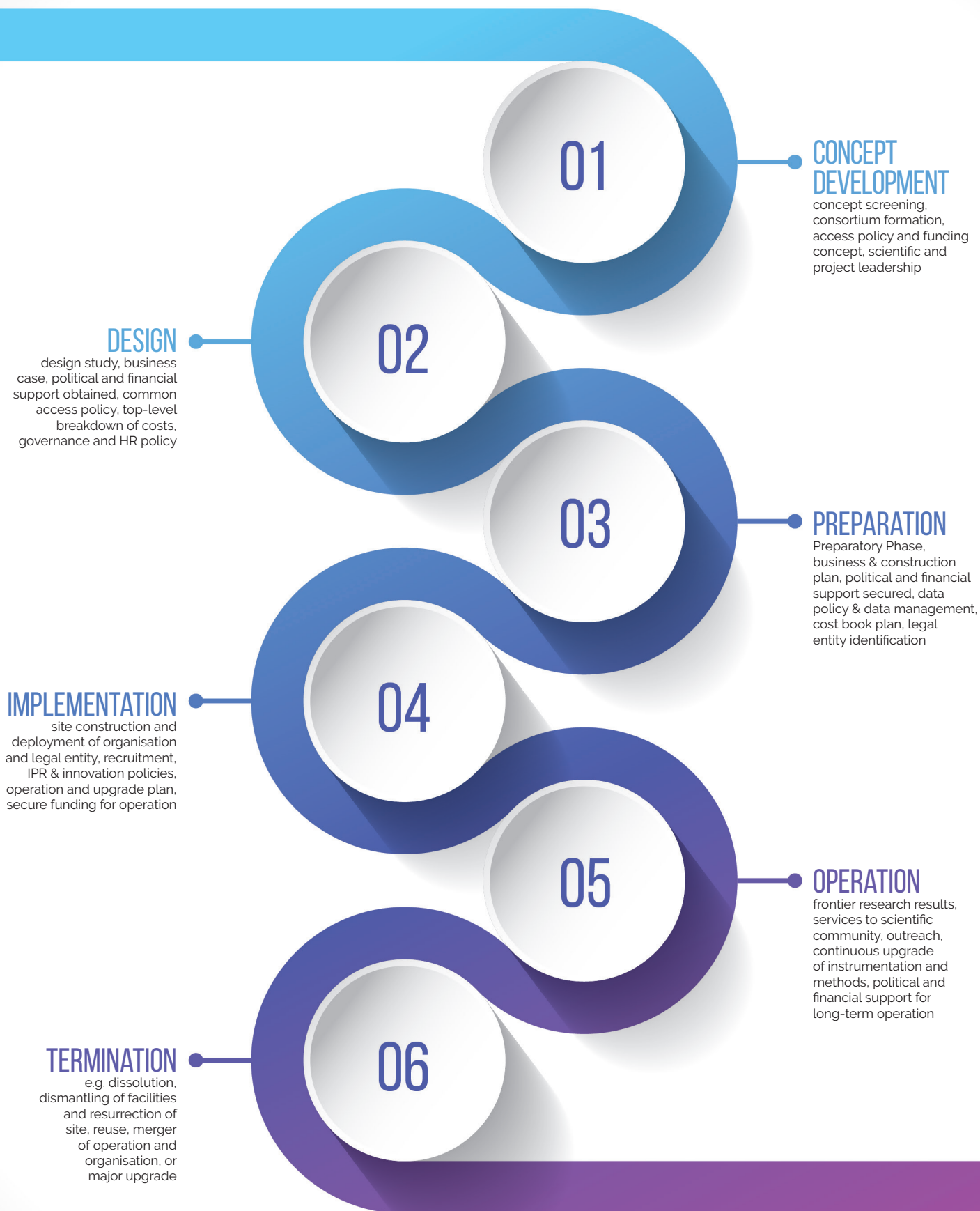


FIGURE 1.
Lifecycle approach

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**.

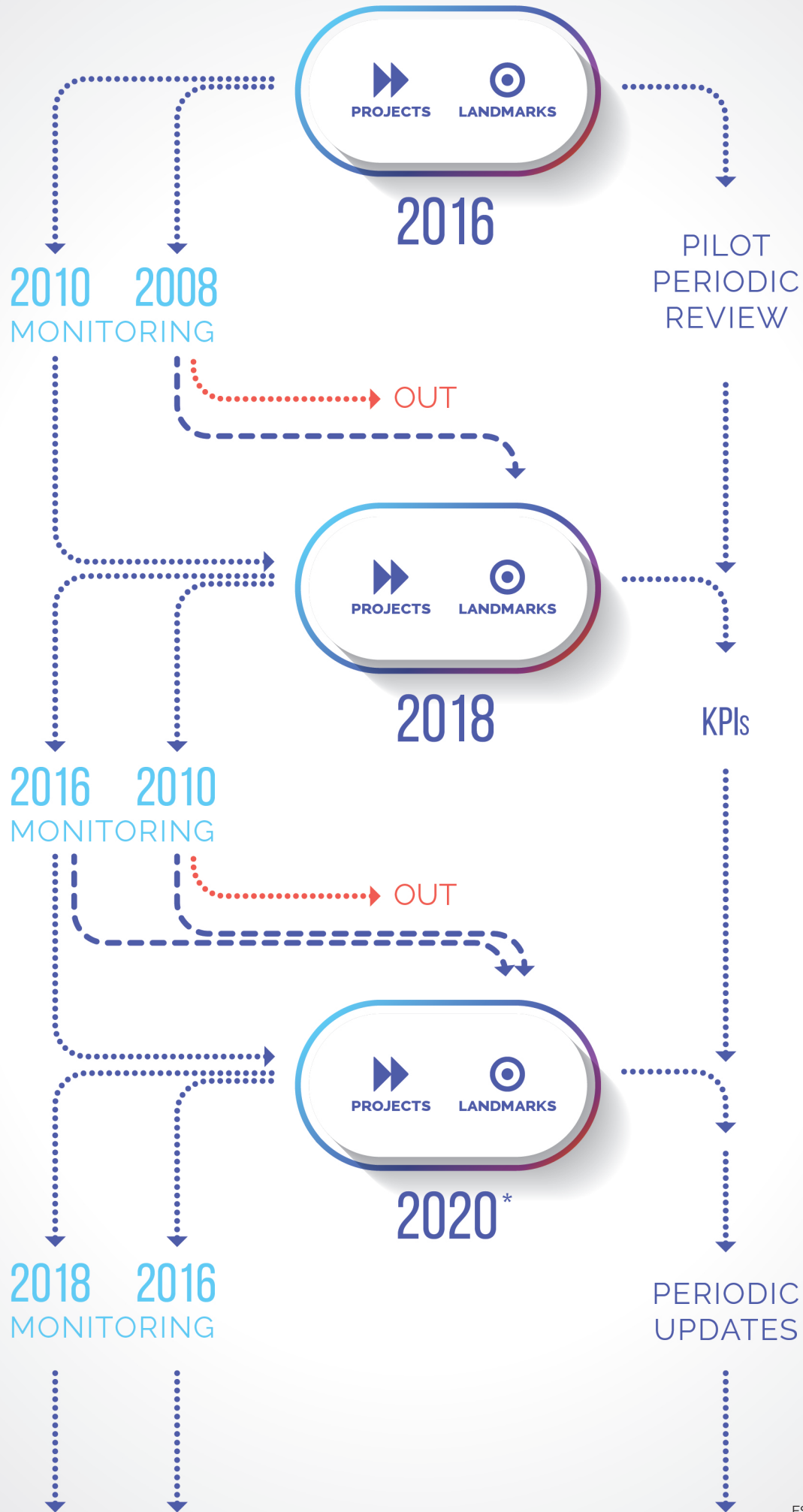


FIGURE 2.
ESFRI Roadmap Dynamics

* 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.

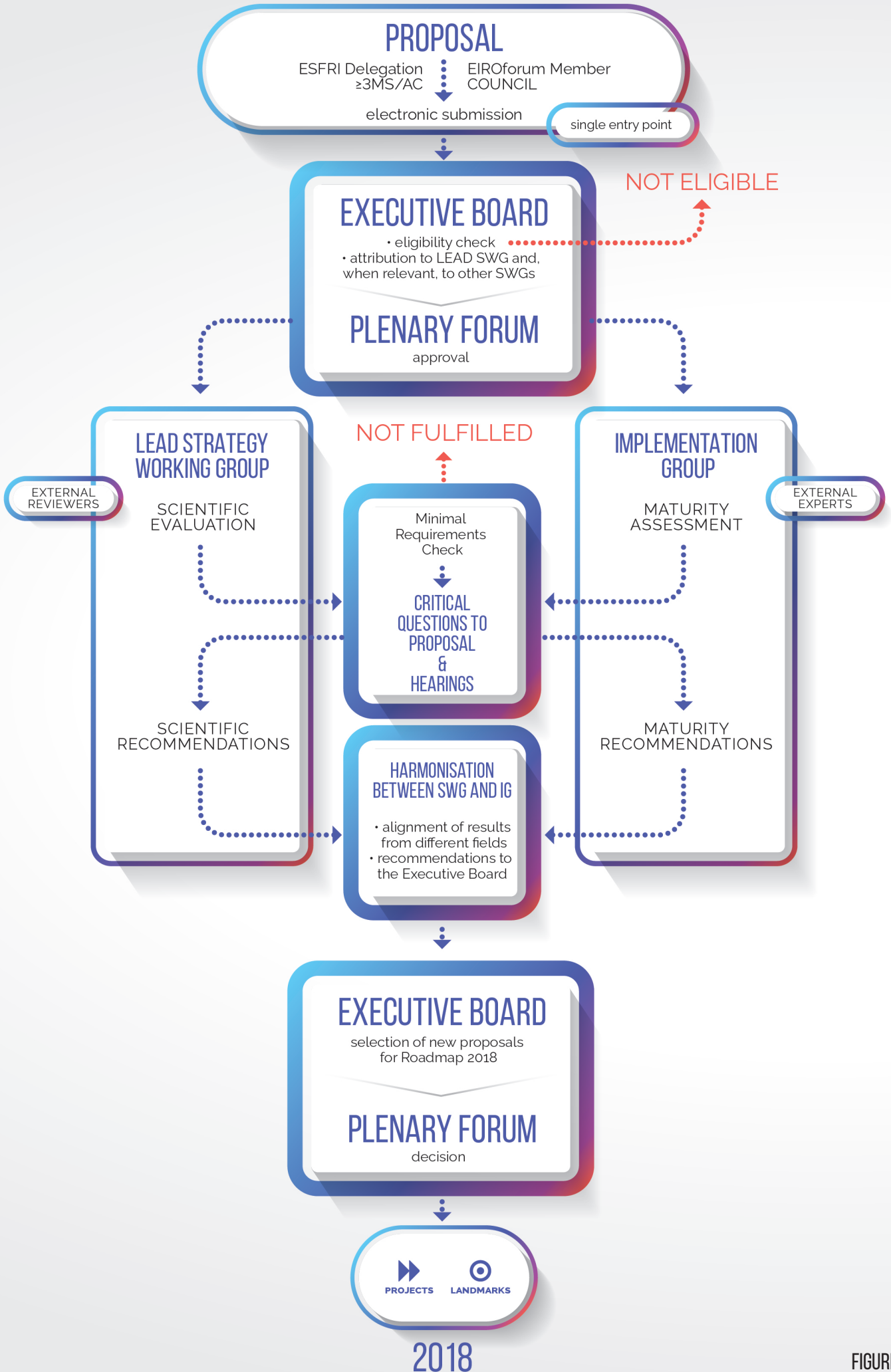


FIGURE 3. ESFRI Methodology for the selection of new proposals

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.gvaat/object/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






PART 2

LANDSCAPE ANALYSIS

The Landscape Analysis provides the current context of the most relevant Research Infrastructures that are available to European scientists and to technology developers typically through peer review of competitive proposals. The unique contribution played by the ESFRI RIs in all scientific domains is analysed along with the interconnections and cross-cutting aspects of the whole European RIs ecosystem.

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

The Landscape Analysis is composed of three sections.

SECTION 1

PAG 47

consists of six chapters – one per scientific domain – and describes the state of play of all Research Infrastructures 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, when needed, in areas or subdomains of research, and the interfaces of the RIs belonging to the same disciplinary area are captured by plots with the 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 multiple and diverse RIs.

In addition, the Section1 indicates *high strategic potential areas of research in the field of Social & Cultural Innovation*, that resulted from the Roadmap preparation work.

SECTION 2

PAG 125

is an all-new analysis effort to render explicit the relevant connections that already exist among different thematic areas by means of the ESFRI RIs, and to identify the critical needs and opportunities for new links and new research practices.

The interconnections mediated by ESFRI RIs are displayed in the graph – **Interconnections between ESFRI RIs and scientific domains** – and in the extended caption – **Description of the interconnections**. The ensemble of the information represents the baseline formed by ESFRI RIs and its high potential for interdisciplinary and multi-disciplinary research. It is clear that the high need of new knowledge across the disciplinary boundaries cannot be addressed by the RIs alone, even less by the sole set of ESFRI RIs; it does involve the organization of research at large. The contribution of well interconnected RIs can play a major role in favouring the establishment of standards and good practices on two fronts: the data interchange/interoperability among RIs – a prototype implementation of the EOSC – and the multifaceted research process that – in case of *Grand Challenges* of non-disciplinary nature – requires effective work-plans across the full system of Research Infrastructures.

SECTION 3

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describes the state of play of the Research Infrastructures in addressing *transversal issues* like education and training, needs for digital infrastructure, contribution to innovation along with the *horizontal analyses* like socio-economic impact, territorial impact, pan-European and global dimensions that are carried out by all RIs.

The impact of RIs on European research, innovation, culture and society is reflected in training to research and higher education, transfer of disruptive knowledge and refinement of technical understanding to the economy sector of production and services. The prime role of RIs in generating high-quality data for enabling a knowledge-based economy is transversal to all disciplines and research practices. The analysis of the impact is conducted for all areas with consistent methodology and gives evidence of the contributions and challenges in generating innovation and socio-economic benefits at national, European, and global levels.

The Landscape Analysis has been realized by the Strategy Working Groups in the **ENERGY (ENE)**, **ENVIRONMENT (ENV)**, **HEALTH & FOOD (H&F)**, **PHYSICAL SCIENCES & ENGINEERING (PSE)**, and **SOCIAL & CULTURAL INNOVATION (SCI)** for the respective domains. The e-Infrastructure Reflection Group (e-IRG) and the Strategy Working Group on **DATA, COMPUTING AND DIGITAL RESEARCH INFRASTRUCTURES (DIGIT)** contributed to the relevant Landscape Analysis.

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PART 2

LANDSCAPE ANALYSIS

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PART2

LANDSCAPE ANALYSIS - SECTION1

ENERGY

ENERGY

The energy sector is key to social and economic development. Especially in some non-OECD countries the energy sector sees very high growth rates due to rising GDP. However, it contributes significantly to global CO₂ emissions. For the EU, the reduction of CO₂ emissions in a sustainable framework is a major driver of its energy policy. This provides opportunities for new technologies both for application within and outside of the EU.

Thus the European Commission's Energy Union¹ strategy has formulated the objective of creating a secure, sustainable, competitive and affordable energy system. This fundamental transformation will be achieved by more flexible, more decentralized and more integrated ways of production, consumption, transport and storage of energy while at the same time promoting the development of existing and novel energy technologies. Energy innovation is driven by stakeholders from industry and research as well as society. For this reason, Europe has elaborated its path towards energy innovation in the Strategic Energy Technology Plan (SET-Plan)². Energy Research Infrastructures (RIs) play a major role in joining Europe's efforts to drive forward, test and demonstrate technologies and their interplay in the future energy system.

Energy RIs are to a great extent interdisciplinary undertakings, as expertise from Physics, Engineering, Computer Sciences and other academic fields converge to support energy technologies and systems development. This is reflected by strong interactions of the energy field with the other ESFRI domains. ESFRI Energy RIs are:

- the **ESFRI Landmark JHR** (Jules Horowitz Reactor), which will serve materials research for the safe operation of current and future nuclear power technologies; the **ESFRI Landmark ECCSEL ERIC** (European Carbon Dioxide Capture and Storage Laboratory In-

frastructure) for the development of carbon capture and storage as well as utilization technologies.

- the **ESFRI Project MYRRHA** (Multi-purpose hybrid Research Reactor for High-tech Applications), a multipurpose fast neutron spectrum irradiation facility for nuclear research; the **ESFRI Project EU-SOLARIS** (European Solar Research Infrastructure for Concentrated Solar Power), the thermal solar power research activities in the field

of renewable energies; the **ESFRI Project WindScanner** (European WindScanner Facility), a distributed RI for renewable energies focusing on the high precision characterization of wind fields; the **ESFRI Project IFMIF-DONES** (International Fusion Materials Irradiation Facility-Demo Oriented Neutron Source) for fusion materials irradiation.

This Landscape Analysis for the energy domain is divided in five main areas, which, in themselves, comprise a number of specific subfields: **ENERGY SYSTEMS INTEGRATION** – including networks, transport, storage and smart cities/districts; **RENEWABLE ENERGY** – solar, renewable fuels, wind, geothermal, ocean; **EFFICIENT ENERGY CONVERSION AND USE** – energy in buildings and in industry, Power-to-X, CCSU; **NUCLEAR ENERGY** – fusion and fission; and **CROSS-SECTIONAL ENERGY RIs** – materials and data, simulation and modelling. A representation of the interplay of the fields and energy RIs is shown in **Figure 1**.

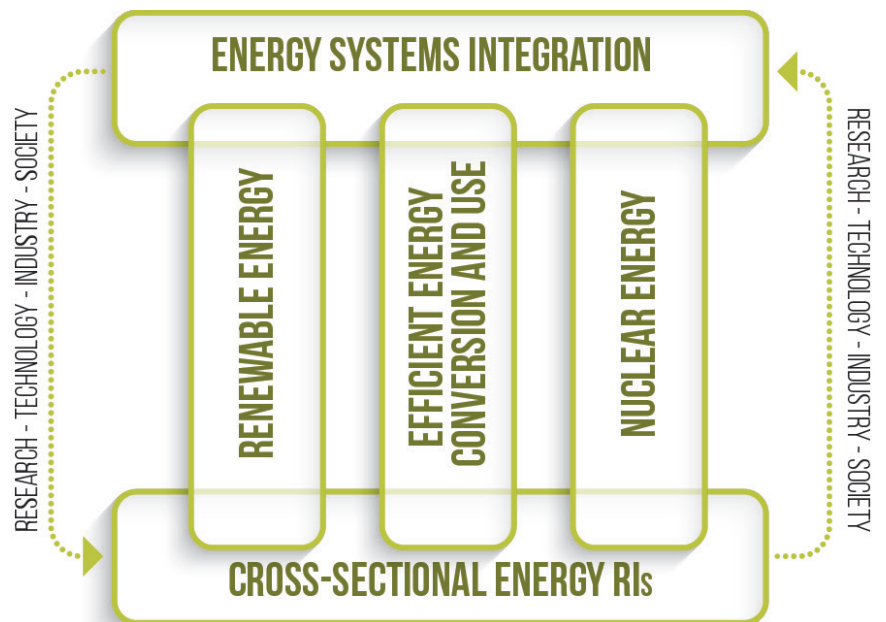


FIGURE 1.
Energy RIs interplay.

1. COM(2015)080, A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy

2. COM(2015)6317, Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation [latest communication]

ENERGY SYSTEMS INTEGRATION

Significant investments in infrastructure for smart energy distribution, storage and transmission systems are underway through the Thematic Objectives³ for Cohesion Policy in 2014-2020. European Regional Development Fund (ERDF) support is available to improve energy efficiency and security of supply through the development of smart energy systems⁴. The SET-Plan and the Energy Roadmap 2050⁵ also highlight the expectation that fossil fuels will continue to have a significant role in European primary energy in the foreseeable future. It is thus of utmost importance to boost energy efficiency in concert with sustainable use of effective energy sources and carriers⁶. However, there is a need to research the design, operation and integration of all parts of the energy system of the future in a safe and secure manner. The main focus of this section is on the technical aspects of energy systems integration. It is also important to point out that the socio-economic and human behavioural aspects are essential for energy transformation processes.

CURRENT STATUS

ENERGY NETWORKS

The future European energy system, with an envisaged high penetration of renewables, needs a strong interplay between different energy carriers such as electricity, heating and cooling – e.g. gas and other chemical fuels. Such a system demands control and integration of intermittent production from renewable energy and variable consumption of all carriers as well as energy storage which is an important technology to stabilize the power fluctuations and to define economically and environmentally sustainable options. *Smart Grid* refers to a progressive evolution of the electricity network towards “a network that can intelligently integrate the actions of all users connected to it – generators, energy storage facilities and consumers in order to efficiently deliver sustainable, economic and secure electricity supply and safety”. It is a combination of the grid control technology, information technology and intelligence management of generation, transmission, distribution and storage. Energy Management Systems (EMSs) are vital tools to optimally operate *Smart Grids*, from *Micro-grids* to buildings. In fact, the need for new EMSs to minimize emissions, costs, improve security at different spatial and temporal scales is the basis of the RIs in this field that implement the interaction among equipment, communication protocols, simulation and control. Over 450 demonstration projects with different RIs have been launched in Europe exploring system operation, consumer behaviour and new innovative technologies.

ENERGY STORAGE

Energy Storage on different scales has a crucial role to support energy system stability and security. The energy storage market is starting to develop: costs are major constraints, as well as regulatory issues, EMSs and technology capabilities. Advanced EMSs that can coordinate distributed storage over the territory and the grid are a challenge for the development of *Smart Grids* and for the satisfaction of different kinds of demands – electrical, loads, thermal loads, etc. Infrastructures to support the design and evaluate *Smart Grid* reference architectures are highly needed.

Demonstration and test of energy storage at medium and large scale, including the possibility to test completely novel components, will give practical information on the use and benefits of the energy storage technology and potential contribution to key policy goals set for Europe.

The main players in the electricity/*Smart Grid* arena are the European Network of Transmission System Operators for Electricity (ENTSO) and the European Distribution System Operators (EDSO): they aim at implementing a flexible electrical network including a number of demonstrations, similarly to the European Technology Platform for *Smart Grid*. Major European universities have built up infrastructures beyond the laboratory scale to operate in real case studies providing collaborations, hosting researchers, sharing data, exchanging lecturers, participating in common projects, delivering University masters and PhD activities. However, improved scientific exchange and collaboration should be achieved through the testing of new algorithms (EMSs) both for designing and operational management in the RIs at international level. The main strategic research agenda challenge is to be able to build and control, through flexible and fast EMSs, an energy infrastructure which can be adapted to a large variety of production and storage systems – weather based energy production, controllable plants, storage systems – from the development of single components up to a complete energy system. Most smart energy network projects have evolved from smart meter read-out pilots into increasingly complex systems to match electrical demand with the variable electricity production of renewable sources. However, only a few up to now are looking at the mixture of energy carriers. Focus has been limited to grid operation overlooking possible communication solutions. Therefore, energy system RIs enabling energy system tests in combination with communication technologies need to reveal their actual potential in dealing with future challenges of even more complex systems. Such test systems should combine meteorological forecasts, energy production facilities, storage devices and systems, end-us-

3. http://ec.europa.eu/regional_policy/en/policy/how/priorities

4. <https://www.energyplan.eu/smartenergysystems/>

5. Energy Roadmap 2050, Communication from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the regions, COM(2011) 855 final, 15.12.2011

6. Energy Efficiency and its contribution to energy security and the 2030 Framework for climate and energy policy, Communication from the Commission to the European Parliament and the Council, COM(2014) 520 final, 23.07.2014

er components, penetration of renewable, different energy carriers like electricity, heating/cooling and gas including market models. Having multiple electricity retailers and the freedom to switch from one electricity retailer to another are not taken into account and could be interesting in a future energy RI. Building integrated smart energy network/storage testing and demonstration infrastructure will give device companies the possibility to test new equipment and EMSs, power producers and network operators' new knowledge about how to operate a future energy network that will strengthen the competitiveness of industry. Also, the ongoing R&D activities on storage technologies based on batteries or other storage systems, on the conversion of excess energy into chemical carriers will, in the long run, make available an integration of the technology into the wider energy system. Generally, the improvements in storage capacity and economy will promote future technologies in the *Smart Grid* and compare to grid extension or curtailment approaches. The results of such RI will therefore facilitate decisions on investments connected to the transformation of the energy system for companies as well as for public operators. The US, China and Korea have large ongoing demonstrator projects with large infrastructure investments – mostly in *Smart Grid* and *Micro-grid*, establishing the capacity of testing the global competitive advantage of individual components.

EFFICIENT CLEAN TRANSPORT

Transport accounts for approximately one quarter of the EU Greenhouse Gas emissions and the target is to reduce this to 60% by 2050. The electrification of private transport is starting to gain market traction; however, the roll-out has been hampered by costs, and by political and techno-economic uncertainties around the launch of charging infrastructures. Cleaner and more energy efficient vehicles are a significant growing part of the European Energy System and have an important role to play in achieving EU policy objectives of reducing energy consumption, CO₂ emissions, and pollutant emissions. The Directive on the Promotion of Clean and Energy Efficient Road Transport Vehicles⁷ aims at a broad market introduction of environmentally-friendly vehicles. It

7. https://ec.europa.eu/transport/themes/urban/vehicles/directive_en

addresses purchases of vehicles for public transport services. Clean Transport Systems can go a long way towards meeting the future energy demands of the transport sector; however, the availability and cost of relevant raw materials – e.g. batteries – is likely to be another major issue to overcome. Investments in transport services and infrastructure directly benefit citizens and businesses. Smart mobility, multi-modal transport, clean transport and urban mobility are particular priorities for Cohesion Policy during the 2014-2020 funding period. Cohesion policy also supports investments in infrastructure for smart energy distribution, storage and transmission systems (particularly in less developed regions). As covered by the public procurement Directives and the public service Regulation. It is also possible to receive EU support for low-carbon transport investments under the Thematic Objective aimed at supporting the shift towards a low-carbon economy in all sectors, in particular for promoting sustainable multimodal urban mobility.

In order to make sure that these investments achieve maximum impact, particular emphasis is placed during the 2014-2020 period on the need to ensure a sound strategic environment, including the adoption by Member States of a *comprehensive transport plan* that shows how projects will contribute towards the development of the Single European Transport Area and the trans-European transport network.

SMART CITIES AND COMMUNITIES AND LIVING LABORATORIES

Smart Cities and Communities emphasis has slowly advanced from energy efficiency in buildings to districts and cities. When coupled to appropriately design physical systems, including transport systems and thermal energy storage systems, ICT can contribute to effective energy use and interactive balancing of real-time energy supply and demand. Well-designed urban interactive ecosystems can become smart sustainable cities and communities that use ICT-enabled systems and tools to tackle complex environmental and sustainability challenges. H2020 is rolling out smart city lighthouse projects to demonstrate drastic improvements and interactions in urban energy (including large-scale building renovation), transport and ICT. This is to be firmly embedded in long-term city planning and user participation, and to facilitate transfer

of best practices to other cities and communities. The European Innovation Partnership on Smart Cities and Communities (EIP-SCC)⁸ aims to promote integrated solutions leading to sustainability and a higher quality of life. The EERA Joint Programme on Smart Cities⁹ contributes to this purpose with new scientific methods, concepts and tools.

Projects and umbrella networks are established to improve learning between and from these pilot projects. A mapping and analysis of Smart Cities in the EU was published by the EU Directorate-General for Internal Policies in 2014¹⁰ also defining and benchmarking smart cities. Smart Cities can leverage the work of existing EU policy and programmes – e.g. CONCERTO, CIVITAS, Covenant of Mayors, future internet and Smarter Travel, among others – and major European initiatives such as EUROCITIES¹¹ or the European Network of Living Labs (ENoLL)¹². Smart cities can be identified and ranked along a variety of axes or dimensions of city structures, including smart energy, smart mobility, smart people, smart governance, smart economy, smart buildings, smart health and smart education. Shared access to data, with a specific challenge focused approach could be attractive to researchers and assist urban decision makers.

8. http://ec.europa.eu/eip/smartcities/index_en.htm

9. <https://www.eera-sc.eu/>

10. [http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET\(2014\)507480_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET(2014)507480_EN.pdf)

11. <http://www.eurocities.eu/>

12. <https://enoll.org/>

▶ GAPS, CHALLENGES AND FUTURE NEEDS

ENERGY SYSTEMS INTEGRATION – OVERVIEW. Research gaps have been identified: improving decision support tools and their data requirements; definition of key performance indicators; smart strategies for resource on demand implementation including energy storage; real time knowledge of city parameters; common data repositories; optimization and control structures to integrate energy systems in smart cities; improved design, installation and control of urban energy systems. European RD&I can take a global lead on integration of smart technologies in existing urban environments, adaptable to specific needs of users and communities. A wide variety of European cities have committed themselves to become urban laboratories to test, iterate and optimise these solutions and processes.

ENERGY NETWORKS AND STORAGE. The main gap is in the design reference architectures and modelling tools for *Smart Grid* control systems that involve different kinds of energy and relation to the local scale (multi-generation Low Voltage grids) that are able to deal with the combination of all use cases, including incentives to grid operator and electricity retailer in a liberalized market model whereby competing economical players work in parallel and operate commercial ICT systems to control a common grid infrastructure. Another gap is in the research into transactional arrangements and the testing of systems such as blockchain and crypto currencies to enable energy trading across multiple platforms that are resistant to cyber security threats. Alongside the electricity network gaps mentioned above there are also gaps in the provision of cost effective energy storage via heat, chemical and physical storage solutions. In terms of energy storage RIs on materials, production technologies and testing of battery cells and systems would be required to align with a European strategy supporting battery cell production in Europe.

SMART CITIES AND COMMUNITIES. There are no dedicated Smart Energy City or Community test bed related RIs in the ESFRI Roadmap. A solution linked to smart cities/communities initiatives could prove to be particularly pertinent and provide a

strong business case for aiding future city and community designs. The same applies for FCH, as the maturity of the technologies requires RIs to comply with the applied research requirements in line with industry's needs, including system testing and validation. We stress the important role of ICT, as this will be crucial in several important ways and especially when promoting the networking of smart cities to leverage experience and shared learning. Data protocols for sharing high volumes of information are needed, as well as particular attention to data privacy matters. Even more important will be how ICT will enable the future designs in urban form, services and infrastructures; moving beyond simply checking which data are available and how to best use these.

CLEAN AND EFFICIENT TRANSPORT. The focus on the need for low emission vehicles and the standardisation of testing is still a gap that needs to be filled. While the commercial vehicle developers are developing the vehicles, there is a lack of understanding on the impact and integration of large scale electrification of transport on the grid as both an energy demand management enabler – e.g. vehicle to grid, storage system integration and other forms of balancing loads and managing demand across heat, electricity and transport systems – and other distributed storage systems elements, not just of the *Smart Micro-grid*, but also of the broader energy systems. As the pace of development of electric vehicles is picking up and with the evolution of autonomous vehicles, it will be important to have RIs to enable researchers to study the effects of the legal frameworks as well as the physical infrastructure within which these will operate.

RENEWABLE ENERGY

Levelised cost of energy (LCOE) have dropped considerably over the last couple of years for renewable energy. This specifically holds for wind and solar PV, due to the development of new and more efficient concepts (research) as well as economy of scale effects due to the rapid increase of deployment. For all renewable options, including solar PV and wind which have already a substantial market penetration, further massive cost reductions can be achieved through development of new concepts – i.e. tandem solar cells, PV printing technologies, 15 MW turbines. With increasing deployment, cost reduction can be achieved through industry driven incremental innovation. However, specifically the development of new concepts requires long term research and state-of-the-art Research Infrastructure. Costs of development of these new concepts are high, knowledge is scattered and markets are often global. Therefore, substantial synergies can be obtained in sharing advanced Research Infrastructures.

Several EU initiatives are currently coordinating research activities in Europe like the Solar European Industrial Initiative (SEII), the EERA Joint Programme on Photovoltaics, the EERA Joint Programme on Bioenergy (EERA JP-Bioenergy), the European Industrial Bioenergy Initiative (EIBI)¹³ and BRIDGE-PPP, the EERA Joint program in deep Geothermal energy, the EERA Ocean Energy Joint program and European Ocean Energy Association (EU-OEA), the European Technology and Innovation Platform on Wind Energy (ETIPWind)¹⁴ and the EERA Joint Programme on Wind Energy¹⁵. In respect to Concentrated Solar Power (CSP), the EERA Joint Programme on CSP and the European Solar Thermal Electricity Association (ESTELA)¹⁶ include the main stakeholders of this sector. Finally, the mix of different hybrid renewable systems helps in defining economically appealing and environmentally sustainable strategies, including supporting grid stability and deliver balancing power.

13. http://www.etipbioenergy.eu/?option=com_content&view=article&id=191

14. <https://etipwind.eu/>

15. <https://www.eera-set.eu/eera-joint-programmes-jps/wind-energy/>

16. <http://www.estelasolar.org/>

|| CURRENT STATUS

PHOTOVOLTAICS

The Joint Research Programmes such as the EERA Joint Programme on Photovoltaic (EERA JP-PV) (37 partners from 19 EU Countries) or SOPHIA (17 partners) and its follow-up CHEETAH (34 partners) contribute to improving EU research and to optimize the use of RIs. According to the SOPHIA project and CHEETAH, the most relevant EU RIs are from Germany (3), Spain and Italy (2), and France, The Netherlands, Belgium, Denmark, Great Britain, Finland, Norway and Austria with one each.

The last strategic research agenda of the EU PV Technology Platform considers that the main challenges are related to the overall costs of the best technologies. A recent study¹⁷ shows data expected in 2020 and 2030, respectively, are: typical turnkey price for a 50 kW system (€/W, excl. VAT) (0.9 and 0.6); typical electricity generation costs in Southern Europe (€/kWh) (0.04 and 0.03 including 4% WACC), typical system energy payback in Southern Europe [years] (0.5-1.0 year in 2050 for smaller systems and depending on PV technology and energy mix¹⁸). For utility scale plants typical generation costs (LCoE) below 0.02 €/kWh are expected in Southern Europe in 2030 (including 4% WACC) and approaching 0.01 €/kWh in 2050. To reach these low LCOE values, or even lower, reliability of PV systems will be key (lifetimes beyond 30 years).

There is a state-of-the-art European basic research on materials and design of large plants, addressing quality and sustainability aspects. RIs strategy tends to be aligned with industrial needs. Financial efforts are focused on testing, pre-industrial facilities. Following the new IP Pillars, three main drivers for the development of new/existing infrastructures are: pilot/demo scale lines, manufacturing technologies/fabrication processes and modelling facilities for simulation and better forecasting the energy output of PV systems applied in different environments (from built environment to large power plants). Furthermore, social aspects for general public support to broadly install PV are becoming more

17. <http://www.etip-pv.eu/publications/etip-pv-reports.html>

18. <http://www.iea-pvps.org/index.php?id=314>

important. Europe's competitive edge rests on the excellent knowledge base of its researchers and engineers along with the existing operating infrastructures. Given the increasingly competitive environment, without steady and reliable R&D funding, this advantage is at risk.

RENEWABLE FUELS

The EU scientific effort is well articulated between associations aimed both at developing R&D and promoting flagship plants. In addition to the EERA Joint Programme on Bioenergy (36 partners from 19 EU countries) and the Bio-Based Industries Joint Undertaking (BBI JU)¹⁹, two other initiatives in the landscape are the European Technology and Innovation Platform (ETIP Bioenergy)²⁰ - created by merging the European Industrial Bioenergy Initiative (EIBI)²¹ and the European Biofuels Technology Platform (EBTP) - and the Joint Task Force on Bioenergy and Biofuels production with Carbon Capture and Storage (Bio-CCS JTF), involving members of ZEP (Zero Emissions Platform) and the EBTP. Research Infrastructures were grouped within H2020 Infrastructures - e.g. the Biofuels Research Infrastructure for Sharing Knowledge II (BRISK2)²², according to SET-Plan objectives and whose activity is to fund researchers from any EU Country to carry out research at any of the 28 EU partners' facilities. The RI was also a part of several Networks of Excellence, related to various aspects of bioenergy production and utilization, like SUSTDEV NOE-BIOENERGY, DER-LAB and ECO-ENGINES. Demo pre-commercial facilities exist, such as the UPM Stracel BTL (FR), Forest BtL Oy (FI), Beta Renewable (IT) or Abengoa 2G Ethanol Demo Plant (ES), among others. The main strategic research challenges are into feedstock and conversion processes of biomass into biofuel. Existing initiatives already connect high-level stakeholders and experts from relevant industries and research centres. The main challenges cover the efficiency, economic competitiveness and system integration of biomass conversion into biofuels and energy.

19. <https://bbi-europe.eu/>

20. <http://www.etipbioenergy.eu/>

21. http://www.etipbioenergy.eu/?option=com_content&view=article&id=191

22. <http://briskeu.com/>

The Standing Committee on Agricultural Research (SCAR) set up the Strategic Working Group *Sustainable Bio-Resources for a Growing Bioeconomy* (SWG SBGB) gathering the representatives of 15 countries and the Collaborative Working Group of 12 countries on *Integrated Biorefineries* (CWG IB). SWG SBGB discusses the issues related to more efficient production of biological resources, logistical questions, the biomass potential available across Europe, and fostering new connections between well-established sectors. The main technical barriers to the successful implementation of the bioeconomy identified by SWG SBGB include utilization of different bio-based feedstocks within a single biorefinery, and standardization of bio-based products. The CWG IB focuses on aspects related to the investment in research, innovation and skills.

EU-US cooperation on advanced biofuels is based on joint initiatives, such as the EC-US Task Force on Biotechnology Research: Bio-Based Products and Bioenergy Working Group. There is also research cooperation between EU and Central/South America through initiatives such as BECOOL in the framework of a joint EU-Brazil call on Advanced Biofuels.

CONCENTRATED SOLAR POWER

The European R&D community related to Concentrated Solar Power (CSP) is well established. The main EU RIs are managed by: DLR in Germany (facilities located in Cologne, Jülich and Stuttgart), ENEA in Italy (with facilities in Casaccia and Portici), CNRS in France (Odeillo) and CIEMAT in Spain (through Plataforma Solar de Almería-PSA). The Cyprus Institute (Cyl), the IMDEA-Energy in Spain and the University of Évora in Portugal have recently expanded the landscape of large-scale facilities, contributing with the Pentakomo (Cyl), Móstoles (IMDEA) and Mitra test sites. Most of these RIs are collaborating, offering international access to their facilities through the FP7 European project SFERA-II (2013-2017). These RIs are also members of the EERA Joint Programme on Concentrating Solar Power (EERA JP-CSP), participating in its FP7 IRPSTAGE-STE (2014-2018) and partly in the **ESFRI Project EU-SOLARIS**.

Two complementary strategic research agendas are in place. ESTELA's (European Solar Thermal Electricity Association)

Strategic Research Agenda (SRA) was published in 2013. This SRA aims to directly meet the industrial 2020 targets through: a) increase efficiency/cost reduction – mirrors, heat transfer fluid and others as selective coatings and prediction/operation tools; b) dispatch ability – integration systems, storage systems and forecasting models to regulate and manage electricity production; c) environmental profile – reduce current impact of heat transfer fluid, water desalination and reduce water consumption without jeopardizing the plant efficiency. Another more recent research agenda is the *Initiative for Global Leadership in Concentrated Solar Power*, which has been submitted to the SET-Plan Steering Group for final endorsement beginning of 2017. It has been developed within the EERA JP-CSP (29 participants) and STAGE-STE project. The **ESFRI Project EU-SOLARIS** is expected to be the first of its kind, where industrial needs and private funding will play a significant role.

From the commercial deployment point of view, it is worth mentioning that CSP plants with a cumulative capacity of about 2.3 GW were in commercial operation in Spain in December 2016, representing about half (48%) of the worldwide capacity. Outside Europe, about 1.74 GW of CSP are currently in operation in the US, while China is championing new developments with 1.34 GW under construction or development. Globally, more than 100 projects are in planning phase, mainly in India, Morocco, South Africa, Middle East countries and Chile. However, the need for additional RIs in Europe has been identified according to the needs of the commercial CSP plants, where the cost competitiveness is a key barrier along with the operational flexibility and energy dispatchability. In this area, the US *SunShot* Initiative programme aims to reduce the levelised cost of electricity (LCOE) generated from CSP systems to 6 cents/kWh, without any subsidies, by 2020.

WIND

Many initiatives coordinate the research activities in Europe: the European Wind Industrial Initiative (EWII) and EERA joint program on Wind energy (49 partners from 14 EU countries), European Technology and Innovation Platform on Wind Energy (ETIP-Wind), driven by the European wind energy industry and coordinated by the European Wind Energy Association, and the European

Academy of Wind Energy (43 entities from 14 EU countries). In this sector, the RIs in the EU are: a) Wind Turbines Test Fields with RIs in Germany (3), Spain (2), Greece, Denmark (2), Netherlands and Norway (1); b) Components Test Facilities with RIs in Denmark and Germany (3), Spain, United Kingdom, Netherlands and Finland with 1; c) Wind Tunnels with RIs in Greece and Netherlands, Norway, Denmark, Finland and Germany (1); d) Wind Energy Integration Testing Facilities distributed in Spain (4), Norway, Netherlands, Germany and Denmark (1). A specific reference goes to the **ESFRI Project WindScanner**, in the ESFRI Roadmap since 2010, which finalised its first Preparatory Phase at the end of 2015. The **ESFRI Project WindScanner** uses remote sensing-based wind measurement systems to provide detailed wind field maps of the wind and turbulence conditions around either a single wind turbine or across a farm covering several square kilometres. There are 4 RIs related to material testing and hydraulic located in Greece, Germany, Denmark and Norway.

The challenges are the following: a) resource assessment and spatial planning, including the publication of an EU Wind Atlas in the next five years and the better understanding of wind characteristics that are relevant for the safe operation of larger and larger wind turbines; b) wind power systems that include the development of new wind turbines and components up to 15-20 MW in the year 2020; c) wind energy integration into the grid, including the long distance connection of large wind farms to the grid; d) offshore deployment and operations that include the development and testing of new structures for deep water. Industry needs test facilities to innovate the design.

The ETIP Wind's Strategic Research and Innovation Agenda (SRIA) has three objectives: i) cost reduction, ii) System integration, iii) First class human resources. WindEurope expect the EU Wind Energy sector to grow to 205 GW, including 24 GW of offshore wind by 2020, to cover 16.5% of EU's electricity demand. By 2030, wind should be able to cover 30% of the EU's electricity demand. The EU wind fleet would consist of 323 GW of wind, including 70 GW of offshore wind. Offshore wind would need to ramp up to a pace of more than 4 GW per year. At the end of 2016, the EU had a fleet of 153 GW of wind power, China had 169 GW, and the US 82 GW. There were 487 GW installed worldwide.

Regarding the existing test facilities abroad, US shows a very competitive scientific community with high level test facilities – e.g. NREL-NWTC blade test facilities, drive train test facilities and field test and Clemson's University, 15 MW drive train testing facility, and the WTTC with a 90m blade test facility.

GEOTHERMAL

Geothermal energy in the Earth's upper few kilometres is vast and the potential in this renewable energy source is of significant importance for the energy shift from fossil to environmental friendly energy. Geothermal energy appears to have the potential to become a very important, potentially even dominant, supply of heat energy and dispatchable electricity production in the near future. The potential for utilization needs to be measured, production technology, and enhanced or new innovative solutions developed to access this energy.

All major research institutions are involved in the EERA Joint Programme on Geothermal Energy – 37 participants from 12 EU countries, including Iceland, Turkey and Switzerland. Other major research centres – which cover wide areas of geothermal research – and technology platforms are located in Iceland, France, Italy, Germany or Spain. There are 5 sites in construction or planned and 2 existing sites focused on research and demonstration: Soultz-sous-Forêts (FR) and Groß Schönebeck (DE). Other large existing industry-owned sites are in Iceland.

Geothermal energy for heat and cold extraction and storage is an increasingly important component in the energy balance of buildings and for neighbourhood heating/cooling systems. For traditional, high, intermediate and low-temperature areas, improvements in production methods, drilling and well completion, mapping and managing the underground reservoirs, are essential. Recent results from deep drilling to access superheated or even supercritical fluids are encouraging, indicating the possibility of dramatic improvements in production as well as addressing unexplored geothermal potential. Possible major production from offshore areas is becoming more relevant, as offshore technology improves and the production cost decreases. A number of major projects investigating enhanced geothermal systems (EGS) are ongoing, including in Europe. In EGS, the

permeability of the deep subsurface is increased using hydro-fracturing and other methods. If cost-effective technology for achieving this can be developed, major large-scale geothermal energy production in many non-traditional areas will rapidly follow. Key issues here include costs and limiting induced seismicity caused by the operations.

The main strategic research agendas are from the Technology Platform (TP) on Renewable Heating and Cooling and the EERA Joint Programme on Geothermal Energy. The challenges in 5 years (Exploration technologies to image the subsurface to reduce the mining risk prior to drilling) are: to define the reservoir characteristics and geothermal potential in different environments, to develop experimental test of materials and treatment to prevent or mitigate corrosion and scaling. The longer term challenges are: cost-effective drilling technologies for very deep geothermal wells at extreme conditions of temperature and pressure including supercritical fluid systems; prediction of geo-mechanical behaviour of fracture zones, with particular focus on reservoir performance evaluation and induced seismicity; improvement of methods to enhance reservoir performance and to study the processes of long-term geothermal exploitation; enhancing the viability of current and potential geothermal resources by improving thermodynamic cycles and optimizing power conversion; securing natural resources and ensuring sustainable utilization of underground space. Currently, the EU RIs for hotter systems are associated with volcanic areas – e.g. Iceland, Italy, Spain, Portugal or Greece. Testing of drilling methods (e.g. PENA, EL) or of process at the subsurface (e.g. GeoLaB, DE), are in construction or planned.

OCEAN

The most relevant EU initiatives are: EERA Joint Programme on Ocean Energy (10 institutions from 8 EU countries); EU-OEA (80 members); OCEANERA-NET with EU research organizations from 9 countries; MARINET2 network with 57 testing facilities at 38 research organisations from 13 countries and the intergovernmental collaboration OES with 21 countries. The list of EU RIs grouped by countries is: United Kingdom (5), Spain (5), Portugal (3), Norway (2), Ireland, Italy, Netherlands, Germany and France (1). In Sweden there are no sea test facilities, only 2 research sites. The Europe-

an Ocean Energy Roadmap 2010-2050 published by EU-OEA identifies: i) installation of ocean energy generating facilities with a combined minimum capacity of more than 240 MWh; ii) developing or refining test sites for ocean energy conversion devices in real operating environments; iii) Grid availability; iv) resource assessment to support ocean energy deployment.

The industrial goals are to install 3.6 GW of ocean energy systems by 2020 and to reach 188 GW by 2050 (EU-OEA Roadmap 2010-2050). However, many systems have not been tested yet under real operation conditions and need to undergo final long-term reliability testing before being commercially deployed in harsh environments. There is widespread international interest in Wave & Tidal (W&T) energy and it is particularly high in Australia, Asia, US & South America. Currently there are a small number of W&T energy systems installed on the global level. Europe has global leadership in W&T energy technologies and industrial know-how. European projects such as SI Ocean may provide a basis for more intensive cooperation in the future.

GAPS, CHALLENGES AND FUTURE NEEDS

In **PHOTOVOLTAIC SOLAR ENERGY**, it is important to establish a long-term European cooperation in the PV R&D sector, by sharing knowledge, organizing workshops, exchange and training researchers inside and outside Europe. An efficient use of infrastructures is also needed to accelerate the implementation of innovative technologies in the PV industry. Furthermore, it will be needed to install relevant pilot production lines to demonstrate these novel technologies and to bring back commercial manufacturing in Europe.

Lack of standardization is the biggest obstacle to rapid cost reduction and definitive deployment of the **CONCENTRATED SOLAR POWER** sector. Activities are currently underway in Europe under control of AENOR (the Spanish official standardization body), the International Electro-technical Committee (IEC) and SolarPACES (IEA Implementing Agreement). Activities in this

respect are on their way within STAGE-STE and SFERA-II projects, too.

Concerning **WIND ENERGY**, better coordination of EU RIs should create the conditions for the long-term development. There is need of new multi-actor facilities – especially in the field of exploring and understanding new physics for larger turbines. In Wind Conditions an important infrastructure can be the the **ESFRI Project WindScanner**. Low-speed, high-Reynold number aerodynamics requires large and dedicated wind tunnels. The development of large turbines become such large investments that the industry requires trans-European RIs for short-term technology validation purposes.

The development of new **GEOTHERMAL** technologies can be expensive and projects may be high-risk in the sense that commercial success is not guaranteed. Therefore society cannot rely only on commercial initiatives, and public R&D support is often necessary. A coordinated trans-European initiative to co-exploit existing and new geothermal test sites would appear to be strongly motivated. Such an initiative would naturally link to and significantly enhance existing ESFRI initiatives such as the **ESFRI Landmark EPOS** (European Plate Observing System, ENV).

In **OCEAN ENERGY**, the establishment of an integrated network of testing facilities is very important, including full scale sites for testing of single units under real operation conditions, as well as up-scaling to the array level (MARINET2, Foresea). There is a need for technical de-risking through the development and implementation of best practices, quality metrics and standards (MaRINET2, MARINERG-i). Increased joint development activity across the test infrastructure community is required to address the technical barriers and deliver viable devices to the market (MARINERG-i).

RI is needed for advancements in production of **BIOFUELS**, biomass upgrading as part of optimized logistics concepts, hydrogen production based on gasification with reforming, efficient cultivation systems for third generation biofuels sources and system integration schemes between different sources and with the grid.

EFFICIENT ENERGY CONVERSION AND USE

Seeking enhanced efficiency in energy production (actually, *harvesting* energy from the natural environment), conversion and use is an important and viable aim, even though it is likely that this will not lead to total reductions in energy use simply because the benefits of using more energy will be considered to outweigh costs, including environmental costs. Especially because of the increase in intermittent energy production from renewable sources, energy efficiency is in practice increasingly and intimately related to energy systems integration and a systems perspective on efficiency is often central. This can relate to the capacity factor of wind turbines and the source of electricity during low-wind periods, the use of relatively small-scale thermal storage functions in buildings to buffer variations in electricity production, or to a systems assessment where the true (energy) costs of improved new buildings or renovations is weighed against the potential energy savings. In the broader picture, it is often the true total system of costs and savings to society which should be in focus, not the energy producer's or consumer's perspective, which may be strongly affected by taxes and subsidies. It is likely that significant new Research Infrastructures will be necessary to optimally approach these challenges. However, the future system is constructed: it is vital that it can reliably and securely supply the necessary base-load power at all times and at reasonable cost.

CURRENT STATUS

ENERGY EFFICIENCY IN BUILDINGS

For effectiveness at a systems level and especially because of the intermittent supply from some electricity sources, it is becoming increasingly important that the energy consumption and efficiency of buildings are considered together with the energy supply mechanisms available, for example plants producing both electricity and heat for use in buildings. Optimal solutions for different types of buildings – e.g. industrial, commercial, single dwelling, high rise flats – in different climatic conditions will be different. It is especially important that rapid changes in demand for heating and cooling in buildings does not destabilize the electricity supply system, which will require some integrated steering of supply and demand. It is also important that optimization of electricity use does not lead to severe de-optimization in buildings, such as increased maintenance costs due to fluctuating internal temperatures and humidity, or (energy) costs for additional insulation which outweigh energy savings for heating/cooling. The practical situation is complex, and consumer behaviour is affected by various political decisions related to, for instance, building norms, taxation and subsidies. It is important that these decisions are based on solid empirical data. This demands investments in *real life laboratory* Research Infrastructures, including monitoring energy use in buildings and energy production. As the European energy system is becoming increasingly integrated, a pan-European perspective is necessary.

ENERGY EFFICIENCY AND USE IN INDUSTRY

The concepts mentioned above regarding buildings and the need for a systems perspective are also relevant for industry. In addition, there are major possibilities for improved energy efficiency and/or reduced greenhouse emissions from many industrial processes. Not all waste products (waste material, heat) are effectively utilized today, seen from an energy efficiency perspective, even if promising results have already been obtained - e.g. in heavy industry. Where a major opportunity for enhanced industrial energy efficiency is assessed, research and development investments may be strongly

motivated. In some cases, public investment in research and pilot and demonstration plants will be motivated. It is important that new insights and solutions developed in different European countries are effectively spread. The following areas may merit major investments over the coming years.

A state-of-the-art automation information technology and connectivity will enable the digitalization of production that goes far beyond conventional automation of industrial production. Initiatives have been started around the globe to foster digitalization, like IIoT (Industrial Internet of Things)²³ in the US, Industrie 4.0²⁴ in Germany, or China 2025²⁵. Another aspect of energy saving represents predictive modelling and simulation, coupled with the artificial intelligence for automatic optimization of processing with respect to use of resources, energy, productivity and product quality. The intelligent combination of sensor technology combined with these digital models lead to new dimensions in the efficient use of energy in industry.

Metals, polymers and ceramics are crucial materials for energy transition and low-carbon economy. Since it will never be possible to produce them without energy, we have to change to carbon-free energy sources in order to reduce or prevent CO₂ emissions in the long term. Industry is working consistently on the further development of the processes towards the stepwise de-carbonization of production. Specifically, the companies plan to make a gradual shift from the use of fossil fuels via bridging technologies to the potential use of hydrogen in the production of materials. Areas which may merit major investment over the coming years include: cement and ceramic production (much CO₂ release), the aluminium, iron and steel industries, pulp mills for paper production, etc. Important energy

23. <https://www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/>

24. <https://www.gtai.de/GTAI/Navigation/EN/Invest/industrie-4-0.html>

25. <https://www.csis.org/analysis/made-china-2025>

saving aspects are also: recycling, refinement, re-use and waste elimination.

Very important energy related research is in the metals industry advancing in the directions of: Light alloys and metal-matrix composites (for lighter vehicles), High-temperature extreme alloys and composites (for increase of thermodynamic efficiency in boilers), and development of thermoelectric alloys that will in the future be able to convert the waste heat into electricity (see project Metallurgy Europe)²⁶.

POWER-TO-X (-TO-POWER)

The increasing use of intermittent sources of energy such as wind and solar demands new solutions to ensure a continuously reliable electricity supply. With the share of renewable energy rising, the electricity grid runs up against its limits due to the large dynamic fluctuations which have to be accommodated. In this context, energy storage on different time scales gains importance. Battery storage can contribute, but long time storage of high energy quantities calls for other solutions. One way which reduces the CO₂ footprint of the whole energy system is to convert electricity at times of surplus power into storable energy, to be released at times of low supply. Long-term storage, needed to meet seasonal variation in supply and demand and which could limit the need for grid expansion, will only be possible by converting excess energy into chemical carriers by using carbon dioxide, water and/or nitrogen, the so-called Power-to-X (P2X) scheme. This includes conversion into hydrogen or methane gas (P2G). Further chemical processing can also lead to liquid fuels or base chemicals for value added products. Apart from their general contribution to decarbonizing the energy supply, these process routes provide potential for the saving of fossil resources in industry. The topic P2X therefore responds to the EU SET Plan actions 1 (renewables), 2 (materials) and 8 (transportation).

Currently, European countries run around 50 P2G demonstration projects, with efforts accelerating and increasing over the past 3 years. The main focus is on splitting of water and/or CO₂ to produce hydrogen or syngas, complemented by the respective work on system integration. For example, the European STORE&GO project focuses

26. <http://metallurgy-europe.eu/>

on the synthesis step at 1 MW level in three demonstration environments in Germany, Italy and Switzerland. France recently started the 1 MW Jupiter 1000 project. Germany released a 10-year Kopernikus research project Power-to-X. With 50 partners from research, industry and society it represents the biggest EU wide concerted effort in the field so far. The focus is on low-emission electricity-based liquid fuels and chemical products. Another German flagship project, Carbon2Chem, targets the conversion of carbon dioxide from the steel industry into fuels and base chemicals. EERA JP Energy Storage covers the area of P2X in its sub-programme Chemical Storage.

CARBON DIOXIDE CAPTURE, STORAGE AND UTILIZATION

Carbon Dioxide Capture, Transport and Storage (CCS) is one of the main objectives of the European energy policy, the low carbon policy. Most of the European countries are focusing on decarbonising the power sector and energy intensive industry and thus reducing anthropogenic CO₂ emissions. However, political uncertainties related to safety on land storage of the CCS force countries with big industrial activities like Germany to step out of research and development in CCS. The Global CCS Institute gives among other information, a database of facilities world wide ranging from large scale, pilot and demonstration to test centres²⁷. NETL's Carbon Capture and Storage Database²⁸ includes active, proposed, and terminated CCS projects worldwide. The database contains several hundred CCS projects worldwide. European activities towards CCS are served by two entities: the Zero emission Platform (ZEP) and the European Energy Research Alliance Joint Programme on CCS (EERA JP-CCS). ZEP is a unique coalition of stakeholders and acts as advisor to the European Commission on the research, demonstration and deployment of CCS for combating climate change. Nineteen different countries contribute actively to ZEP's activities, while 40 different companies and organisations comprise the Advisory Council. The EERA Joint Programme on CCS (EERA JP-CCS) has a strong R&D focus and encompasses 40 public European research centres and universities working on a common

27. <https://www.globalccsinstitute.com/>

28. <https://www.netl.doe.gov/research/coal/carbon-capture>

programme. The EERA JP-CCS including a new CO₂ transport sub programme and has contributed to the SET Plan Integrated Roadmap. Member States are involved in the CCS deployment activities and plans through the European Industrial Initiative EII on CCS. Technology Centre Mongstad (TCM) is the world's largest facility for testing and improving CO₂ capture using two units each approximately 12 MWe in size, able to capturing 100.000 tonnes CO₂/year. A new legal operation agreement for TCM is established through 2020. The major open access RI on the ESFRI Roadmap is the **ESFRI Landmark ECCSEL ERIC**, a top quality European Research Infrastructure devoted to second and third generation CCS technologies. For accelerating the commercialisation and deployment of CCS methods, the **ESFRI Landmark ECCSEL ERIC** has been transferred to a European Research Infrastructure Consortium (ERIC) as a legal entity recognised by the Council Regulation of the European Commission offering access to 44 research facilities. The UKCCSRC Pilot-scale Advanced Capture Technology (PACT) facilities are national specialist R&D facilities for combustion and carbon capture technology research. The purpose of PACT is to support and catalyze industrial and academic R&D in order to accelerate the development and commercialization of novel technologies for carbon capture and clean power generation. There is a network coordination between TCM, **ESFRI Landmark ECCSEL ERIC** and PACT. Long-term monitoring and documentation of stored CO₂ in geological reservoirs have been achieved. The Sleipner CO₂ Storage facility was the first in the world to inject CO₂ into a dedicated offshore geological sandstone reservoir since 1996 and over 16.5 million tonnes have been injected at the end of 2016. The Snøhvit CO₂ Storage facilities has captured more than 4 million tonnes of CO₂ at an LNG facility in northern Norway and transported in a pipeline back to the Snøhvit field offshore and injected into a storage reservoir. To capture CO₂ from industrial processes has some advantages like lower capture cost, excess energy that can be used for CO₂ capture and stable CO₂ source. The concentration of CO₂ in the flue gas is often higher than in power systems, in cement plants typically from 18 to 22 vol%. They are often also located in industrial clusters/coastal locations which can possibly lower transport cost. There are three pilot plants in Captur-

ing Carbon in Norway; Norcem AS (cement plant), Yara Norge AS (ammonia plant) and Klemetsrudanlegget AS (waste-to-energy-recovery plant) selected for detailed studies of full-scale carbon capture at their respective plants. Total CO₂ injection capacity for all three plants in full scale operation is approximately 1.3 Mtpa. A combined pipeline and shipping system is being examined for CO₂ storage in the Smeaheia area offshore. A final investment decision is targeted for 2019 with ambitions to begin operation in 2022.

There is increasing attention towards CO₂ utilisation (CCU). Specifically, a number of facilities that use CO₂ in products, or to support operations have been constructed or announced in the last decade. It is important to note that not all CO₂ utilisation options will necessarily contribute to longer term climate change mitigation: the storage lifetime can be counted in days to years as opposed to centuries. There are many different ways to use CO₂ and key technologies can be grouped into polycarbonate plastics, chemicals and mineralization/cements. Development of new catalysts replacing chemical products usually derived from fossil fuels is of major interest. Notwithstanding the above points, the market for products derived from use of CO₂ is small relative to what is needed to be stored in order to limit global temperature rise to well below 2°C – a cumulative 90 Gigatonnes of CO₂ captured and stored in the period to 2050.

▶ GAPS, CHALLENGES AND FUTURE NEEDS

It can be argued that research has been focussing on single components, rather than concentrating on the analysis of complex energy systems on different scales where the different elements interact. Research Infrastructures investigating systems in practical use could be of significant benefit. One example of this is the use of **ENERGY IN BUILDINGS**, and increasing the supply of energy from buildings. The latter may relate to production of electricity, for example, or exploiting the thermal storage potential of buildings to facilitate the use of intermittent electricity production from renewable sources. Similarly, projects related to the use of waste products from industry for energy production have significant potential. Realizing such potentials may demand Research Infrastructure initiatives, leading into pilot and demonstration activities on commercial scale.

POWER-TO-X addresses core research questions on electrolysis and plasmochemical conversion, including catalysis, materials, membranes and efficiency on one hand, and the synthesis of fuels and base chemicals on the other hand. For P2X processes to be a major component in the future energy system, they must be adequately energy efficient and cost efficient. Major investments, from research to pilot and demonstration plants, will be necessary to achieve this. The R&D tasks range from basic research over questions of up-scaling to the demonstration of large plants combining production and use. Local infrastructures and expertise in electro-chemical and plasma-chemical conversion, physical separation of gases and chemical synthesis needs to be combined and developed on European scale and size for creating efficient and effective integrated P2X solutions. This gap could be filled by an ESFRI distributed RI bringing together resources and testing facilities of EU Industry, government and non-governmental organizations.

It remains unclear if large scale **CARBON DIOXIDE CAPTURE, STORAGE AND UTILIZATION** will become an important part of the energy system, but there is a possibility that this is the case. Therefore, further major investments in relevant Research Infrastructure should be considered.

NUCLEAR ENERGY

II CURRENT STATUS

NUCLEAR FISSION

The 128 Nuclear Power Plants²⁹ (NPPs) are supplying 815.2 TWh (about 30% of electricity) in the EU. 4 NPPs are under construction and 24 in planning. Nuclear power thus plays an important role to provide a stable, base load electricity. The main strategic objectives are the safety aspects and the long-term waste disposal. The previous landscape analysis made a detailed list of aimings towards these objectives. Since the analysis is rather recent, no major change has occurred. In the field of Accelerator Driven System which could be used for transmutation of long-lived actinides, a staged approach was adopted by the **ESFRI Project MYRRHA**, leading to the full realisation of the facility by 2030.

In many countries, the issue of prolonging the life of existing NPPs leads to the development of materials research under nuclear irradiation. This could be done through experiments and numerical simulations. The latter, with the development of high performance computers (HPC), has great potential for a cross-fertilisation with other materials science in general, and in particular in the field of nuclear fusion (see below).

In view of the ageing of NPPs, as well as the decision from some countries to step out of nuclear energy, the issue of the dismantling of NPPs is becoming an important one. Many Master Programmes have included this topic in their cursus.

Present NPPs are based on three main concepts (Heavy Water, Pressurized Water or Boiling Water). The Generation IV Initiative offers the perspective of a better use of the fuel, increase of safety and reducing the amount of long-lived waste. Another new development of interest that should be encouraged is the Small Modular Reactor, delivering about 300 MWe.

NUCLEAR FUSION

The European fusion programme³⁰ has two

29. <http://www.world-nuclear.org/information-library/country-profiles/others/european-union.aspx>

30. <https://www.euro-fusion.org/programme/>

main objectives, to prepare the successful operation of ITER and the preparation of DEMO. The construction of the ITER tokamak is now moving at full speed, with a first plasma by 2025 and the D-T operation by the end of 2035.

From a physics perspective, two concepts are being explored in the Euratom programme, the tokamak and the stellarator. The consortium EUROfusion operates all the main installations, the tokamaks ASDEX-Upgrade, JET, MAST, TCV and WEST and the superconducting stellarator W7-X. For the study of the physics of the divertor – a key element where heat and particles are exhausted from the plasma – a dedicated device, the Divertor Test Tokamak (DTT)³¹, is being considered and was recently approved. In the framework of the Broader Approach (BA) Agreement³² EU and Japan are building a new superconducting tokamak JT-60SA, which will be jointly exploited by EU and Japanese teams.

The second main objective of the EU fusion programme is the design of a DEMO demonstration fusion reactor. DEMO will produce a substantial amount of electricity and be self-sufficient in Tritium³³ and is scheduled to be operational by the mid of the 21st century. During Horizon 2020, DEMO work will be in the pre-conceptual phase, where many design concepts are examined, and a concept selection will be performed in FPg.

The construction of a fusion reactor relies on the knowledge of suitable material under the irradiation by 14 MeV neutrons. Within the BA, R&D for the neutron irradiation source IFMIF is being developed for critical components. However, the BA does not foresee its construction. The EUROfusion programme – based on the roadmap to the realisation of fusion energy – still supports IFMIF and proposes the **ESFRI Project IFMIF-DONES** (International Fusion

31. Italy is considering the funding of DTT as a national programme while waiting for a later funding by EUROfusion

32. The Broader Approach agreement between Japan and EURATOM covers many other activities <http://fusionforenergy.europa.eu/understandingfusion/broaderapproach.aspx>

33. Tritium, a « fuel » of the fusion reactor does not exist in nature and must be produced by the fusion reactor itself, if one considers an industrial deployment of fusion electricity.

Materials Irradiation Facility-Demo Oriented NEutron Source) as an interim step.

The EUROfusion programme benefitted since its beginning from the HELIOS HPC in Rokkasho. After its decommissioning, since 2016, a new European HPC Marconi-Fusion is in operation with a capacity of 6 petaflops. This opens up new possibilities for fusion plasma simulation as well as for materials science.

Both fission and fusion are part of EURATOM. The impact of the Brexit on these two fields is still to be negotiated. In the case of fusion, JET is the main and largest tokamak in operation with the ability to operate with D-T mixture and plays a pivotal role in the scientific preparation of ITER. How the issue will be solved will have impact on the medium term fusion programme.

CROSS-CUTTING ISSUES BETWEEN FISSION AND FUSION

Many topics are common to fission and fusion. Materials research is the most prominent one. For fission it is a key element for the prolongation of NPP operation. For fusion, the qualification of suitable material is crucial for the construction of a fusion reactor. As mentioned, the field of experimental investigation and numerical simulation are cross-cutting fields. Another cross-cutting issue is the development of accelerator to be used in ADS for fission and neutron source for fusion material irradiation.

▶ GAPS, CHALLENGES AND FUTURE NEEDS

Two main gaps have been identified: i) for fission, the interest in SMR should trigger an experimental effort in this field; ii) for fusion, the issue of the divertor and of material development require the implementation of the **ESFRI Project IFMIF-DONES** device.

As research on nuclear energy is linked to national policies on the use of nuclear generated electricity, the above considerations of the research goals in this area do not engage, in any ways, national financial or political commitments.

CROSS-SECTIONAL ENERGY RIs

RIs for simulation and modelling, as well as advanced characterization and testing facilities, are essential tools for designing advanced materials, for exploring energy conversion processes and for designing and optimizing energy systems. Energy technology-oriented roadmaps have prioritized the need for such RIs in Europe. Progress in energy research specifically could be enhanced by comprehensively using methods or data that are already available or newly generated. The energy research community thus would strongly benefit from exploiting synergies across different technologies and could further advance the cross-cutting methodological development. Cross-cutting RIs providing these services therefore are the key to accelerating innovation in this sector.

|| CURRENT STATUS

ENERGY MATERIALS

Energy technologies with their high and rapidly changing technical demands are particularly dependent on fast innovations in the structural and functional materials sector. The markets for materials for energy and environmental applications are expected to grow at an above average rate. The main research task in this context is to develop materials with increasing performance and reliability at lower costs. At European level the topic, for example, is addressed as part of the *SET-Plan Roadmap Materials for Low Carbon Technologies* and in various cross-sectional aspects of the 10 key actions to the SET-Plan. It finds expression in the correspondent research and industrial platforms (e.g. EERA, Ells, EMIRI). Energy materials research currently exploits large-scale European characterization facilities, such as the synchrotrons **ESFRI Landmark ESRF EBS** (European Synchrotron Radiation Facility Extremely Brilliant Source, PSE), PSI, DESY, Diamond, ALBA, Soleil, BESSY, ANKA, Elettra, the future **ESFRI Landmark European Spallation Source ERIC** (PSE), the neutron facilities **ESFRI Landmark ILL** (Institut Max von Laue - Paul Langevin, PSE), ISIS, FRM-2 Munich, SINQ and latest generation electron microscopes. Computational materials science gains importance with regard to creating new materials or chemical agents with tailor-made properties (Computational Materials Design). For this, High Performance Computing (HPC) Infrastructures and data processing (see below) are increasingly used in the analysis of experimental data to determine materials properties and in simulating complex 3D dynamic transport, reaction, ageing and damage processes.

DATA, SIMULATION AND MODELLING

The multi-disciplinarity of energy-related themes means that it is difficult to identify a community for this field at first sight. The task is integrating activities with the objective of developing and applying scale bridging approaches to design new materials and to study materials as well as energy related processes. Energy networks and systems, from local to macroscopic scales, need detailed and large volume data handling and model-based processing. Quite a number of cross-disciplinary energy-relevant topics have to be addressed like, for example, new materials design; energy conversion processes; systems design and operational and lifecycle optimization. Further examples are process modelling for nuclear repositories, fusion reactor modelling or energy market modelling via high-resolution renewable energy production forecasts. The European Technology Platform for High Performance Computing (ETP4HPC), and the **ESFRI Landmark PRACE** (Partnership for Advanced Computing in Europe, DIGIT) facilitate high-impact scientific discovery and engineering research and development across all disciplines. The new Energy oriented Centre of Excellence for computing applications (EoCoE), working closely with associated experimental and industrial groups, is expected to have a multiscale integrating character and contribute to filling this gap, along with databases and research platforms. Distributed RI platforms such as DERlab and ERIC-Lab and a rising number of national *living* laboratories collecting and processing data of complex real energy systems have the potential to advance the digital realtime integration of distributed and volatile energy resources into energy systems.

▶ GAPS, CHALLENGES AND FUTURE NEEDS

ENERGY MATERIALS. In spite of the availability of quite a number of methods and facilities, large cross-sectional RIs and research platforms explicitly dedicated to R&D for energy materials still often lack coherence with regard to scale-bridging and multi-method approaches. RI for materials discovery/development and for materials characterization covering length scales – from the atomic structure to macroscopic engineering components – and for different time scales – ranging from sub-picoseconds up to the lifetime of energy systems of tens of years – should also include life cycle experiments, ageing and non-equilibrium loads. The future of characterization therefore is expected not only to include individual techniques which are pushed to their limits, but also to be a situation where the community devises coherent and synergistic strategies employing a range of cutting-edge characterization methods to address complex multiscale problems in materials and systems. In addition, there is a particularly strong need to develop techniques for *in situ* and *in operando* studies of energy materials and components during operation – e.g. for electrochemical and electronic materials and devices.

DATA, SIMULATION AND MODELLING. At the front end of the energy-related innovation chain, the objective of computational materials science and chemistry is to create new reliable and cost-efficient materials or chemical agents for changing demands within the new energy systems. For this, dedicated HPC and integrated databases are needed for the rational design of new materials in terms of structure and properties, but also in simulating complex conversion processes on all scales and *in situ/in operando*.

On the energy system's side, a multi-scale approach is needed to properly address the interaction between local power, heat generation and energy carriers, as well as between the distributed and local energy systems and the central energy system. The corresponding system transformation, based on emerging technologies, requires tests and validation before implementation. In order to meet these requirements, while keeping legal, technical and environmental standards, there is a need for expanding the European capacity in energy systems real-time simulation. Modelling of large-scale energy storage, power grids and complete urban system structures is necessary, including information on the social and economic dimensions. RI in this field would provide a virtual environment of the energy system in which new policies, regulation, control strategies or technologies can be tested and optimized *ex ante*. Since much of the development and smart resource management happen locally, the models should be able to capture data with very detailed geographical resolution. On the other hand, merging regional, national and European views is needed when outlining the design of the future energy system and related policies. This knowledge requires adequate HPC capacities as well as concerted approaches of handling big data volumes. It is key to further political decisions and to determining the immense investments needed in the energy sector in coming years.

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PART2

LANDSCAPE ANALYSIS - SECTION1

ENVIRONMENT

ENVIRONMENT

Environmental sciences are traditionally divided into four research and study domains: **ATMOSPHERE**, **HYDROSPHERE**, **BIOSPHERE** and **GEOSPHERE**. These different *spheres* are closely interlinked, and therefore environmental sciences can also be presented according to *Grand Challenges*, such as loss of biodiversity, pollution, depletion of natural resources, risks, hazards and climate change.

Atmosphere, hydrosphere, biosphere and geosphere are closely interlinked spheres of environmental sciences responding to big human challenges from loss of biodiversity to climate change.

Many of the most critical and urgent issues that human society faces are linked to key environmental challenges. Managing and responding to natural and anthropic environmental changes need to be understood at the Earth System level. The effect of pollution and climate change, including associated impacts on biodiversity and ecosystem integrity, need to be fully understood urgently. The sustainable and responsible use of key natural resources and ecosystem services such as food, water, energy and minerals by a more demanding and growing population is vital. Modern society is progressively vulnerable to the increased frequency of natural hazards such as extreme weather, earthquakes, space weather, epidemic disease outbreaks, which can cause loss of life and have an enormous impact on the society with large economic deficits. Tackling environmental challenges is crucial for mankind and for life on Earth and given the scale, complexity and the interlinkages of the challenges, a multidisciplinary approach is essential. Layers of complexity to carrying out environmental research are added by the multidisciplinary aspect amongst the main Earth system domains and by the considerable range of spatial and temporal scales involved.

Because of its complexity, the environmental research as a whole should be facilitated by comprehensive observations with an integrated approach including experiments and modelling which are essential for un-

derstanding and predicting the Earth's environmental system. A federated approach to IT resources and e-science facilities – including liable data policies according to the FAIR principle – is also necessary. The objective of achieving a comprehensive multidisciplinary approach to improve our scientific understanding of the Earth's system can be obtained with the realisation of the current ensemble of RIs in the Environmental domain which are highly integrated in respective global efforts. The existing Environmental RIs already adopt this approach; many include observing systems which generate key data for the European and the international scientific communities, and contribute to global data systems, among them Global Atmosphere Watch (GAW)⁴ and the European component of GEO² in creating a Global Earth Observation System of Systems (GEOSS)³ that will link Earth observation resources world-wide across multiple Societal Benefit Areas – agriculture, biodiversity, climate, disasters, ecosystems, energy, health, water and weather – making those resources also available for better informed decision-making. Their main objectives are:

1. _____
GAW aims to understand and control the increasing influence of human activity on the global atmosphere.
<http://www.wmo.int/pages/prog/arep/gaw/history.html>
2. _____
GEO, established in 2005, is a voluntary partnership of governments and organizations that envisions "a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information". GEO Member governments include 96 nations and the European Commission, and 87 Participating Organizations comprised of international bodies with a mandate in Earth observations
<https://www.earthobservations.org/index2.php>
3. _____
Global Earth Observation System of Systems (GEOSS)
<http://www.earthobservations.org/geoss.php>

- achieving national and international objectives for a resilient society, sustainable economies and a healthy environment worldwide;
- addressing global and regional challenges by deepening the understanding of Earth system processes and improving the link between scientific understanding and policy-making;
- fostering new economic opportunities, improving efficiency, and reducing costs to public sector budgets through innovation and collaboration.

Several RIs in the Environmental domain are also feeding in the European Union's flagship Copernicus⁴ programme, focusing on operational monitoring of the atmosphere, oceans and land services, whose main users are policy-makers and public authorities. Copernicus is providing validated information services in six areas: land monitoring, marine monitoring, atmosphere monitoring, emergency management, security and climate change.

Other linkages with the Joint Programming Initiatives (JPI's)⁵ such as JPI Climate, JPI Oceans, JPI Water, JPI-FACCE as well as with other initiatives such as EMODNET⁶, the European Environment Agency (EEA)⁷ and the INSPIRE Directive⁸ should be strengthened.

The ESFRI environmental RIs play also a key role at global scale in the UN framework, contributing to the UN Sustainable Development Goals⁹, the UN Framework

4. _____
Copernicus – European Programme for the establishment of a European capacity for Earth Observation
<http://www.copernicus.eu/>
5. _____
Joint Programming Initiative (JPI)
http://ec.europa.eu/research/era/joint-programming-initiatives_en.html
6. _____
EMODNET
<http://www.emodnet.eu/>
7. _____
European Environment Agency (EEA)
https://europa.eu/european-union/about-eu/agencies/eea_en
8. _____
INSPIRE Directive
<https://inspire.ec.europa.eu/>
9. _____
UN Sustainable Development Goals
<https://sustainabledevelopment.un.org/>

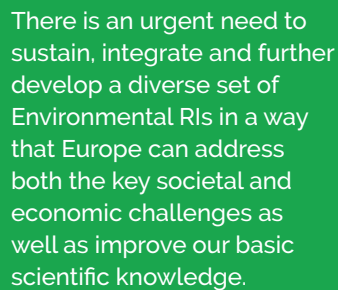
Convention on Climate Change (UNFCCC)¹⁰ and the Convention on Biological Diversity (CBD)¹¹.

Environmental RIs play an important role for the scientific community and the society at large by:

- providing centres of frontier scientific research as focal points for education and training of researchers and contributing significantly to the European skills base;
- delivering essential data for more reliable communication to the general public on events such as volcanic eruptions, earthquakes, poor air quality and extreme weather as well as information on biodiversity impacts;
- generating coherent, comparable and sustained time-series of key environmental variables;
- producing accurate data and scientific and technical knowledge that underpin the construction of tools supporting decision making and development of efficient regulations and policies;
- opening access to environmental *big data* from space-based and *in situ* observations as key driver for the development of new services and for promoting activities in the private sector;
- developing new technologies, such as laser-based sensors, high resolution wireless networks and remotely operated autonomous systems, which leads to additional co-benefits.

Environmental Research Infrastructures have multiple roles in tackling the *Societal Challenges* as listed in the EU Horizon 2020¹² program with *Climate action, environment, resource efficiency and raw materials* being closest connected to them. *Health, demographic change and wellbeing* as well as *Food security, sustainable agricul-*

ture and forestry, marine and maritime and inland water research, and the Bioeconomy are strongly dependent on the whole environment, particularly when it comes to climate change adaptation, pollution, or overuse of ecosystem services. Environmental catastrophes can shutter societal security and cause migration with related security problems. The *Societal Challenges Secure, clean and efficient energy* and *Smart, green and integrated transport* even directly respond to environmental necessities and can receive guidance from a comprehensive understanding of the Earth System. Needless to say that societies that concern their environment are inclusive, innovative and reflective.



There is an urgent need to sustain, integrate and further develop a diverse set of Environmental RIs in a way that Europe can address both the key societal and economic challenges as well as improve our basic scientific knowledge.

10. UN Convention on Climate Change (UNFCCC)
<https://unfccc.int/>

11. UN Convention on Biological Diversity (CBD)
<https://www.cbd.int/>

12. H2020 Societal Challenges
<https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges>

ATMOSPHERE: FROM NEAR GROUND TO THE NEAR SPACE ATMOSPHERE

The atmosphere hosts many physical and chemical processes and represents a major part of the environment to which the life on Earth is sensitively responsive. The atmosphere is part of the larger connected global environment and is central for climate, weather, and transport of chemical species over large distances.

It also has to cover the full altitude range from the planetary boundary layer near the surface across the tropopause and stratosphere up to the middle atmosphere – i.e. from ground to 50 km altitude and beyond. The atmospheric domain interacts with marine, terrestrial, freshwater, solid earth systems and the near space.

poses a foremost scientific challenge because of large uncertainties in our current knowledge on climate change processes. Particularly, the understanding of climate feedback mechanisms requires considerable joint research where enhanced cooperation of existing Research Infrastructures has to play an important role.

Perturbation of the atmosphere impacts on different thematic areas like climate change, air quality, environmental hazards, environmental risks, food security and the water cycle.

The research on the atmosphere is multidisciplinary, embracing atmospheric chemistry, physics, dynamics and radiation; and it combines observations and modelling.

The atmosphere contains a wide range of trace species. The identification and quantification of their properties, atmospheric transport and transformation processes and life cycles require highly interdisciplinary approaches. Both natural and man-made gases and aerosols may be transported from emission to receptor sites over long distances in the atmosphere across national borders and continents. Thus, atmospheric research and monitoring requires close international collaboration. Climate change

Atmospheric Research Infrastructures do not only provide monitoring, but exploratory infrastructures are also needed to study the processes. Atmospheric processes are multiscale in time and space, from the sub-second, sub-micron scale of microscopic processes to the decadal global scale characteristic of climate change. In this context, the atmospheric infrastructures should be sufficiently equipped to be able to inform across a similar range of scales.

II CURRENT STATUS

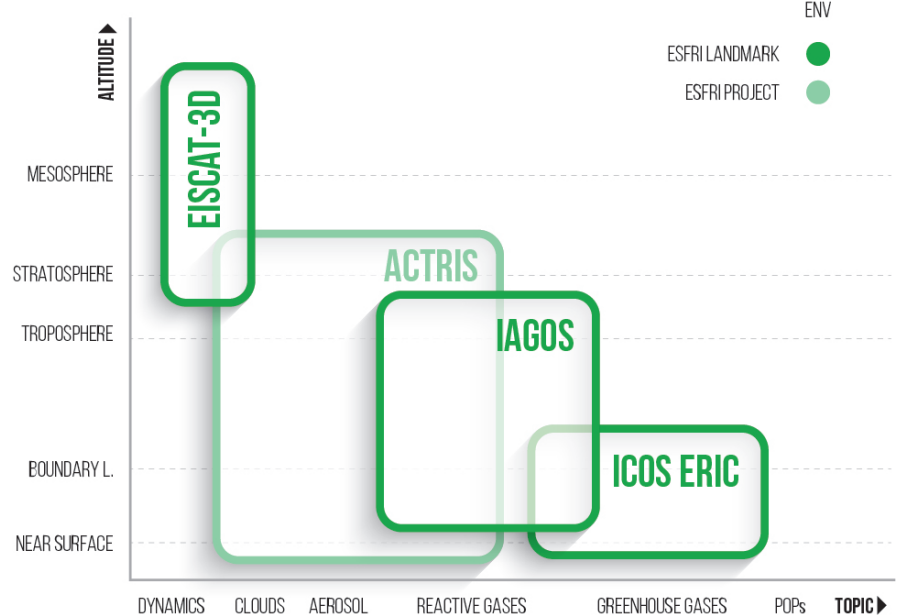
The European atmospheric landscape covers a wide range of actions ranging from the establishment of ESFRI long-term atmospheric Research Infrastructures to EU-funded projects such as Integrating Activities (IA), Design Studies, and other projects.

- Modelling development and experiments: IS-ENES (global climate and earth system models).

The European atmospheric research community is well recognised at an international level and in many specific research topics it has an undisputed leadership. Atmospheric RIs have a fundamental role to strengthening the EU position and leadership in this research area by providing unique informa-

- Long-term atmospheric observation platforms: the **ESFRI Project ACTRIS** (Aerosols, Clouds and Trace gases Research Infrastructure); the **ESFRI Landmark IAGOS** (In-service Aircraft for a Global Observing System) (Airborne, lower atmosphere); the **ESFRI Landmark ICOS ERIC** (Integrated Carbon Observation System); ARISE (Atmospheric dynamics Research Infrastructure in Europe) and the **ESFRI Landmark EISCAT_3D** (Next generation European Incoherent Scatter radar system) (upper atmosphere); SIOS (Svalbard Integrated Arctic Earth Observing System) (Integrating all observations, terrestrial, marine and atmosphere at Svalbard).

The atmospheric subdomain landscape is sketched in **Figure 1** in a topic (x-axis) versus altitude (y-axis) graph.



- Exploratory process oriented research, atmospheric chemistry including aerosols: the **ESFRI Project ACTRIS**; EUROCHAMP 2020 (laboratory studies); EUFAR (Airborne platforms for field experiments).

FIGURE 1. Schematic overview of the ESFRI RI landscape for the atmosphere sub-domain

tion, services, tools and reference methodologies that are used and applied by a very wide community also outside Europe.

An assessment of the user community conducted in 2018 in the framework of the cluster of environmental Research Infrastructures (ENVRI) provided more than 3,000 users and more than 25,000 user requests per year for the Atmosphere Domain RIs. Areas of data use include fundamental research on atmospheric processes, climatological studies on the long-term evolution of the atmosphere and trends of key species, validation of Earth System Models, assimilation of data for numerical weather prediction, validation of satellite products and development of new measurement technologies.

One major user of Atmosphere RIs data products and services is COPERNICUS Atmosphere Monitoring service (CAMS)¹³. The **ESFRI Project ACTRIS**, and the **ESFRI Landmarks IAGOS** and **ICOS ERIC** data are used by CAMS, for example, for Near-Real Time Model Validation, Monitoring Air Quality in Europe and for providing forecast of air quality in Europe for European cities, also shown daily on EURONEWS.

▶ GAPS, CHALLENGES AND FUTURE NEEDS

In response to the status of the existing RIs, specific gaps and challenges have been identified. It is important to study not just components of the atmospheric system but observe as many of those components synergistically as possible to fully understand processes and linkages. A synergistic approach must include the use of *in situ* ground based observations, together with columnar and vertical profile, aircraft and satellite observations and models to study and understand atmospheric composition and processes. Long-term data records for atmospheric parameters, which are relevant for both air quality and climate research, are inadequate at the moment and the geographical coverage by atmospheric observing infrastructures in the Mediterranean including North Africa and Eastern Europe is incomplete. Understanding the atmospheric composition changes and processes is a global issue, and the relevance for Europe is not limited to observations performed on sites located in European regions; there is a responsibility of Europe to explore where further atmospheric observations could be supported, in Africa to start with. Moreover, harmonised measurements on larger geographical scale are crucial and strong international cooperation is needed. A better integration of existing programs and projects in the atmospheric area will help to build and sustain the European component of GEOSS.

Interconnections with other domains – i.e. Health – need to be better explored. Air pollution is a major environmental risk to health. Short-lived atmospheric compounds have recognized adverse health effects at concentrations typically found across Europe and potentially lead to more than 400,000 premature deaths annually in the EU28. In particular, the effect on children's health should be better explored and in this context the role of atmosphere RIs to foster scientific cooperation in this field is of primary importance.

13. COPERNICUS Atmosphere Monitoring service (CAMS)
<https://atmosphere.copernicus.eu/>

HYDROSPHERE

Water is essential for human life and nature and plays a critical role in most natural processes. Water covers about 70% of the Earth's surface and over 97% of it is in oceans, and most of the remaining freshwater is in the form of ice.

Water is of huge global geopolitical importance and is central to all the key, current environmental issues: climate change, biodiversity, natural hazards, pollution, ecosystem services, and desertification.

Most water on Earth, including that present in lakes, rivers, deltas/estuaries, lagoons, etc., is part of the hydrological cycle and is inter-linked with the atmosphere, cryosphere, soils, sediments and the rest of the geosphere, as well as with the entire biosphere. Water must therefore be seen and studied in a holistic way.

Climate change, land use and abuse, economic activities such as energy production, industry, agriculture and tourism, urban development and demographic change mostly impact negatively on the status of water and as a result, the ecological and chemical status of EU waters, from mountain springs to coastal zones, is threatened. In addition, more parts of the EU are at risk of water scarcity. Water ecosystems – on whose services our societies depend – become more exposed to extreme events such as floods and droughts. It is essential to better address these challenges on the basis of improved scientific understanding of all relevant processes so as to preserve our resource base and increase its resilience for life, nature, society and to protect human health in the changing climate.

FRESHWATER: ICE, GROUNDWATER, LAKES, RIVERS, ESTUARIES

A holistic view on the water cycle requires integrated, interdisciplinary and trans-sectorial approaches that provide solutions to managing water-related societal risks. Environmental monitoring agencies across Europe continuously collect vast amount of data on freshwater. Linking this routine sampling with high-resolution data from freshwater supersites and remote sensing data would benefit society directly as well as by supporting research in the area. Some research facilities have collected data on snow, ice and freshwater and complementary environmental and ecological information for more than a century. These long time series have been instrumental in understanding the coupling between the water cycle, the changing climate and ecosystems. It is of vital importance to ensure that the long-time series are continued. Experimental facilities for studying complex water-related phenomena – e.g. physical modifications of estuaries, behaviour of substances and energy in mesocosms, etc. – allow physical models to underpin better systemic understanding, often in conjunction with mathematical models.

CURRENT STATUS

Much of the current science is done relying on access to existing water bodies, i.e. without specific and dedicated large-scale Research Infrastructures. The **ESFRI Project DANUBIUS-RI** (International Centre for Advanced Studies on River-Sea Systems), supporting interdisciplinary research in river-sea systems, is the only physical pan-European Research Infrastructure devoted to support also research on transitional zones between coastal marine and freshwater areas, together with the **ESFRI Landmark LifeWatch ERIC** (e-Infrastructure for Biodiversity and Ecosystem Research) as the only e-RI, which extends its area of interest also to the whole freshwater environments. There are European networks of basins for hydrological monitoring and research, such as the European Network of Hydrological Observatories (ENOHA). The HYDRALAB+

network supports the use of environmental hydraulic facilities. The **ESFRI Project AnaEE** (Infrastructure for Analysis and Experimentation on Ecosystems, H&F) also offers access to experimental facilities in freshwater environments.

GAPS, CHALLENGES AND FUTURE NEEDS

Europe needs a dense, highly instrumented super-sites network of freshwater monitoring, as well as simulation and experimental platforms. Lake, river and ground water monitoring and experimental super-sites should serve as calibration, validation and development services for remote sensing applications as well as for ecosystem and for ecosystem service modelling. For the comprehensive analysis of the changes in the aquatic ecosystems an integrated basin approach is necessary to understand the impact of different drivers and to find measures for sustainable water resources management. The **ESFRI Project DANUBIUS-RI**, with its structure consisting of the four Nodes (Observation/Measurements – Analysis – Modelling – Impact), is aiming to bridge the before mentioned gaps, at a basin-wide, river-to-sea approach.

The Water JPI Strategic Research and Innovation Agenda¹⁴ and the WssTP Strategic Innovation and Research Agenda¹⁵ provide frameworks for collaborative research and innovation efforts. The Water JPI intends to increasingly play a role in facilitating the use of relevant RIs, whereas for example WssTP advocates the use of "real life living labs" where innovative solutions can be tested hence facilitating the scaling up of solutions.

14. Water JPI, 2016
<http://www.waterjpi.eu/images/documents/SRIA%202.0.pdf>

15. WssTP, 2017
http://wssTP.eu/wp-content/uploads/sites/102/2017/01/WssTP-SIRA_online.pdf

MARINE: FROM COAST TO DEEP OCEANS AND ICE CAPS

Shelf seas and the world-embracing ocean form a group of dynamic complex systems with a strong interplay of physical, chemical and biological phenomena at multiple spatial and temporal scales. Due to inaccessibility, even their *static* features – e.g. ocean bathymetry – are poorly known. Seas and oceans provide food, energy, and many other resources on which mankind depends. The oceans have a fundamental influence on our climate. Society is increasingly concerned about global change and its regional impacts. Sea level is rising at an accelerating rate, the Arctic sea ice cover is shrinking as high latitude areas are warming rapidly, and storminess is forecast to increase. Since 1955, over 90% of the excess heat trapped by greenhouse gases has been stored in the oceans¹⁶. The oceans are affected by the increased amount of CO₂ in the atmosphere leading to ocean acidification which poses threats for many species. Changes in the thermal structure of water masses are likely to influence currents and stratification. The effects of climate change add to other stresses, such as pollution, in particular lmicrol-plastics, and overfishing that are already threatening the biodiversity and health of the seas and oceans.

Last but not least, sources of geo-hazards such as slide prone slopes, active tectonic structures and volcanoes to mention some, lay in marine environment at various depth and distance from the coasts. Wherever they are adjacent to populated regions, to economically developed areas or sites of strategic relevance, they represent threats for the socio-economic fabrics and wellness. Marine observatories provide an essential integration to land-based RIs for a broader vision in the comprehension of the natural phenomena.

Ocean observation is currently a key component of the EU Strategy for Marine and Maritime Research and has become a high priority on the worldwide environmental political agenda.

CURRENT STATUS

Marine RIs consist of up to 800 – increasingly networked – distributed facilities in Europe, serving various domains such as ocean – seafloor, subseafloor and water layers above – and coastal sea monitoring, marine biology research, blue biotechnology innovation, research in aquaculture and ocean engineering. Their observation and data management components form the foundation for a European Ocean Observing System (EOOS), providing the platforms and services to deliver environmental data, information and ultimately knowledge. Marine RIs, including e-RIs, are as diverse as: research vessels¹⁷ and their underwater vehicles for sea access and deep sea exploration/sampling; voluntary vessels for surface and sub-surface monitoring; fixed and mobile, autonomous, including drifting, *in situ* observing systems for sea-water column and seabed observation and monitoring; satellites for remote sensing for sea-surface monitoring; marine data centres; land-based facilities for ocean engineering, such as deep wave basins, water circulation canals, sensors tests and calibration laboratories; and experimental facilities for biology and ecosystem studies and for marine genomics, biodiversity, blue biotechnology, aquaculture, mesocosms; virtual research experimental facilities for biodiversity and ecosystem studies integrating data resources from the physical infrastructures and observation systems. Marine research stations, of which there is a high density around Europe, often provide a combination of services to marine researchers.

Key RIs for water-related research are fostered in ESFRI, as reported in **Figure 2**, while there are also other EU projects and initiatives supporting networks that are directly relevant for research.

17. UNESCO (2017). Global Ocean Science Report—The current status of ocean science around the world. L. Valdés et al. (eds), UNESCO Publishing, Paris <https://en.unesco.org/gosr>

- River-sea interaction, freshwater, water-ice: the **ESFRI Project DANUBIUS-RI**, the **ESFRI Landmark LifeWatch ERIC** – as e-RI, HYDRALAB+, AQUACOSM (mesocosms).

- Open ocean mobile platforms: the **ESFRI Landmark EURO-ARGO ERIC** (European contribution to the international Argo Programme), EuMarineRobots.

- Open ocean fixed point observatories: the **ESFRI Landmark EMSO ERIC** (European Multidisciplinary Seafloor and water-column Observatory).

- Research vessels and underwater vehicles: ARICE, EUROFLEETS.

- Coastal/shelf seas observatories: JERICO-NEXT.

- Data storage and standards, access: EMODnet and linked Copernicus Marine Service (CMEMS) for operational oceanographic services; EuroGOOS, SeaDataNet/SeaDataCloud.

- Marine biology, *omics* and bio-informatics: the **ESFRI Landmark ELIXIR** (A distributed infrastructure for life-science information, H&F), the **ESFRI Landmark EMBRC ERIC** (European Marine Biological Resource Centre, H&F), the **ESFRI Landmark LifeWatch ERIC** – as e-RI – and the **ESFRI Project AnaEE** (H&F).

- Carbon cycle: the **ESFRI Landmark ICOS ERIC** and the **ESFRI Landmark LifeWatch ERIC**, as e-RI.

GAPS, CHALLENGES AND FUTURE NEEDS

Taking into account recent efforts to define research priorities and infrastructure needs, such as European Marine Board position paper, JPI Oceans SRIA agenda, SEAS-ERA reports, a gap analysis has been performed by the marine community to identify gaps and weaknesses of the present understanding of how the ocean functions and our observing system. Marine regions in open seas are under-sampled, thus additional observatory nodes, together with an acceleration of technological developments, are required – e.g. deeper

16. IPCC (2013) WG1 AR5 <http://www.ipcc.ch/report/ar5/wg1/>

measurements from Argo floats, Biogeochemical Argo floats and from SMART Cables¹⁸. The UNESCO Intergovernmental Oceanographic Commission (IOC) is preparing the UN Decade of Ocean Science for Sustainable Development (2021-2030) to improve the scientific knowledge base, in view of humanity's increasing reliance on ecosystem goods and services from the ocean. The current global knowledge base is very weak – e.g. IOC estimates that 99% of habitable marine areas lack basic biodiversity knowledge for their management¹⁹. However, efforts are on-going to employ newly developed sensors and samplers that can be mounted on observing autonomous platforms – buoys, glider, profiler etc. – or vessels and ships seizing opportunities for more automated sampling and analysis for biochemical and biological parameters. The use of oppor-

18. ITU/WMO/UNESCO IOC Joint Task Force <https://www.itu.int/en/ITU-T/climatechange/task-force-sc/Pages/default.aspx>

19. IOC, 2018. The United Nations Decade of Ocean Science for Sustainable Development (2021-2030) <http://unesdoc.unesco.org/images/0026/002619/261962e.pdf>

tunistic sampling needs to be further expanded, e.g. sensors could be further deployed on commercial ships operated by the private and public sector (analogue to **ESFRI Landmark ICOS ERIC**).

Beyond the development of existing or planned individual Research Infrastructures and networks, a more holistic approach is needed for the observing components which are serving many different communities, including but not limited to the scientific community. The observation component is the first crucial part of the system which needs standardisation and interoperability effort to ultimately allow us to better know and understand the functioning of marine ecosystems. Other components will require more sophisticated models. From the perspective of a user of scientific information for utilisation in policy, a large gap is the frequent absence of science-based assessment criteria to evaluate the impact of human activities on environmental status²⁰ and ecosystem services, indicating a strong

20. Identified gaps on MSFD assessment elements. PERSEUS Project. ISBN 978-960-9798-01-3. Laroche S. et al., 2013. <https://bit.ly/2uppYmC>

need to understand better the multiple cause-effect chains in the marine environmental realm as a contribution to sustainable use of marine and maritime resources.

Economic constraints impose a flexible and multi-use approach, innovation towards cost-effective observing strategies, and prioritisation among possibly conflicting needs. Efforts towards an integrated and sustained EOOS are ongoing with discussions among the community on a specific strategy, implementation plan and sustainable budget. EOOS should build on the wealth of existing RIs capabilities and multi-platform assets already operational across European waters. EOOS would integrate marine observations from the coast to the open ocean and from surface to deep sea; promote multi-stakeholder partnerships for funding observing systems and sharing of data and align with global efforts within a robust framework. The EOOS should also be smart, resilient and adaptable, driven by scientific excellence, stakeholder needs and technological innovation, to fill the need for cross-disciplinary research and multi-stakeholder engagement.

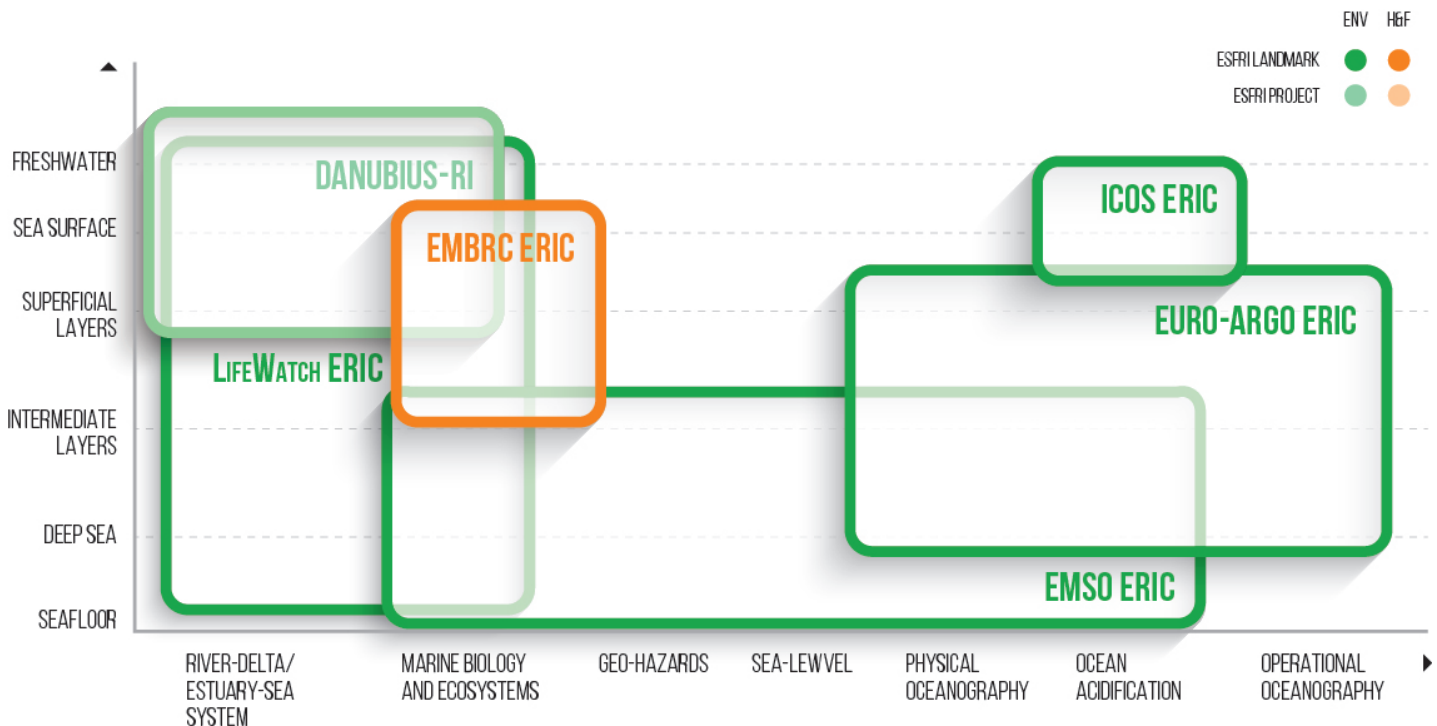


FIGURE 2. Simplified diagram of the observation capabilities of ESFRI Landmarks and Projects respect to the hydrosphere components (Y axis) and to the environmental processes therein (X axis).

BIOSPHERE: BIODIVERSITY AND ECOSYSTEMS

Biodiversity research integrates the study of the diversity and variability of Life on Earth – namely terrestrial, marine and freshwater ecosystems, and including diversity at genetic, species and ecosystems. Ecosystem functions refer to the structural components of the ecosystems – e.g. water, soil, atmosphere and biota – and how they interact with each other, within ecosystems and across them, and how they interact with societal activities.

A better understanding of the interconnections, including quantitative relations, between biodiversity and ecosystem services will allow a better response to Grand Challenges, namely those included in the Sustainable Development Goals.

Biodiversity plays a central role in ecosystem functioning and provision of ecosystem services and is thus linked to key *Societal Challenges* such as a secure and safe supply of food and water and other natural resources, human health, energy as well as climate regulation and pollination. The biodiversity and ecosystem research is highly complex not only because of necessary multi-spatial and multi-temporal approaches, but also because associated time scales can range from microseconds up to millennia. Therefore, biodiversity and ecosystem research requires a multi- and interdisciplinary integrated approach.

Over the past 50 years or more, ecosystems have changed dramatically due to human pressure. Ecosystems have been affected by soil exploitation, land-use change – for example formation of large monocultures, over-exploitation of natural resources, habitat destruction and contamination. Furthermore, invasive species has resulted in biodiversity loss and disruption of natural communities. As a result, in Europe, a several species are threatened with extinction. For instance, it is estimated that 15% of all mammals are threatened with extinction, 13% of all birds, 37% of all fishes, 19% of all reptiles and 23% of all amphibians. These impacts affect the structure and functioning of ecosystems and consequently their sustainability.

The land-use change which causes habitat destruction and the alien invasive species

are the most serious threats to biodiversity, the loss of which is recognised to cause decrease of ecosystem services by affecting ecosystem functioning and stability. The effective strategies to control invasive species include the early detection, regular monitoring of the growth of invasive alien species populations, and prediction of future spread. Research Infrastructures could be instrumental to develop these strategies, providing facilities to mobilize, access and analyse data of citizen science, remote sensing, and develop species distribution modelling for current and future distributions.

In order to protect biodiversity, it is important to also understand the societal drivers, such as demographic, economic, socio-political, cultural and religious, and scientific and technological changes (Millennium Ecosystem Assessment, 2005) as well as their impact on the ecosystems – habitat change, invasive alien species, and overexploitation of species – and thereby indirectly identify reasons for biodiversity loss.

Ecosystem integrity is indispensable to reach the UN Sustainable Development Goals (SDGs)²¹. Goal 15 directly refers to terrestrial ecosystems: Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. Furthermore, standardised observations from the terrestrial ecosystem and biodiversity domain comprise essential climate variables (ECVs) and essential biodiversity variables (EBVs) and thus provide knowledge towards the UN Conventions on Climate Change (UNFCCC)²² and Biological Diversity (CBD)²³.

Long-term observations and monitoring as well as long-term research programs are indispensable for the interpretation of ongoing ecosystem changes, including those responsible for biodiversity loss and erosion.

21. UN Sustainable Development Goals (SDGs)
<https://www.un.org/sustainabledevelopment/sustainable-development-goals/>

22. UN Convention on Climate Change (UNFCCC)
<https://unfccc.int/>

23. UN Convention on Biological Diversity (CBD)
<https://www.cbd.int/>

CURRENT STATUS

The European landscape for terrestrial ecosystem and biodiversity RIs covers the complexity of the research agenda (see **Figure 3**). The ESFRI RIs are built on or closely connected to EU-funded projects such as Integrating Activities (IA).

- Observatories and Monitoring Facilities: the **ESFRI Landmark ICOS ERIC**, the **ESFRI Projects DANUBIUS-RI** and **eLTER** (Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure), the IA InterAct (ongoing), InGOS (until 2015), and SIOS (Svalbard Integrated Arctic Earth Observing System) (Integrating all observations, terrestrial, marine and atmosphere at Svalbard).

- Facilities for *in situ* and *in vivo* experimentation: The **ESFRI Project AnaEE** (H&F), the IA AQUACOSM.

- Biological collections, Data infrastructures and reference data: the **ESFRI Project DISSCo** (Distributed System of Scientific Collections), the **ESFRI Landmark ELIXIR** (H&F), and the **ESFRI Project MIRRI** (Microbial Resource Research Infrastructure, H&F), the IA SYNTHESYS (until 2017).

- e-Infrastructures for analysis and modelling: the **ESFRI Landmark LifeWatch ERIC**, and the IA IS-ENES (ongoing).

The size of the researcher community served by these RIs might be estimated using as proxy the number of researchers engaged with national and international ecological associations, which raises up to 10.000 in Europe and 40.000 worldwide and additional researchers from climate and GHG communities. Other direct users include officers of regional, national and European environmental agencies responsible for national inventories and nature conservation, local and national administration, and environmental NGOs supporting decision making and policy implementation.

The paradigm shift in terrestrial ecological research from searching for a unifying ecosystem theory to tackling specific *Grand Challenges* (and in addition a shift from

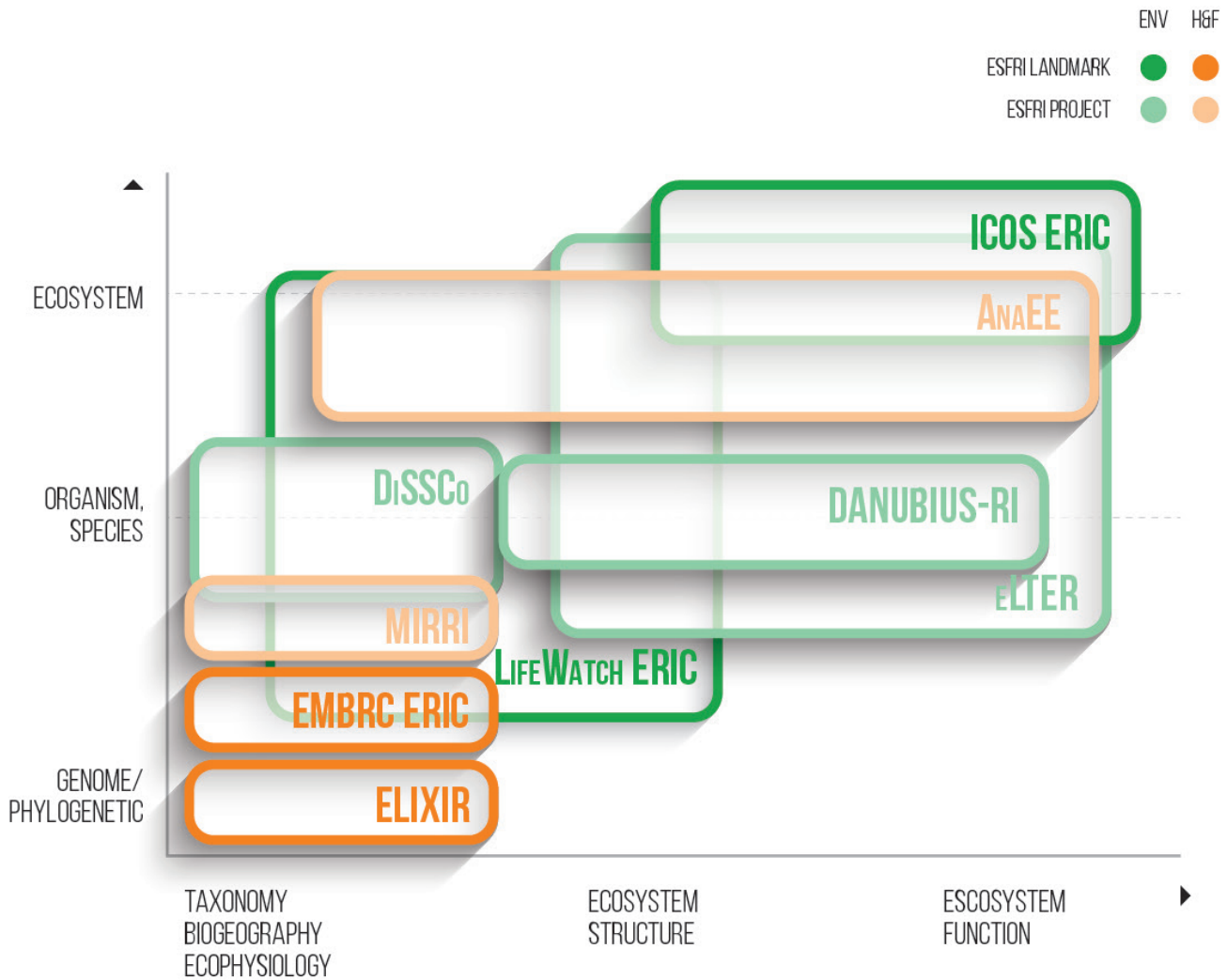


FIGURE 3.

Schematic landscape of biodiversity and ecosystem ESFRI Research Infrastructures.

ecosystem conservation to preservation of ecosystem services) is mirrored by all Research Infrastructures in the domain but differs in the degree of being conducted in the basic concept of individual RIs. With the strongest relation to the approach of ecological integrity, the **ESFRI Project eLTER** is tackling a broad spectrum of ecological challenges, however the theoretical base is starting from understanding ecosystems. The **ESFRI Project AnaEE** (H&F), providing experiments instead of observations, and with stronger focus on agriculture and food security, is starting a bit more specific from a defined set of ecological and societal challenges and has a more anthropocentric objective in the preservation of ecosystem services, food security as well as specific contributions to bioeconomy.

In contrast to the **ESFRI Projects eLTER** and **AnaEE** (H&F) with their basis in the ecological integrity approach or in a broad

spectrum of related *Grand Challenges*, the **ESFRI Landmark ICOS ERIC** is following a cross-domain approach that aims to understand the carbon cycle and to provide necessary information on the land-ecosystem exchange of CO₂, CH₄ and N₂O with the atmosphere. The **ESFRI Landmark LifeWatch ERIC** has, similar to ICOS, a cross-domain approach and a focus on the *Grand Challenges* of preserving biological diversity and of protecting ecosystem health. The **ESFRI Landmark LifeWatch ERIC** is an e-Infrastructure without own observations and enables knowledge-based solutions to environmental managers by providing access to a multitude of sets of data, services and tools. Specific issues related with biodiversity research, the role of biodiversity in ecosystem functioning and conservation are addressed by the construction and operation of Virtual Research Environments (Virtual Laboratories & Deci-

sion-support Applications) where integrated models at the meso- or higher scales are executed.

The digitalisation of biological collections and the connection to genomics is a game changer in the biodiversity research aiming to close the taxonomic gap which still is a major limitation to biodiversity knowledge. Of the 8 million species that are estimated to exist, only 1.8 million are currently scientifically described. For some biological groups – insects, nematodes, and microorganisms – only 10% of the species are known, and many species become extinct without being discovered. Many parameters in taxonomy need specialized human efforts. The overall ensemble of RIs in the terrestrial ecosystem and biodiversity field covers comprehensively the scales from molecules to continents and responds to a wide range of environmental challenges.

▶ GAPS, CHALLENGES AND FUTURE NEEDS

The *Grand Challenges* related to biodiversity, ecosystems and biodiversity are highly inter-related. Land-use change is usually accelerating both loss of biodiversity and climate change by release of CO₂ and by creating agricultural monocultures or land degradation.

Firstly, urged by the biodiversity loss, the taxonomic gap needs to be overcome, in order to discover and describe the ¾ of the biodiversity still to be known. Rapid advances in genetic sequencing and ICT, including big data analysis of genetic sequences, and mass digitization can be integrated to provide more automated systems with respect to genomics, species and ecosystem analysis.

Other challenges are the invasive species which can affect native species and habitats, alter the ecosystem primary productivity and thus the carbon sequestration. Consequently, the RIs need to better integrate their data life cycles and to seek common geographical coverage of their observing infrastructures by co-location and a mutual strategy to fill geographical gaps. Observations and experiments need further scientific integration. Modelling can be a powerful tool for the conjunction of organismic and process-oriented approaches as well as multiple challenges perspectives in ecosystem analysis. However, most existing ecosystem models represent only facets and require further development.

Monitoring biodiversity and ecosystems changes requires also the development and implementation of the Essential Biodiversity Variables²⁴ as ecological data products underpinned on data and metadata standards, data quality and data preservation would ensure the needed interoperable resources to perform ecological studies and assessments.

The manifold connections to other fields, particularly Health & Food, but also Social Sciences and Energy are obvious. Agriculture and Bioenergy directly affect ecosystem integrity which itself is an important factor for human health, but also for food production. Environmental literacy and behaviour are important interfaces to Social Sciences.

24. Pereira, H.M. et al., 2013. Essential Biodiversity Variables. *Science* 339, 277–278
<https://doi.org/10.1126/science.1229931>

GEOSPHERE: FROM THE SURFACE TO THE INTERIOR OF THE EARTH, FROM GEOHAZARDS TO GEORESOURCES

The solid Earth science is concerned with the internal structure and dynamics of planet Earth and with surface processes. Solid Earth science deals with multiscale physical and chemical processes, from microseconds to billions of years and from nanometres to thousands of kilometres.

Geology, natural hazards, natural resources and environmental processes, in general, do not respect national boundaries, therefore seamless, trans-national integration of measurements and calibrated data is crucial to enable research and societal applications.

Progress in Solid Earth science relies on integrating multidisciplinary data acquired through long-term monitoring, new observing systems, and high-level taxonomy data products. The understanding of en-

vironmental changes requires unravelling complex and intertwined processes. Solid Earth science contributes to systemic and highly cross-disciplinary investigations, representing an essential component of the investigation of the Earth system. The ash and gas dispersion during a volcanic eruption is a key example of the multidisciplinary observations required to monitor a natural phenomenon and its underlying processes – e.g. seismic activity, ground deformations, magma rheology – and of the cross-disciplinary implications for meteorology, atmospheric sciences, marine sciences, and the life sciences.

In addition to enable fundamental scientific advancement in understanding planet Earth, RIs in the solid Earth domain provide a crucial contribution to two areas of high societal relevance: geo-hazards and geo-resources. In particular, they:

- enable assessing and mitigating the risks caused by natural hazards, such as earthquakes, volcanic eruptions, tsunamis and landslides;
- make available monitoring infrastructures, experimental facilities and expertise for optimising exploration and exploitation of geo-resources and monitoring of natural resources, including geo-energy resources (i.e. geothermal energy, conventional oil and gas, shale gas), underground storage (carbon, gas, nuclear waste), raw materials, minerals and rare earth elements, and for estimating and mitigating the risk of anthropogenic hazards, such as earthquakes possibly induced by the extraction of geo-energy resources;
- provide the monitoring and research background for a correct use of the underground, taking into account considerations of RIs, long-term environmental sustainability and economic viability.

II CURRENT STATUS

The solid Earth domain is represented in ESFRI by a single Research Infrastructure, the **ESFRI Landmark EPOS** (European Plate Observing System). The large community of RI operators and users chose to establish an all-encompassing RI framework, including all the different RI classes covering seismology, near-fault observatories, geodetic data and products, volcano observations, satellite data, geomagnetic observations, anthropogenic hazards, geological information and modelling, multi-scale laboratories, and geo-energy test-beds for low-carbon energy. As a result, the **ESFRI Landmark EPOS** integrates several hundreds of individual RIs, distributed in all countries of the Euro-Mediterranean region, with the aim to obtain an efficient and comprehensive multidisciplinary research platform for the Earth sciences in Europe based on novel e-infrastructure concepts for interoperability and provisions of distributed data through Integrated Core Services (ICS) and Thematic Core Services (TCS). In order to enable the required access to inter-disciplinary obser-

ventions, the **ESFRI Landmark EPOS** established strategic and synergetic alliances and specific TCSs with existing data- and service-providers, such as ESA for the satellite data, the EuroGeoSurveys for the geological data and interpretations, INTERMAGNET for magnetic data and EUREF for reference GNSS data and products.

In addition to the **ESFRI Landmark EPOS**, other geosciences RIs and projects are operated globally or in fields currently not formally included in the EPOS RI framework; on-going work is conducted to ensure the required coordination and integration (**Figure 4**). These include:

- the continental- and ocean-drilling RI and programs (ICDP and IODP/ECORD);
- the collections of exploration data (oil and gas, minerals);
- the underground laboratory facilities established for research on geological

waste repositories, now federated by the new initiative EUROL;

- European ERANET programs covering mineral and energy resources, ERA-min²⁵, coordinating research and development in Europe in the field of mineral prospecting, coordinating and integrating national infrastructures, data management and technical development to support the joint European research efforts with the aim to contribute to European mineral security; ACT, to advance carbon technologies towards the establishment of a carbon-free society; GEOTHERMICA, for the advancement of geothermal and petrothermal technologies for electricity and energy generation and storage;
- Research Infrastructures projects, for access to data, services and infrastructures in seismology and earthquake engineering

²⁵—
ERA-min
<http://www.era-min-eu.org/>

SERA; for access to observatories and Research Infrastructures for volcanology EUROVOLC;

- supersites EC projects in GEO, MEDSUV and FUTUREVOLC (Volcano observatories), MARSITE (Near Fault Observatories);

- international organization involved in coordinating national RIs and monitoring networks in seismology and seismic risk, ORFEUS (seismological data) and EMSC

(seismological products), key contributor to EPOS;

- research projects on seismic hazard, early warning and risk assessment – SHARE, SAFER, REAKT, MATRIX, STREST;

- e-science Virtual Environment Projects, including VERCE, EUDAT, ENVRI and ENVRI+ (with a strong EPOS participation).

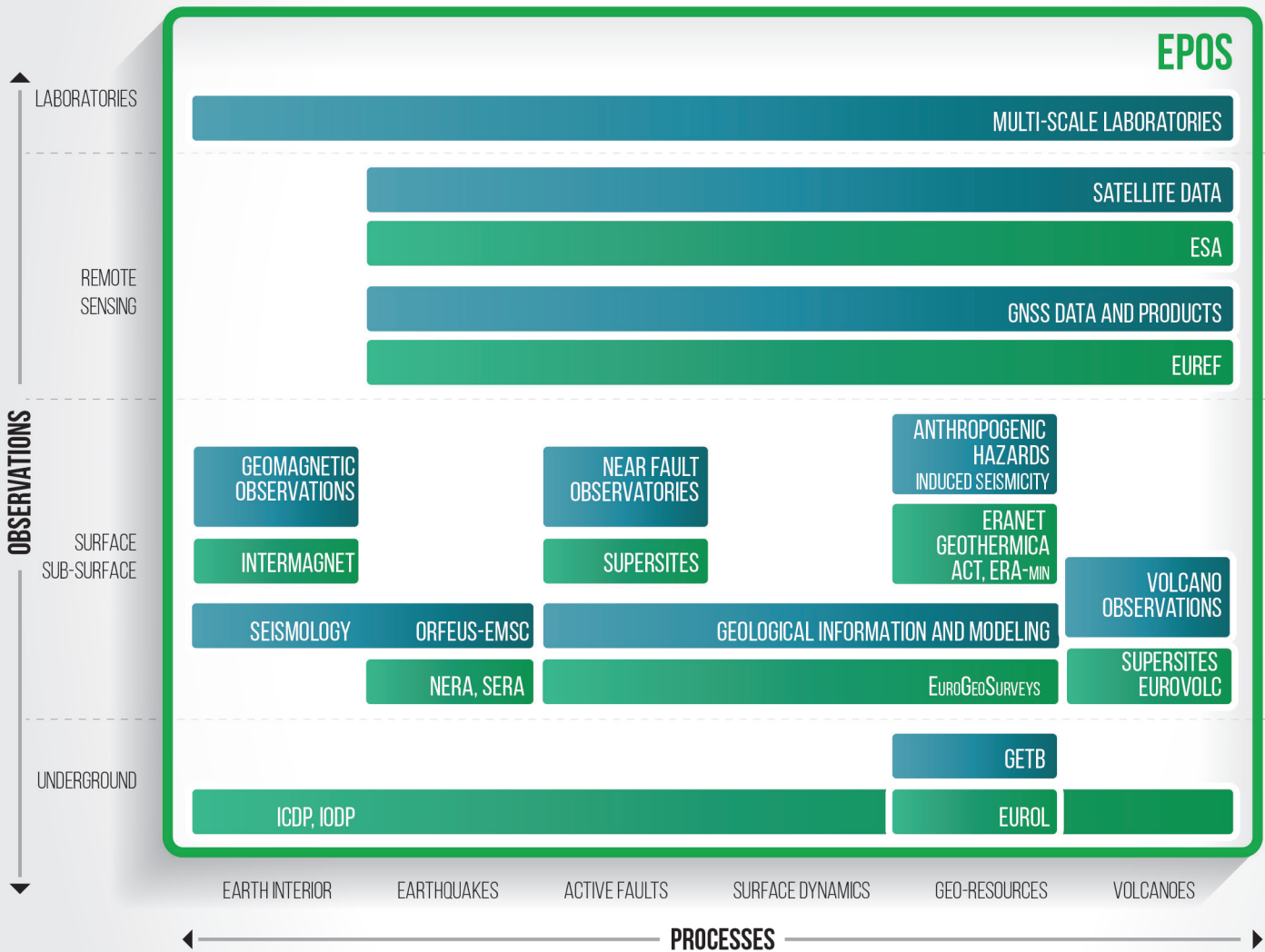


FIGURE 4.

Landscape of solid Earth science platforms and key application areas for the geosphere domain. Blue boxes identify the EPOS Thematic Core Services (TCS). Green boxes refer to other geosciences RIs and projects operated globally or in fields currently not formally included in the EPOS RI framework. (GETB=TCS Geo-Energy Test Beds for low carbon energy).

▶ GAPS, CHALLENGES AND FUTURE NEEDS

In the future, integration and cooperation in the Geosphere domain needs to concentrate on a few strategic priorities.

The interactions and collaborations between industrial stakeholders and the public sector – such as the European geological surveys – needs to be strengthened. This also involves the accountability of data and data providers as well as the adoption of effective interaction strategies in which the role of scientists is clear. This is mandatory to face ethic issues in communicating science and geo-hazards to society.

Europe uses about 20% of the world's primary metal supply, but produces far less than this (3-8%); the situation is worse for *critical metals* and rare earth elements; new RIs and data are urgent in the fields of geo-resources and mining, in order to achieve meaningful targets of energy and mineral security in Europe; the involvement of laboratories – rock deformation labs, deep underground labs, geophysical exploration data, technologies for environmentally friendly mining, analytical facilities for geochemistry and mineral resources, and modelling facilities are key required ingredients.

There is also a need for RIs to enable member states to fulfil the requirements for scientific research and technological development for safe management of high and medium grade nuclear waste in accordance with international and European legislation – e.g. Directive on the Management of Radioactive Waste and Spent Fuel, 2011.

Ocean and continental drilling equipment and programmes need to be intensified, this to increase geographical coverage in critical areas; this requires to collect observations on the solid Earth from oceanic regions, including dense ocean-bottom geophysical and seismic monitoring and floating devices.

Finally, the **ESFRI Landmark EPOS** will be completed and it could serve as a European platform for fostering integration and coordination of all observing and surveillance systems and their services at European scale and for increasing global coordination in solid-Earth observing systems, in cooperation with IASPEI, FDSN, IAVCEI, WOVO, GEO and other international programs and organizations.

VISION AND PERSPECTIVES

The medium to long-term vision (2020-2040) for environmental Research Infrastructures is based on the objective to better facilitate and enable researchers to work in a more integrated manner towards universal understanding of our planet and its behaviour, and to tackle environmental challenges. It is important to study not just individual domains of our planet, but to observe as many of those domains synergistically. This should result in the evolution of a seamless holistic understanding of the Earth's system. Three interdependent resources, that of technological capital, cultural capital and human capital are needed to develop and achieve that vision: *technological resources* which entails the building of monitoring/observational, computational and storage platforms and networks; cultural resources entailing open access to data – requiring rules, licenses and citation agreements on metadata and data; and *human capital* requiring *data scientists* as well as *discipline scientists*.

A federated approach should help to reduce overlaps, to maximise synergies and benefits, and to coordinate Research Infrastructures in order to optimize observing systems ranging from *in situ* and remote sensing data measurement and collection, to data analysis in the laboratory. Concrete actions towards this direction have started already within the ENVRIPLUS (Environmental Research Infrastructures Providing Shared Solutions for Science and Society) project, the cluster of ENV RIs, built around ESFRI roadmap and associated leading e-infrastructures and Integrating Activities, and RIs from other domains as Health & Food for fostering cross-disciplinarity.

ENVRI has proven to be an excellent tool to coordinate Environmental RIs regarding everything from Management, Access policy, Data handling etc. It is of imperative importance that this initiative is continuing.

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PART2

LANDSCAPE ANALYSIS - SECTION1

HEALTH & FOOD

HEALTH & FOOD

KEY MESSAGES

The Health & Food RIs landscape is consolidating firmly in the European Research Area with now 10 Landmarks and 6 Projects covering the vast remit of health, agri-food and the bioeconomy.

To generate readiness to meet current challenges and demands, the Health & Food RIs need to continue cementing their efforts and connecting between them using their different competences and technologies at the service of the user community.

Gaps in the Health & Food landscape can be identified at many levels and it will also be important to connect infrastructure efforts with other domains, as significant innovations and new developments often occur at the boundaries of research areas.

In the field of data, further efforts are required to promote and facilitate the interaction between domains and to avoid fragmentation of the data continuum.

There is a broad consensus that future competitiveness in a globalised knowledge economy depends on research capability. Research Infrastructures (RIs) in the Biological, Agri-Food and Medical Sciences – i.e. Health & Food – continue to establish themselves as research, innovation and skills hubs and as a motor for economic impact. This is reflected in increasing levels of industrial access to RIs, and in their European and global positioning.

The economic impact of investments in large-scale biomedical research, such as the 3.75 billion € investment in the Human Genome Project, has spurred an estimated 900 billion € in economic growth, i.e. a 178-fold return on investment¹. The bioeconomy on the other hand is estimated to be worth at least 2 trillion € in the EU². The arrival of the digital age allows sharing and collective working on a large and distributed scale. Health & Food RIs are key catalysers of progress and change in this new age. The increasing level of sophistication in instrumentation, tools and techniques means that even very large institutions or laboratories cannot provide and maintain access to all services relevant to the field in question, hence services need to be more specialised and distributed. Distributed RIs offer an interdisciplinary set of skills, complemented by disciplines outside the Biological, Agri-Food and Medical sciences, and are well positioned to address the challenges facing our society today, which see no countries, boundaries or disciplines.

ESFRI has been instrumental and influential in the co-ordination of national decision-making and investment in European RIs in Health & Food. The landscape continues to evolve and it is important to ensure its ability and agility to respond to current and future demands. Much effort has been

invested nationally and at EU level in identifying and establishing the current RIs in the ESFRI Roadmap (see **Figure 1**). These key infrastructures are at different stages in their implementation, providing access to a range of key services and giving much visibility to the Health & Food landscape.

Health & Food RIs are also taking an increasing role internationally. The Report of the Group of Senior Officials on Global Research Infrastructures³ lists the **ESFRI Landmarks BBMRI ERIC** (Biobanking and BioMolecular Resources Research Infrastructure), **ELIXIR** (A distributed infrastructure for life-science information) and **INFRAFRONTIER** (European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models) as Research Infrastructures of Global Interest recognising their global leadership.

There has been continued progress towards alignment of the Health & Food landscape with the national roadmaps. This is contributing to increased efficiency between existing RIs and will help consolidate existing and new RIs. The landscape requires sustained effort to complement with new RIs, to maximise current services, and to cement new functionalities, integration and interactions with the relevant fields. The Health & Food landscape considers the current and future challenges in Europe, notably in the provision of healthcare and sustainable and healthy food in the context of a changing cli-

1. _____
Economic Impact of the Human Genome Project. Battelle Technology Partnership Practice for United for Medical Research – Tripp, S. & Grueber, M., 2011
<https://bit.ly/2NaAzBQ>

2. _____
A Bioeconomy Strategy for Europe, 2012
<http://ec.europa.eu/research/bioeconomy/>

3. _____
GSO Progress Report, 2017
https://ec.europa.eu/research/infrastructures/pdf/gso_progress_report_2017.pdf

2006 RIs
2008 RIs
2010 RIs
2016 RIs
2018 RIs

BIOLOGICAL SCIENCES

BIOLOGICAL RESOURCES & PRODUCTION SYSTEMS

MEDICAL SCIENCES

Bioinformatics ELIXIR

Structural Biology INSTRUCT ERIC

Functional Genomic in the mouse INFRAFRONTIER

Clinical Research ECRIN ERIC

Translational Medicine EATRIS ERIC

Biobanking BBMRI ERIC

Chemical Biology EU-OPENSREEN ERIC

Biological and Biomedical Imaging EURO-BIOMAGING

Marine Biology EMBRC ERIC

High Security Labs ERINHA

Systems Biology ISBE

Biorepositories-Microorganisms MIRRI

Agri-ecosystems ANAEE

Plant Phenotyping EMPHASIS

Food and nutritional metrology METROFOOD-RI

Industrial Biotechnology EU-IBISBA

FIGURE 1.

Health & Food Research Infrastructures in ESFRI Roadmap 2018

mate and limited land availability. In order to generate readiness to meet the challenges and demands, the Health & Food RIs need to continue connecting with each other and with the entire scientific landscape, using their different competences and technologies at the service of the user community. Health & Food RIs⁴ provide complementary and synergistic infrastructure facilities (see **Figure 2**), and contribute to building the ERA by:

- providing pan-European open access to cutting-edge technology platforms for academia and industry;
- enabling researchers to find new solutions to meet the major societal challenges they face collectively, including the health of

the ageing population and the environmentally sustainable supply of affordable and nutritious food;

- promoting interdisciplinary and excellent research in Biological, Agri-Food and Medical Sciences across Europe, alignment and standardising the European research landscape and reducing fragmentation;
- promoting interdisciplinary connections with other domains in Energy, the Environment, Physical Sciences & Engineering, and in Social & Cultural Innovation;
- rapidly translating findings from basic science to new applications in Biology, Agri-Food and Medicine;
- delivering synergies and highly interoperable research processes, creating seamless value chains;

▪ identifying and accelerating the development and integration of technologies into the infrastructures to meet emerging needs;

- generating opportunities to maximise the competitiveness of Europe's knowledge-based industry and the bioeconomy – e.g. the agricultural, pharmaceutical, biotechnology and food industries, plus advanced equipment manufacturers, as well as development and utilisation of intellectual property;
- providing training and education to current and future Research Infrastructure professionals;
- attracting and retaining world-leading scientists within the ERA.

4. Biological and Medical Sciences Thematic Working Group Report, 2010
http://ec.europa.eu/research/infrastructures/pdf/bms_report_en.pdf

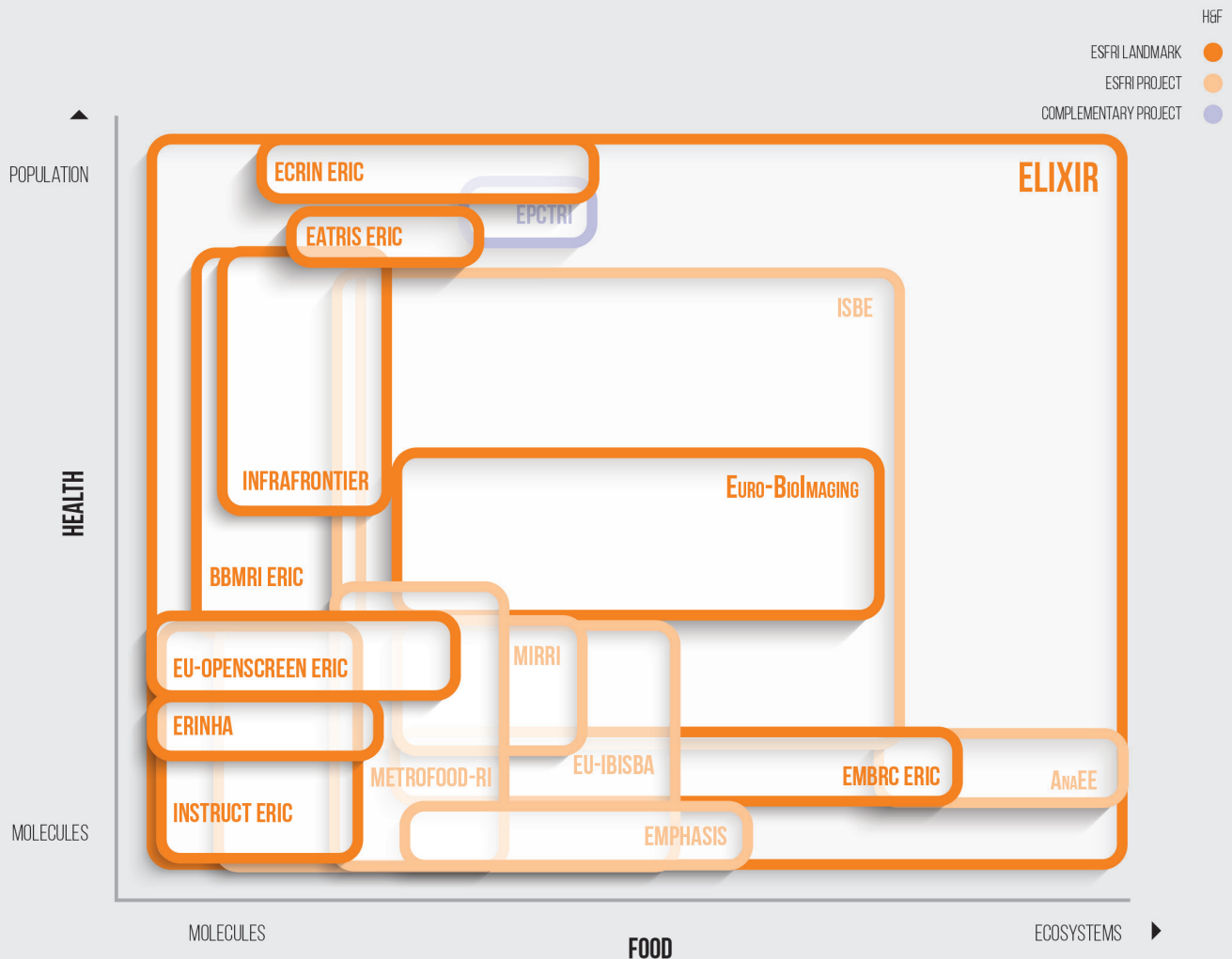


FIGURE 2. The indicative position of ESFRI RIs relative to the different levels of organisation in the Health & Food domain

THE HEALTH CHALLENGE

There is a rising demand for health care in Europe and worldwide, brought by an ageing population with a complex disease-pattern and chronic diseases. Modern lifestyles further add to the costs, e.g. through increasing incidence of disease like diabetes type 2, cancer and infectious diseases. Moreover, changes in climate are likely to affect human health in Europe particularly in older people and those with chronic diseases (IPCC, 2014). Increase in the incidence of mental health problems also needs to be addressed. Developing relevant and effective prevention, screening, early diagnosis, treatment and rehabilitation, research questions call for research which is capable to use complex inter- and cross-disciplinary research models, technologies, and bridges between scientific

disciplines and society^{5,6,7}. The next generation will have demands on the health and care community based on all information which can be accessed. This combined with an overall improved economic situation where tomorrow's elderly will need to get the most effective treatment, prediction of illness and home care. This is one societal challenge to be addressed and communicated. There is a need to continue bringing together leading healthcare companies across multiple industry sectors, public and private research centres, and top universities, to accelerate entrepreneurship and innovation in healthy living and active ageing for the benefit of all EU citizens⁸.

We are in a transition phase moving away from a *one-size-fits-all* approach into cus-

tomised health care that is tailored to the needs of the individual. Personalised medicine focuses on the patients based on their individual clinical characterization. Precision medicine focuses on identifying which approaches will be effective for which patients based on genetic, environmental, and lifestyle factors. This transition towards customised health care is data- and knowledge-driven. The challenge of data- and knowledge- collection, management and stewardship for precision medicine is already beginning to be met by pan-European infrastructures like the **ESFRI Landmarks ELIXIR, BBMRI ERIC, INFRAFRONTIER** and others (see **Figure 3**), – including ethical, legal and social implications. For proper storage and smart retrieval of these data and knowledge, ICT for health is indispensable. Data relevant to precision medicine are not only generated in the laboratory and clinic. Citizens and patients are increasingly taking advantage of social media and app technologies to share information about their own health and lifestyle. Data shared by patients have already been

5. Advice For 2016/2017 of the Horizon 2020 Advisory Group For Societal Challenge 1. Health, Demographic Change And Wellbeing, 2014
<http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetailDoc&id=15073&no=1>

6. Shaping Europe's Vision for Precision Medicine, 2015
http://www.permed2020.eu/_media/PerMed_SRIA.pdf

7. The Precision Medicine Initiative Cohort Program – Building a Research Foundation for 21st Century Medicine, 2015
<https://acd.od.nih.gov/documents/reports/DRAFT-PMI-WG-Report-9-11-2015-508.pdf>

8. EIT Health
<https://www.eithealth.eu/>

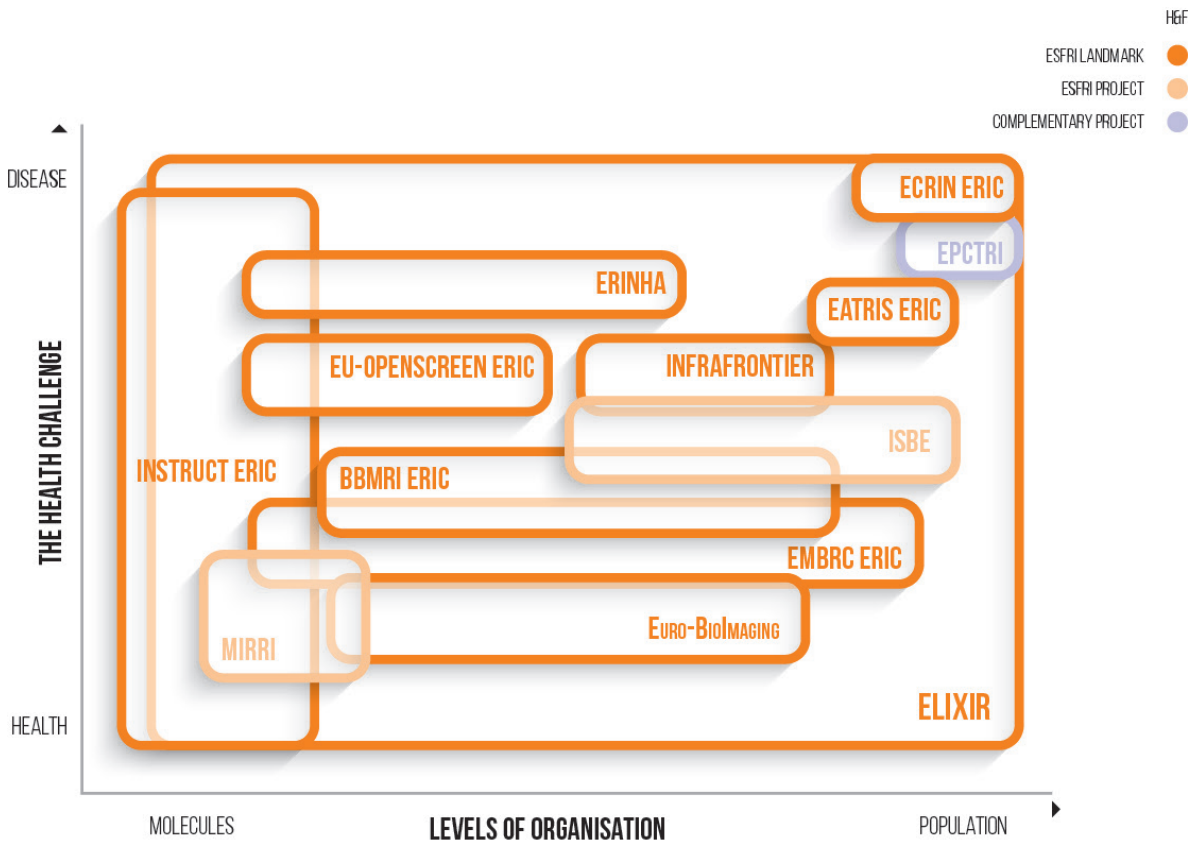


FIGURE 3.
The indicative position of ESFRI Research Infrastructures relative to the different levels of organisation in the Health domain

used effectively for research purposes and it is apparent that this sort of citizen-led collaboration can serve to accelerate clinical research.

The development of increasingly tailored interventions will require smooth translation – the **ESFRI Landmark EATRIS ERIC** (European Advanced Translational Research Infrastructure in Medicine) – and new clinical trial designs to take account of the shift in focus from population to well-defined cohorts of even individuals – the **ESFRI Landmark ECRIN ERIC** (European Clinical Research Infrastructure Network) and the complementary project EPCTRI (European Paediatric Clinical Trial Research Infrastructures), which is focused on paediatric clinical trials. The experience can be extrapolated to other designs involving relatively few patients, e.g. rare diseases. The EU launched a Consultative Group on the European Joint Programme (EJP) for Rare Diseases, in which the **ESFRI Landmarks EATRIS ERIC** and **ECRIN ERIC**, and the complementary project EPCTRI, are actively participating. The aim is to consolidate the transnational research on rare diseases through existing European platforms, and in the framework of the Horizon 2020 work programme 2018-2020, under Societal Challenge 1 - Health, Demographic change, and Well-being. Customised health-care is becoming one of the highly valued new possibilities for science and society. New threats, including pandemics, and exacerbation of diseases thought to be already eradicated, require the developments of innovative treatments and new strategies for the design of new drugs and potent vaccines – the **ESFRI Landmark INSTRUCT ERIC** (Integrated Structural Biology Infrastructure). Improved health-care will inevitably face the problem of the need for new therapies requiring bioinformatics – the **ESFRI Landmark ELIXIR**; experimental analysis of targets – the **ESFRI Landmark INSTRUCT ERIC**; medicinal chemicals and new biologicals – the **ESFRI Landmarks EU-OPENSREEN ERIC** (European Infrastructure of Open Screening Platforms for Chemical Biology) and **INSTRUCT ERIC**; an integrated approach to modelling disease – the **ESFRI Project ISBE** (Infrastructure for Systems Biology Europe); and state-of-the-art imaging technologies – the **ESFRI Landmark Euro-BiImaging** (European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences). In the case of emerging infectious diseases, as recently demonstrated by the Ebola outbreak, high-containment infrastructures will be crucial for new research – category 4 containment, the **ESFRI Landmark ERINHA** (European Research Infrastructure on Highly Pathogenic Agents) – including contained characterisation methods (category 3 and 4 electron microscopy). Important underpinning bioscience developments, such as the Human Cell Atlas, are in preparation. The Human Cell Atlas is an ambitious international programme with active participation by European countries, aiming to facilitate a comprehensive reference maps of all human cells as a basis for understanding human health and diagnosing, monitoring and treating disease^{9,10,11,12,13}.

9. _____
The Human Cell Atlas
<https://www.humancellatlas.org/>

10. _____
The 2015 Ageing Report
http://ec.europa.eu/economy_finance/publications/european_economy/2015/pdf/ee3_en.pdf

11. _____
The Data Mapping Project
<http://www.jpi-dataproject.eu/>

12. _____
EIT Health
<https://www.eithealth.eu/about>

13. _____
Towards Cleaner Air Scientific Assessment Report 2016
<http://www.unece.org/index.php?id=42861>

THE FOOD CHALLENGE

The global demand for food is predicted to increase 50% by 2030 and 100% by 2050. In many European countries, the growth trends of the yields of major crops, especially wheat, have declined over the past two decades and the variability of crop yields has increased as a consequence of extreme climatic events, such as the summer heat of 2003, which led to 36 billion € economic losses. FAO's 2016 report on the State of Food and Agriculture estimates decrease in yield of major European crops like wheat, maize and soybean under different climate scenarios. We need to produce more food whilst considering the influence of a changing climate, by increasing crop yield, and the efficiency, resilience and sustainability of the food chain, i.e. more product for less water, energy and chemical inputs. Substantial improvements with regard to livestock production are also needed, including new or more efficient strategies for preventing and managing livestock pathogens and the impact of antimicrobial resistance. But food security is also about improving nutritional and health benefits of foods, and making it accessible and affordable, globally, also minimising food waste. The UN sustainable development goals set food waste reduction targets of the following "halve per capita global food waste at the retail and consumer level, and reduce food losses along production and supply chains by 2030". Additionally, the Paris Agreement in 2015 recognised the important role of food production system in a changing climate and offers many opportunities in the food and farming sectors to limit the global temperature increase to well below 2 degrees.

The food system is by far the largest industrial sector in Europe in terms of turnover, value added and employment. In 2014, the activities with the strongest growth were agriculture, forestry and fishing (2.8%) and food services (2.1%) among others. An innovative bioeconomy in support of a *green growth* strategy that combines economic growth, natural resource preservation, highly efficient resource utilisation in well integrated value chains and greenhouse gas reduction is necessary. The bioeconomy is estimated to be worth at least 2 trillion € in the EU and employing around 22 million people. The objective is to secure sufficient supplies of safe, healthy and high quality food and other bio-based products, by developing resource-efficient primary production systems, fostering related ecosystem services and the recovery of bio-diversity, alongside competitive and low carbon supply chains^{14,15,16,17,18,19,20,21,22}. The food system fits in the concept of circular economy as a regenerative system that aims to preserve and enhance natural capital, optimises resource yields, and minimises system risks. Embedded in the framework of sustainable development, the goal is to produce goods and services while reducing the consumption and wastage of raw materials, water and energy sources²³. The *blue economy* is another area with great potential for innovation and growth, representing roughly 5.4 million jobs and generating a gross added value of almost 500 billion € a year²⁴. There is a need to continue developing the marine biotechnology pipeline towards Blue Growth, and deliver the long term strategy to support sustainable growth in the marine and maritime sectors²⁵.

Important steps have been taken with G7 Future of the Seas and Oceans Initiative²⁶, COP21²⁷ and FOOD 2030. The realisation of these, among other large initiatives, will require new collaborations between Research Infrastructures and perhaps new configurations and approaches.

Europe is well placed to address these issues. The European RIs currently on the Roadmap constitute the starting point to achieve this ambitious goal for Europe: the **ESFRI Project AnaEE** (Infrastructure for Analysis and Experimentation on Ecosystems) on experimental manipulation of managed and unmanaged terrestrial and aquatic ecosystems, the **ESFRI Project EMPHASIS** (European Infrastructure for Multi-scale Plant Phenomics and Simulation), the **ESFRI Landmark EMBRC ERIC** (European Marine Biological Resource Centre) on marine ecosystems and biological resources, the **ESFRI Landmark ICOS ERIC** (Integrated Carbon Observation System, ENV) on high precision monitoring of greenhouse gas fluxes, other RIs from the ENV domain, the **ESFRI Project MIRRI** (Microbial Resource Research Infrastructure) on microorganisms-oriented services applied to biotechnology and food production, the **ESFRI Landmark Euro-Biolmaging** on integrating imaging technologies and services (with links to crop phenotyping), the **ESFRI Landmark ECRIN ERIC** on clinical trials and nutritional trials, the **ESFRI Landmark INSTRUCT ERIC** on the use of structural biology to support plant and animal sciences, the **ESFRI Project ISBE** on integrated approach to food systems, and the **ESFRI Landmark ELIXIR** on life sciences large-scale data and knowledge management – applied to agriculture and bioindustries – and their links to other multidisciplinary RIs (see **Figure 4**).

14. How to feed the world in 2050. Food and Agriculture Organization of the United Nations (FAO), 2009 http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

15. Climate Change 2014, Synthesis Report - IPCC, 2014 <http://www.ipcc.ch/report/ar5/syr/>

16. A European science plan to sustainably increase food security under climate change. Soussana et al. Global Change Biology 18 (11), p. 3269–3271, 2012

17. European Statistics (Eurostat) - European Commission, 2008 <http://ec.europa.eu/eurostat>

18. The Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI) <https://www.faccejpi.com/>

19. Joint Programming Initiative - A Healthy Diet for a Healthy Life (JPI-HDHL) <https://www.healthydietforhealthylife.eu/>

20. A Bioeconomy Strategy for Europe, 2012 <http://ec.europa.eu/research/bioeconomy/index.cfm>

21. Sustainable Agriculture, Forestry and Fisheries in the Bioeconomy. A Challenge for Europe. 4th SCAR Foresight Report, 2015 <https://ec.europa.eu/research/scar/pdf/ri-01-15-295-enn.pdf>

22. Sustainable Development Goals 17 Goals to Transform the World <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>

23. Circular Economy European Summit <http://www.circulareconomysummit.com/>

24. Maritime affairs, Integrated maritime policy - Blue Growth https://ec.europa.eu/maritimeaffairs/policy/blue_growth_en

25. The European Marine Biological Research Infrastructure Cluster: An Alliance of European Research Infrastructures to Promote the Blue Bioeconomy - Grand Challenges in Marine Biotechnology, pp 405-421, Piña M. et al., 2018 https://doi.org/10.1007/978-3-319-69075-9_10

26. G7 Future of Seas and Oceans http://www.g7italy.it/sites/default/files/documents/ANNEX_1_WG_Future_of_the_Seas_and_Oceans.pdf

27. COP21 <http://www.cop21paris.org/>

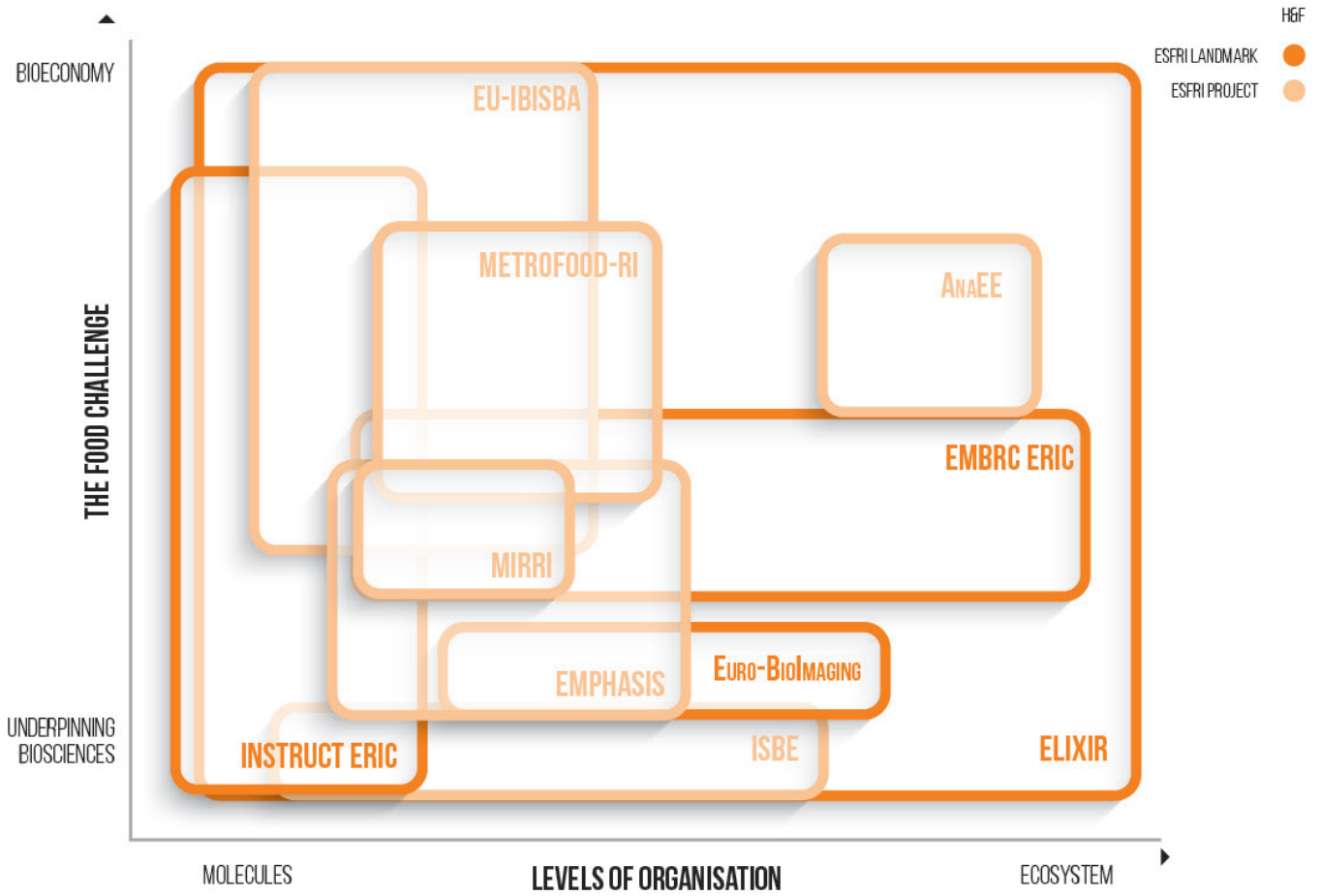


FIGURE 4.
The indicative position of ESFRI Research Infrastructures relative to the different levels of organisation in the Food domain

THE FAIR DATA REVOLUTION

The Open Data agenda has been driven steadily by the Health & Food distributed infrastructures in collaboration with relevant stakeholders. DNA sequencing technologies have revolutionised the life sciences, from basic biological research right through to biomedical, biotechnology and agri-food applications. High-throughput sequencing technologies now produce billions of bases of nucleotide data per experiment, at a low cost. There are now more opportunities to cross-fertilise different omics platforms, data sets and informatics. Imaging technology is producing vast amounts of data revealing life in unprecedented detail. Structural investigation technologies are also accumulating data at a rate in excess of Moore's law. Cloud computing is estimated to reach a total cumulative gain of 940 billion € in the period 2015-2020. The life science sector is an intensive user of High Performance Computing and it is expected this will increase further^{28,29,30}. The data and knowledge generated are contributing to extend the boundaries of frontier and applied research, and to respond to the Health & Food challenges. This will increase opportunities for all stakeholders to be part of the landscape and build competencies, regardless of whether they have the RI in their own country.

ESFRI Health & Food RIs are at the heart of realising the data revolution, by providing pan-European access to the specialised research services and data, suitably open for innovation by industry. A growing number of European and National RIs and projects are established following the EC recommendation on access to and preservation of scientific information³¹. Some e-Infrastructure projects – i.e. OpenAire – offer infrastructure for researchers to support them in complying with the EC Open Access pilot and the

28. _____
Biology: The big challenges of big data. Marx, V. *Nature* 498, 255-260, 2013

29. _____
Quantitative Estimates of the Demand for Cloud Computing in Europe and the Likely Barriers to Uptake, 2012
http://ec.europa.eu/information_society/newsroom/cf/dae/document.cfm?doc_id=1115

30. _____
e-IRG White Papers, 2014
<http://e-irg.eu/white-papers>

31. _____
Commission Recommendation, 2012.
<https://bit.ly/20kxYvB>

ERC Guidelines on Open Access. The European Charter for Access to RIs³² sets out non-regulatory principles and guidelines for defining access policies for RIs. The Charter promotes interaction with a wide range of social and economic activities, including industry and public services, to maximise the return on investment in RIs and to drive innovation, competitiveness and efficiency. A number of e-RI projects address Data Management Policy in coordination and synergy with Health & Food RIs³³, e.g. BioMedBridges Charter for Data Sharing³⁴, or in the ERIC process. FAIRDOM³⁵ is an internationally sustained service to manage project data from instrument to publication since 2008. Establishing good data and model management practices ensures that data and models are findable, accessible, interoperable and reusable (FAIR). The high-level FAIR Guiding Principles³⁶ were established to precede implementation choices, and do not suggest any specific technology, standard, or implementation-solution. They act as a guide to data publishers and stewards to assist them in evaluating whether their particular implementation choices are rendering their digital research artefacts Findable, Accessible, Interoperable, and Reusable. It is anticipated that these high level principles will enable a broad range of integrative and exploratory behaviours, based on a wide range of technology choices and implementations. Indeed, many repositories are already implementing various aspects of FAIR using a variety of technology choices. ESFRI Health & Food RIs are playing a key role in the promotion and implementation of these principles. In addition,

32. _____
European Charter for Access to RIs, 2015
https://ec.europa.eu/research/infrastructures/pdf/2016_charterforaccessto-ris.pdf

33. _____
Towards coordination of international support of core data resources for the life sciences. Anderson et al., 2017
<https://www.biorxiv.org/content/early/2017/04/27/110825>

34. _____
BioMedBridges, Principles of data management and sharing at European RIs. 2014.
<https://zenodo.org/record/8304/files/BioMedBridges-principles-of-data-management-and-sharing-at-RIs.pdf>

35. _____
FAIRDOM
<https://www.fairdomhub.org/>

36. _____
The FAIR Guiding Principles for scientific data management and stewardship
<https://www.nature.com/articles/sdata201618>

life sciences research relies extensively upon a set of core resources that archive, curate, integrate, analyse, and enable ready access to data, information, and knowledge generated worldwide by hundreds of thousands of researchers. The sustainability of core data resources is being discussed internationally, with the **ESFRI Landmark ELIXIR** playing a key role³⁷.

The FP7 BioMedBridges and the H2020 CORBEL projects represent a successful joint effort of Health & Food RIs to develop common approaches and standards for data integration in the biological, medical, translational and clinical domains. The **ESFRI Landmark INSTRUCT ERIC** has developed ARIA, a platform for harmonised user access to biological and medical technologies, biological samples and data services required by cutting-edge research. Within CORBEL, the ARIA platform has been further optimised for integrated access to multiple RIs. The current global research data landscape is highly fragmented, by disciplines or by domains, from oceanography, life sciences and health, to agriculture, space and climate. Health & Food RI experts participate actively in the Research Data Alliance³⁸, a high profile international initiative – over 2,500 membership from 92 countries – aiming at building the social and technical bridges across these areas that enable open sharing of data. Health & Food RIs are also contributing to shape the European Open Science Cloud (EOSC), an EC-led initiative aiming at interconnecting existing Research Infrastructures to offer European researchers and professionals a virtual environment to store, share and re-use their data across disciplines and borders. EOSC will be underpinned by the European Data Infrastructure, deploying the high-bandwidth networks, large scale storage facilities

37. _____
Data management: A global coalition to sustain core data
<https://www.nature.com/articles/543179a>

38. _____
The Research Data Alliance is supported by The Australian Commonwealth Government through the Australian National Data Service supported by the National Collaborative Research Infrastructure Strategy Program and the Education Investment Fund (EIF) Super Science Initiative, the European Commission through the RDA Europe project funded under the 7th Framework Program and the United States of America through the RDA/US activity funded by the National Science Foundation and other U.S. agencies.

ties and super-computer capacity necessary to effectively access and process large datasets stored in the cloud. The **ESFRI Landmarks ELIXIR, ECRIN ERIC, INSTRUCT ERIC** and **BBMRI ERIC** are participating actively in EOSC Pilot. The EOSC's Stakeholder Forum in November 2017 attracted all Health & Food RIs to help define EOSC future. A group of EU member states is preparing the GO FAIR initiative, which is a proposal for the practical implementation of the EOSC initiated in the life sciences domain by the ELIXIR node DTL in The Netherlands among others. The current H2020 WP2018-20 for Research Infrastructures includes a call for cluster projects targeted to ESFRI projects and landmarks in all domains: Biomedical Sciences, Environment and Earth Sciences, Physics and Analytical Facilities, Social Sciences and Humanities, Astronomy, Energy. Research Infrastructures can only participate in one cluster. Further efforts may be required to promote and facilitate the interaction between domains and to avoid fragmentation of the data continuum.

The Open Access concept is widely accepted and promoted by ESFRI Landmarks in Health & Food. The **ESFRI Landmark BBMRI ERIC** and its Common Service ELSI aim at facilitating and supporting cross-border exchanges of human biological resources and data attached for research uses, whilst giving proper consideration of ethical, legal and social issues. The **ESFRI Landmark INSTRUCT ERIC** has adopted a data policy that specifically encourages its users to make their data open and mandates the development of the required tools. The **ESFRI Landmark ELIXIR**, together with the **ESFRI Landmark CLARIN ERIC** (Common Language Resources and Technology Infrastructure, SCI) and **ESFRI Landmark DARIAH ERIC** (Digital Research Infrastructure for the Arts and Humanities, SCI), in the social sciences and humanities, and the DASISH cluster project, have endorsed the eduGAIN Data Protection Code of Conduct. Health & Food RIs are actively managing all aspects related to the implementation of the new General Data Protection Regulation (GDPR), effective from May 2018. The GDPR applies to both automated personal data and to manual filing systems where personal data are accessible according to specific criteria.

INTERCONNECTED SERVICES AND CAPABILITIES

The Health & Food RI landscape is made up of a vast number of national infrastructures interconnected at different levels. Many of the framework programme Integrating Activities (IA) have provided the foundation and primary integration for more complex RIs, as communities mature and the case for higher integration and connection is refined.

For instance, the **ESFRI Landmark INSTRUCT ERIC** integrates a series of IA projects of specialised structural technologies and tools, i.e. X ray diffraction, NMR, EM and Mass Spec (Bio-NMR, BioStructX, PrimeX, PCUBE) pushing beyond the horizon of each individual technology. The **ESFRI Project EMPHASIS** integrates IA projects EPPN and EPPN2020, facilitating access to 31 key plant phenotyping installations, developing novel technologies and methods for environmental and plant measurements, tools for statistical analysis and information systems, and integrating phenotyping facilities and users in the EU and internationally. The combination of research capability and capacity of ESFRI RIs and IAs enhances the landscape and accelerates the transfer of data and technologies into services and innovation.

The Health & Food RIs constitute an advanced level of integration at pan-EU scale, bringing together facilities, services and resources for research, and taking them to a new level of expertise and synergy. ESFRI in its incubator role has enabled the current Health & Food RIs to significantly change the infrastructure landscape: they are in a unique position to offer complementary or sequential processes and services in different fields. This is the model of the **ESFRI Landmarks INFRAFRONTIER, INSTRUCT ERIC, EATRIS ERIC** and **ECRIN ERIC** together with EPCTRI, in association with the **ESFRI Landmarks BBMRI ERIC** and **ELIXIR**. In early stage drug discovery, the **ESFRI Landmarks EU-OPENSREEN ERIC** and **INSTRUCT ERIC** provide a platform for identifying candidate compound hits for target pipelines; the **ESFRI Landmark INFRAFRONTIER** provides animal models to test hypotheses preliminary

to human testing; the **ESFRI Landmarks INSTRUCT ERIC** and **EATRIS ERIC** provide the translational pre-clinical and early clinical research facilities; and the **ESFRI Landmark ECRIN ERIC** provides the clinical infrastructure for the clinical research on diagnostic and therapeutic procedures and clinical trials of drugs and devices in patients. The Complementary Project EPCTRI, offers a facility to deliver clinical trials involving children with uniform standards across Europe. EPCTRI and the **ESFRI Landmark ECRIN ERIC** have aligned their efforts at strategic and operational level, for mutual benefit. The H2020-funded project PedCRIN is helping to consolidate these efforts. It is expected that similar integrated service pipelines will be established in other areas of the Health & Food landscape, e.g. marine biotechnology, industrial biotechnology, and sustainable agri-food systems, where the **ESFRI Landmark EMBRC ERIC**, and the **ESFRI Projects AnaEE, EMPHASIS, EU-IBISBA** (Industrial Biotechnology Innovation and Synthetic Biology Accelerator), **METROFOOD-RI** (Infrastructure for promoting Metrology in Food and Nutrition) and **MIRRI** will play a significant role.

Integrating technologies at different levels of complexity is allowing RIs to tackle problems using a systems approach. The **ESFRI Project ISBE** is an example of a RI with a role in integrating life sciences technologies, data and services between the Health & Food RIs, with complementarities with ESFRI Landmarks and Projects, like the **ESFRI Landmark ELIXIR**. An example of integration of services at thematic level can be that for diagnosing rare diseases, as critical amount of data is gathered and shared from different countries in Europe that otherwise would not be available. Meta- or global infrastructures with a thematic and/or a technological focus are key elements of the landscape.

▶ GAPS, CHALLENGES AND FUTURE NEEDS

There are some significant gaps to be filled and connections to be enabled across the pan-European landscape of infrastructures in Health & Food. There is a need for a pan-EU approach on food and nutrition as well as in sustainable agriculture and bio-economy, building a natural link between the two complex medical and agriculture fields. Gaps can be identified at many levels and in order to complete the landscape, it will also be important to connect infrastructure efforts within Health & Food and with other domains. Significant innovations and new developments often occur at the boundaries of research areas, and Health & Food Strategic RIs have already established effective connections between them and

across other ESFRI domains. As the landscape keeps evolving, new connections will and need to be made; ESFRI Landmarks and Projects in all domains have a key role to play as a driver in promoting and facilitating effective and fruitful connections, as well as in supporting the ERA.

These new connections need to be pursued to maximise current efforts by ESFRI RIs and build on the technical and thematic knowledge gained in ESFRI Clusters, to deliver new knowledge and new services, and enhanced socio-economic impact. Different levels of integration and connections will continue to build the infrastructure landscape in the Health & Food sector, to-

wards true interdisciplinarity and convergence (see **Figure 5**).

Boundary areas have the potential to provide a new level of integration and organisation. It is proposed that boundary areas can lead to the formation of Interdisciplinary Clusters in order to realize the added value of RIs being connected not only to new RIs but also to other relevant initiatives. Interactions with stakeholders like the healthcare and agri-food sectors and industry will benefit from those formations. This is important in order to continue building the ERA, capitalising on the generated knowledge and translating these into the benefits for society.

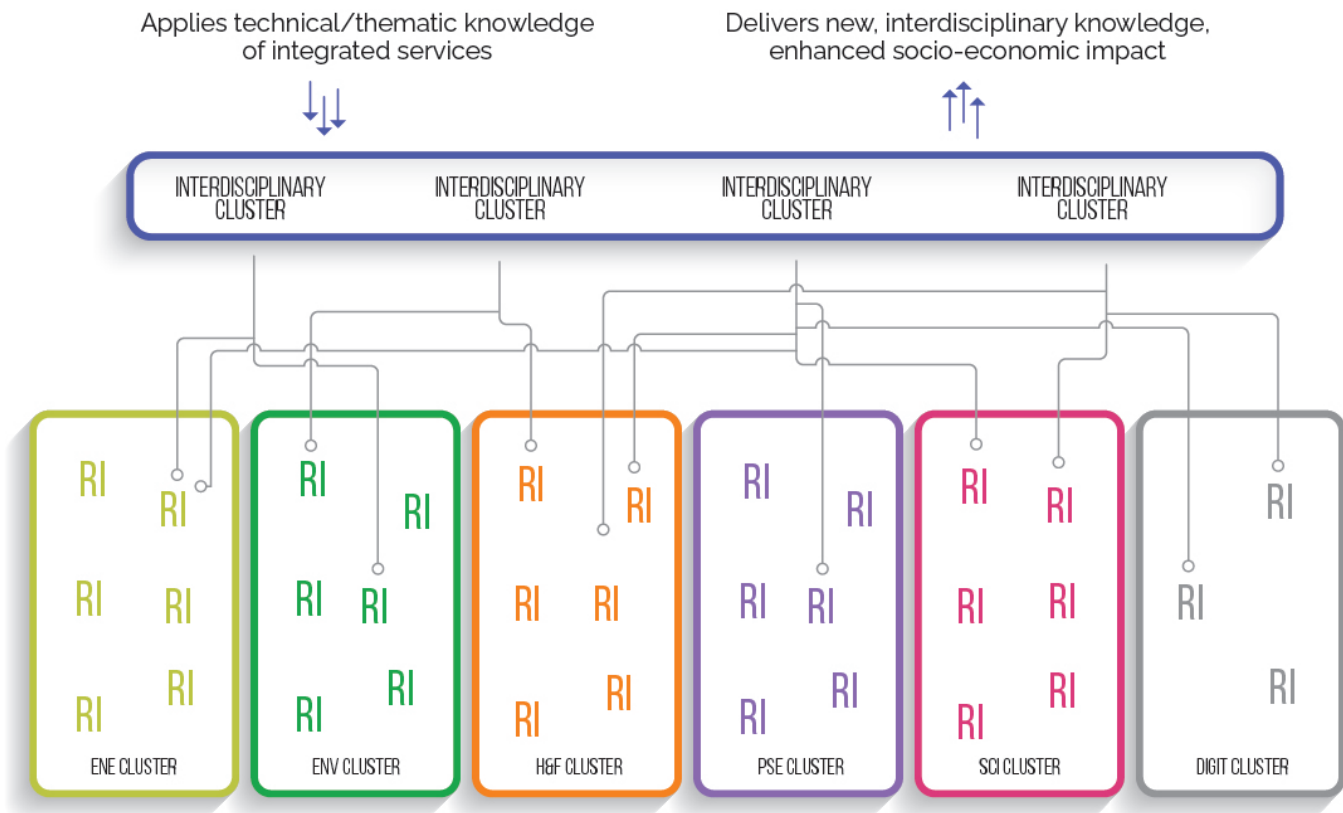


FIGURE 5.
Interdisciplinary clusters - new connections in the ESFRI RIs landscape

GAPS AND CONNECTIONS IN FOOD

In the context of a changing environment, an increasing human population and pressure on land, a concerted effort to continue bringing together national facilities at pan-European level in the field of *animal genetic resources, phenotyping and breeding, animal health* is needed to contribute to address the challenge to produce safe, healthy and sustainable food. Continued RI efforts at EU-level are needed to provide livestock genetic resources, phenotyping and breeding, including large farm animals, poultry and fish; genetic resources for adaptation to climate change and protein production; genomic selection and genetic modification and sustainable intensification for higher feed efficiency, precision livestock farming and precision feeding; platform of technologies and capabilities for epidemiological modelling and surveillance, including host-pathogen interactions and vaccinology towards countering the threats of animal-borne disease. There is a need to proactively combine world-class facilities for the integration, conservation, and coordination of national and international animal genetic stock, and potential stock lines for adaptation to climate change. New efforts should include integrated facilities for bio-imaging, digital imaging, genomics, proteomics and metabolomics along with field and veterinary facilities with farm-scale experimental platforms for animal studies and phenotyping, including aquaculture and animal disease facilities, e.g. building on AQUAEXCEL³⁹, NADIR⁴⁰ and VetBioNet⁴¹. Animal genotype-to-phenotype infrastructures and capability at pan-EU level will have a positive impact on global food production and on European competitiveness, and enhance international effort in this important field.

Food related diseases are costly; the EU national health systems are the most under

pressure. The key is to fully understand the interrelation between nutrition and health, particularly the digestive process and the role of food consumption, including the gut microflora, food pathogens, immunology and many other factors, that together can help develop new strategies to deliver healthy and nutritious food and encourage favourable changes in consumption patterns. Regulatory demands relating to health and novel foods impose comprehensive safety assessment procedures and scientific evidence. European research base and expertise in nutrition and food science is unique but it remains highly fragmented and, in some areas and countries, it is below the critical mass^{42,43,44}.

New infrastructure efforts are needed at EU-level in the field of *food, nutrition and processing*. There is a need to connect RIs across EU and globally, and across the entire food chain. Food systems cover a number of intertwined important areas, spanning social, cultural, economic, geo-political, and environmental dimensions, and involving a great diversity of stakeholders. There is a role for Research Infrastructures to be able to connect food systems and stakeholders. The **ESFRI Projects AnaEE, METROFOOD-RI, EMPHASIS**, and other EU initiatives like the EC-funded project Richfields contribute to achieve this aim, from sustainable food production to consumer behaviour. The **ESFRI Landmark EMBRC ERIC** supports fundamental and applied research activities towards sustainable solutions in the food sector, as well as in health and the environment.

Connections to food and feed production systems are key. The **ESFRI Project EMPHASIS** is central to this stage, currently establishing connections to relevant ESFRI Projects and Landmarks as well as other infrastructures and large scale initiatives. The International Wheat Yield Partnership (IWYP), led by public funders of UK, France, USA, Canada, Australia, India, Mexico is

a global mechanism established in 2012 bringing together funding from public and private research organisations from around the world with the goal to raise the genetic yield potential of wheat by 50% in 20 years. This important gap area is of interest to many EU countries and current efforts to connect relevant infrastructures and large scale initiatives should continue^{45,46}.

The **ESFRI Project METROFOOD-RI** aims at providing high quality metrology services in food and nutrition, comprising an important cross-section of highly inter-disciplinary and inter-connected fields throughout the food value chain, including agro-food, sustainable development, food safety, quality, traceability and authenticity, environmental safety, and human health. This gap area is vast and there are in addition several IA addressing complementary aspects on food and nutrition, which are breaking ground for future infrastructure in nutrition and health, e.g. FoodManufature EuroFIR, NuGO, Food4Me, Eurogene, EURRECA, QuaLiFY, and EuroDISH^{47,48}. In addition, the combination of fundamental science, translational research and clinical trials, positioned alongside a major clinical gastroenterology service and tissue repository, will ensure a seamless interface between research, clinical practice and the pharmaceutical and biotechnology industries, also cross linking with RIs at the boundary areas.

Food production and its accessibility are increasing worldwide. Legal and ethical issues are critical and have to be addressed as well as information and communication. Nanotechnologies create the possibility of foods with new flavours and textures, and also healthier food products with reduced salt, fat or sugar content or increased vitamin and nutrient content, using nanocapsulation. Due regard needs to be given to safety and sustainability aspects in their broadest sense as well as to public perception and stakeholder engagement in align-

39. Aquaexcel
<http://www.aquaexcel.eu/>

40. NADIR - The Network of Animal Disease Infectiology Research Facilities
<https://www.nadir-project.eu/>

41. VetBionet
<http://www.vetbionet.eu/>

42. JRC Foresight study, Tomorrow's healthy society – Research priorities for foods and diets, 2014
<https://ec.europa.eu/jrc/sites/jrcsh/files/jrc-study-tomorrow-healthy-society.pdf>

43. 3rd and 4th SCAR foresight exercises
<https://ec.europa.eu/research/scar/pdf/ri-01-15-295-enn.pdf>

44. ETP Food for Life Implementation Plan, 2018
<http://etp.fooddrink.eupe.eu/>

45. The International Wheat Yield Partnership (IWYP)
<http://iwyp.org/>

46. Wheat Initiative
<http://www.wheatinitiative.org/>

47. EuroDISH
<http://www.eurodish.eu/>

48. Precision agriculture and the future of farming in Europe
[http://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU\(2016\)581892_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf)

ment with the principles of Responsible Research and Innovation. These principles apply to all Health & Food areas but are flagged here for their relevance in the nanotechnology field.

The increasing digitalisation of agricultural practices is realising the production of plant and animal products with ever higher efficiency and ever lower environmental impact – Precision agriculture and the future of farming in Europe. Precision agriculture is a modern farming management concept using digital techniques to monitor and optimise agricultural production processes. Beyond sustainable food production, precision agriculture offers technologies for producing more food with less input, e.g. sensor-based monitoring systems provide farmers with better information and early warnings on the status of crops, and improved yield forecasts. Precision agriculture also plays a major role in animal husbandry. The **ESFRI Projects EMPHASIS** and **AnaEE** aim to collaborate in bringing innovative solutions for a sustainable intensification of agriculture. By integrating the study of plant phenomics and agricultural ecology they hope to foster the development of novel scientific concepts, sensors and integrated models⁴⁹. Integrated approaches including e-infrastructures are needed to systematically predict, diagnose, prevent and treat plant and animal disease, and to devise effective responses to mitigate the impact on agri-ecosystems. Legal and ethical issues are critical as well as information and communication.

Health & Food RIs and their connections with ENV SWG and ENE SWG RIs are critical to address issues associated with *agriculture and land-use change*, food and non-food systems, and bioenergy. The **ESFRI Project AnaEE** is working with the **ESFRI Landmarks ICOS ERIC** (Integrated Carbon Observation System, ENV), **LifeWatch ERIC** (e-Infrastructure for Biodiversity and Ecosystem Research, ENV), and others in the EC projects ENVRI and ENVRI+, Common Operations of Environmental RIs linking across e-infrastructure initiatives. The links to the social sciences are also important. The global demand for food includes challenges regarding efficiency, resilience and sustainability. The field of bioenergy and biorenewables in particular links to energy and environmental facilities.

49. European infrastructures for sustainable agriculture. Roy et al. (2017) <https://www.nature.com/articles/s41477-017-0027-3>

The sustainable production and conversion of biological raw materials for use as sources of renewable energy, materials and chemicals can provide alternatives for diminishing fossil resources and drive the growth of the knowledge based bio-economy. Addressing the demand for sustainable supplies of materials, fuels and food through biological means required the use of biological resources towards environmental and economic sustainability. An effort at European level is required to bring together pilot-scale facilities, demonstrators and up-scaling facilities to enable access to the production and processing of materials, chemicals (e.g. antibiotics) and energy, using biological resources, including plant, algae, marine life, fungi and micro-organisms. The **ESFRI Project EU-IBISBA** proposes a distributed RI on industrial biotechnology with applications in energy (liquid biofuels), chemicals (organic acids), materials (bioplastics) and ingredients for the food, feed, cosmetics and pharma sectors (enzymes, antioxidants, antibiotics). The **ESFRI Project EU-IBISBA** aims to deliver translational research in industrial biotech, allowing researchers to access cutting-edge technology, infrastructure and expertise to move projects up to TRL6. The **ESFRI Project EU-IBISBA** has the potential to accelerate TRL2 to TRL6 processes, and in reducing time to market. It will interact with and connect to existing infrastructures such as the **ESFRI Projects ISBE** and **MIRRI**, the **ESFRI Landmarks BBMRI ERIC**, **ELIXIR**, **INSTRUCT ERIC**, and **EU-OPENSREEN ERIC**, and other RIs in the environment, and energy sectors. The infrastructure uses synthetic biology as one of their approaches. Synthetic biology applies engineering to the biosciences, seeking to design and construct/modify new or existing biological parts and systems to deliver novel functions that do not exist in nature. The field is expected to impact many sectors of the economy, and to provide tools to better tackle areas of great social and environmental interest, including health, energy and food security⁵⁰. Synthetic biology is both highly interdisciplinary and technically and scientifically demanding. It and also addresses a range of social, economic, ethical, and legal issues.

50. ERA-Net SynBio <https://www.erasynbio.eu/>

GAPS AND CONNECTIONS IN HEALTH

The future of health research offers high potential to patients, to citizens, and the economy. The move in the sector towards precision and stratified medicines and personalised healthcare at much lower cost to the consumer brings with it a need to test new technologies and provide multi-scale facilities as test-beds for pharmaceutical and biopharmaceutical (therapeutics) manufacturing. These activities apply primarily to industries for technological development based on academic input and evidence. Investment to date has focused more on fundamental science and discovery, meaning that there is a gap between discovery and actual manufacture. This area should constitute an excellent platform of technology development and include the complete manufacturing process from a scientific, engineering, regulatory and supply chain perspective, with the ultimate aim of providing affordable access to innovative therapies in collaboration with the **ESFRI Landmarks EATRIS ERIC**, **ECRIN ERIC**, and **EU-OPENSREEN ERIC** and other relevant RIs, and Innovative Medicines Initiative (IMI2). Research in this area is expected to be highly innovative and will lead to three key benefits: better diagnosis and earlier interventions, more efficient drug development, and more effective therapies. Existing infrastructures such as the **ESFRI Landmarks BBMRI ERIC**, **EATRIS ERIC**, **ECRIN ERIC**, **ELIXIR**, **ERINHA** and others could connect aiming at providing a full pipeline for drug development.

Advances in the sector of personalised health care require computational approaches, and integration with innovations in biomedical engineering, analytical research, and other relevant fields as well as with social, ethical and regulatory aspects. The challenge of *antimicrobial resistance* and pandemics also calls for an integrated effort. Next generation sequencing technologies and mass spectrometry platforms for genomic, transcriptomic, proteomic, metabolomics and metagenomics applications, coupled with advanced imaging, set the basis for personalised and stratified drug discovery and development. Combined high-end technology platforms with specialised expertise, bringing together hospitals, research centres and

the private sector in an integrated network that will offer a point of single access for the development of next generation medicines. All ESFRI Health & Food Landmarks and Projects with applications in health have the capacity to play a significant role in enabling research activities towards developing tailored healthcare interventions and robust models for prevention and treatment strategies, bridging the gap between genomic information and clinical practice.

New therapies are needed in order to cure and treat *complex diseases*. Challenges exist in the development of new applications and new modes of treatment approaches in *imaging, diagnostics and novel therapeutics*. The **ESFRI Landmarks INSTRUCT, ERIC, Euro-BioImaging, INFRAFRONTIER, EATRIS ERIC** and **ECRIN ERIC** are of relevance. Interdisciplinary interactions will be critical in order to handle upcoming issues and implications – e.g. in the *ageing population* and neuroscience research⁵¹. Links of relevance are the Joint Programming Initiative "More Years, Better Lives – The Potential and Challenges of Demographic Change" seeking to map data sources on ageing at the European and national levels⁵² and the Knowledge and Innovation Community initiative EIT Health, promoting innovation in healthy living and active ageing⁵³. New advances in technologies, such as nanotechnologies, are having impacts on therapeutics, diagnostics, imaging and regenerative medicine, particularly in cardiovascular diseases, diabetes and cancer. Due regard needs to be given to public perception and stakeholder engagement and the principles of Responsible Research and Innovation. Tools for health planning are required. A Health information System is supported by the EC DG SANTE as a joint action to harmonise health indicators and surveillance tools across Europe, and to host health-related databases including population based and clinical registries for diseases, biobanks, health protocols as well as metadata for health determinants.

51. The 2015 Ageing Report
http://ec.europa.eu/economy_finance/publications/european_economy/2015/pdf/ee3_en.pdf

52. The Data Mapping Project
<http://www.jpi-dataproject.eu/>

53. EIT Health
<https://www.eithealth.eu/about>

Longitudinal population studies and cohorts are an invaluable resource for research, in health and disease conditions. These studies gather data over a long period of time and provide a rich resource with connections to several domains. In particular, this is an area to explore together with the ESFRI Social & Cultural Innovation SWG and its Research Infrastructures, which flagged "integration of biosocial data and resources – longitudinal and cohort studies" in their landscape as an important area of connection to Health & Food Research Infrastructures. There is a need to enable a Research Infrastructure environment that will facilitate research on the *human health and wellbeing* at all stages in development, including ageing, nutrition and behavioural studies, and their connections to the social sciences and humanities. There are also geographic, economic and environmental drivers affecting human health and wellbeing. Climate change, extreme weather, dramatic changes in ecosystem services, *environmental pollution and exposure to harmful chemicals* represent a new combination of issues that require an integrated approach at pan-European level. At the heart of this approach is the exposome, taking a holistic view throughout the human lifetime on the effect of exposures to diet, lifestyle, and the environment on human health and disease. The exposome coupled with advanced genetic and medical approaches represents an opportunity to tackle this complex issue by connecting to the landscape of Health & Food RIs and other domains. Ongoing EU projects and networks on human biomonitoring (HBM4EU and EMEP) are important steps to bring together relevant parties⁵⁴.

Health & Food RIs provide a framework for applications in other domains, such as anthropological studies, using biobanking, omics, and metabolomics. Cohorts include biological material of specific diagnoses and general populations either longitudinal or case by case. Multidisciplinary databases contain data of different aspects related to the addressed hypothesis. The combination of these has the potential to enable better understanding of disease and the identification of disease mechanisms.

54. Towards Cleaner Air Scientific Assessment Report 2016
<http://www.unece.org/index.php?id=42861>

VISION AND PERSPECTIVES

ESFRI has been instrumental and influential in the co-ordination of national decision-making and investment in European RIs in Health & Food. The landscape continues to evolve and it is important to ensure its ability and agility to respond to current and future demands. Significant innovations and new developments often occur at the boundaries of research areas. To continue cementing the critical role of distributed RIs in Health & Food as they progress in their lifecycle, it will also be important to connect infrastructure efforts with other domains. This is territory largely unexplored and where Health & Food RIs have the potential to pioneer new ways of working and realise true interdisciplinarity.

There is a need to develop well-established procedures for the systematic assessment of the social and economic impact of Health & Food RIs, to demonstrate effective use of resources and accountability for public money, to inform future decision making and evidence for policy-making, to demonstrate evidence of societal and economic benefits and to ensure their long term sustainability. Overall, this will help demonstrate the collective impact that the distributed RIs in Health & Food have had in shaping the landscape of research infrastructures in the last 12 years since the first ESFRI Roadmap was published, and will signal their potential to transform the landscape in the years to come.

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PART2

LANDSCAPE ANALYSIS - SECTION1

PHYSICAL SCIENCES & ENGINEERING

PHYSICAL SCIENCES & ENGINEERING

Research Infrastructures are integral part of the day-to-day activity of Physical Sciences & Engineering. Historically and today the PSE RIs are integrated in the way research is done in these disciplines, and major advances in knowledge are achieved by the research performed at RIs. However, the RIs are much more than research tools; they are truly *Hubs of Knowledge & Innovation* with a complete multidisciplinary approach and a systematic impact on many areas beyond Physical Sciences and Engineering.

To date there are few assessments of the socio-economic impact of RIs over their lifecycle^{1,2,3}. There are even fewer studies that take into account the wider impact on society; benefits which are not directly economic, such as health, a safer and fairer society, and a cleaner environment. Indeed, the methodology for such studies is still a subject of debate. However, the PSE RIs enable a vast range of science and engineering research that has an impact on almost all the identified areas of societal challenge, including health and the aging population; cleaner energy and a greener environment; better transport and improved cities; improved communications; national and personal security.

A major challenge that confronts scientists and policymakers is the increasing cost of the tools needed for achieving progress at the frontiers. Basic research as conducted today in these areas is truly international. About 30% (in some cases much more than 50%) of the users of the large and medium sized RIs are from outside the country where the facility is located. Support for the

operations of these facilities has historically been provided by the host country or region with a policy of free and open access by the international scientific community and with beam-time and observation-time allocated based upon the merit of the proposed research.

Inside the PSE domain we identify three thematic subareas: **ASTRONOMY AND ASTROPARTICLE PHYSICS**, **PARTICLE AND NUCLEAR PHYSICS** and **ANALYTICAL PHYSICS**. In the following, the three areas will be described, with the corresponding RIs available, and the identified gaps and challenges for the near future.

Astronomy and Astroparticle Physics is evolving over recent years towards a multi-observatory approach. This new approach is contributing to our holistic understanding of the universe and its components to an unprecedented degree. Also beneficial and deep-rooted are the interactions with **Particle Physics** through the common theoretical framework and via *multi-messenger*, multi-instruments studies, covering an extraordinary range of electromagnetic wavelengths, different particles and most recently gravitational waves. Fast data analysis, together with an early alert network system, makes possible a direct observation of the same event by multiple observatories, thus elucidating the same phenomena with complementary techniques. The convergence of the different disciplines and different messengers is providing a very fertile approach

and new results, which directly impact on the understanding of the physical world, from infinitely small to extremely large scales. The Astronomy and Astroparticle Physics community involves more than 12,500 scientists⁴.

Particle Physics aims not only at understanding the elementary constituents of matter, but also at building a coherent theoretical framework including all fundamental forces, which would allow us to understand the evolution of the universe from its earliest instants. Probing the limits of the Standard Model of particle physics and beyond, therefore involves understanding gravitation as well as elucidating the *Dark Sector* of the Universe: Dark Energy and Dark Matter. The tools to achieve this goal are manifold, from the highest energy particle colliders and highest intensity beams to extremely low background detectors and the observation of cosmic messengers at the interface with astrophysics and cosmology, as well as ultra-high-precision experiments at the frontier with atomic physics. Some 13,000 scientists are registered as users of CERN alone.

Nuclear Physics is the study of atomic nuclei and nuclear matter and of the fundamental forces responsible for their properties and behaviour. It aims at studying the fundamental properties of nuclei from their building blocks, protons and neutrons, and understanding the emergent complexity in terms of the strong interaction from the underlying quark and gluon and their degrees of freedom within Quantum Chromodynamics (QCD). This requires detailed knowledge of the structure of hadrons, of the nature of the residual forces between nucleons resulting from their constituents and of the limits of the existence of bound nuclei and ultimately of hadrons themselves.

The significant global effort in basic nuclear physics research involves around 13,000 scientists and support staff with funding of

1. _____
The importance of physics to the economies of Europe
<https://www.eps.org/default.aspx>

2. _____
Long-Term Sustainability of Research Infrastructures,
ESFRI Scripta Vol2, October 2017
http://www.esfri.eu/sites/default/files/u4/ESFRI_SCRIPTA_TWO_PAGES_19102017_1.pdf

3. _____
SUSTAINABLE European Research Infrastructures
https://ec.europa.eu/research/infrastructures/pdf/swd-infrastructures_323-2017.pdf

4. _____
This number includes only the members of the
International Astronomical Union

approximately 2 billion € per year. Investment in basic science results in long-term economic benefits. Advances in nuclear physics techniques and accelerator technology have made significant contributions to national and societal priorities, including new approaches in energy, national security, industry, and medicine. The discoveries and technical advancements that result from nuclear physics research make important contributions to other scientific fields and national and societal priorities. The forefront research facilities attract and train a next generation of scientists for research and national needs.

Analytical Physics includes the fine analysis of matter by scattering of beams and by spectroscopy, the nanofabrication of complex materials and systems and the *in operando* study of their functionalities. Europe is extremely competitive in this field with several world-leader **Analytical Research Infrastructures (ARIs)** facilities including sources of photon, neutron, electron and ion beams such as **Synchrotron Radiation (SR)** storage rings, **Free-Electron Lasers (FELs)**, **Neutron Scattering (NS)**, advanced **Electron Microscopes (EM)**, **Nuclear Magnetic Resonance (NMR)**, high-performance lasers (**Ultra Short Pulse and High Intensity Lasers**) and **High Magnetic Fields (HMF)**.

The size of the current user community for **Synchrotron Radiation** facilities was estimated in 2017 as at least 24,000⁵. The current user community for **Free-Electron Lasers** is in its infancy and is probably less than 1,000. The size of the current user community for **Neutron Scattering** in Europe has been estimated as over 5,577 distinct users in 2017,

based on data provided by the facilities⁶. The size of the current user community for **Electron Microscopy** in the physical sciences Europe was estimated⁷ as 5,000 excluding proprietary industrial users. This number is likely doubled if users in structural biology are considered because of the sudden proliferation of Cryo-EM users following technological leaps in recent years which enable unprecedented resolution. The current user community for **Ultra Short Pulse and High Intensity Lasers** in Europe mainly comes under the umbrella of the LaserLab Europe network which now undergoes its 4th edition. This has a population of about 3,500 individuals from about 50 laboratories across Europe. The **ESFRI Landmark ELI** (Extreme Light Infrastructure) offers significantly enhanced research opportunities to the global academic and industrial community of users and with the increased availability of state-of-the-art beamlines, there is a potential for the growth of the scientific community. The size of the current user community for **High Magnetic Fields** in Europe can be estimated as 2,500 users and slowly growing based on the current number of users of the **ESFRI Landmark EMFL** (European Magnetic Field Laboratory). Adding up the numbers of users above quoted, a sum of approximately 45,000, including multiple users, is obtained. To the best of our knowledge, there is no quantitative study of cross-technique use across Europe, though the estimate of cross-facility use is of the order of 10%⁸ wherever there are co-located facilities – for example SR and neutron scattering facilities on the same campus.

There is a tendency to develop clusters of activity and to set up complementary facilities, both large and small in scale, around

Analytical Research Infrastructures, notably at research campuses like in Grenoble, Hamburg, Harwell, PSI Villigen, Paris-Saclay, Trieste, Barcelona and Lund. This, in turn, attracts partnerships with universities and industries which create effective hubs for research and innovation across a very wide range of disciplines and can make very significant contributions to the local economy. In most cases, ARIs also develop technologies or products as bio-products or derivatives of their core technology development. For example, in the field of laser technologies, the following areas developed: i) remote sensing for airport security and food safety; ii) medicine and medical imaging, in particular related to cancer therapy; iii) photonic devices and new laser technologies. One of the resounding success stories is Cobalt Light Systems Ltd. an STFC spin-off company, which produces the Insight100 machine⁹, a bottled liquid screener that is now being used in most airports worldwide.

This Landscape Analysis does not cover the research facilities for engineering or purely applied research as they escape the exact definition of RI, often operating as test facilities or technology demonstrators. Nevertheless, there are areas – like the cleanrooms for Nanoscience and Nano-Engineering – that support both the applied industrial end users, and fundamental research programs – e.g. in the development of emerging technologies as Artificial Intelligence, Quantum Technologies and Computing.

5. Brochure for the launch of LEAPS, November 13th 2017
<https://www.leaps-initiative.eu/>

6. Neutron Users in Europe. Facility based insights and scientific trends - Brightness project
<https://bit.ly/2uqOZpS>

7. As part of a survey of pan-European EM requirements for state of the art installations within the ESTEEM2 consortium. This figure excludes the life sciences and users of standard instruments who are likely to be at least equal to this number. It is important to recognise that an increase in demand for transitional access between the ESTEEM and ESTEEM2, INFRA projects, the latter offering 3,300 user days over a four-year period indicates unsatisfied bandwidth and hence provides support for consolidated (and more efficient) infrastructures and for an overall expansion of EM provision

8. Estimates of dual-use of facilities have been made in Grenoble and at Harwell

9. Insight100 machine
<https://www.coballight.com/products/insight100series/>

ASTRONOMY AND ASTROPARTICLE PHYSICS

Astronomy and Astroparticle Physics deal with the understanding of the universe and its components: from its still not well known beginnings to its growing complexity, with the formation and evolution of galaxies, stars and planetary systems, until the emergence of life. It relies on various kinds of observations, theoretical work and modelling, and more and more on laboratory experiments. The level of precision necessary to constrain models requires high-performing space, ground-based and underground observatories, mostly built and managed through international collaboration, and exploited in synergy. Observations spread well beyond the historical optical domain, to the whole electromagnetic spectrum from radio astronomy to the observation of gamma-rays, and new messengers such as gravitational waves and neutrinos. *Multi-messenger* astronomy, with its multi-wavelength, multi-instrument studies, is the new frontier to study the evolution and present phenomena of the Universe. Underground physics investigates the rarest phenomena to discover dark matter and the nature of neutrino mass.

The main science drivers are:

- understand the origin of the universe, its main constituents and the extreme conditions it hosts;
- observe the formation of galaxies and their evolution;
- understand the formation of stars and planets;
- understand the solar system and the conditions enabling life, searching for other planetary systems in our galaxy.

The recent observation of gravitational waves is the dawn of gravitational wave astronomy, a highlight which opens a new window for observation of stellar bodies and phenomena. Exoplanetary research also builds up as an inter/multidisciplinary field where a *multi-messenger* approach – e.g. landers, sample return – is taking place.

The science drivers of Astronomy and Astroparticle Physics merge with those of Particle and Nuclear Physics, linking the physics

from the infinitely large to the infinitely small, giving a holistic view of the overall Research Infrastructure investment in the Physical Sciences & Engineering field.

CURRENT STATUS

Research in Europe in this area remains at the leading edge. The intergovernmental organisations ESO¹⁰ (European Southern Observatory) and ESA¹¹ (European Space Agency) enable Europe to compete at the global level in ground and space-based astronomy. Another key factor is the strong organisation of communities at national and European levels. The ASTRONET¹² and ASPERA¹³ ERA-NETs have strengthened a Europe-wide collaboration between research communities and funders and are the key players proposing strategies. ASTRONET covers research from the Sun and Solar System to the limits of the observable universe, and the ERA-NET is giving rise to a co-ordinating Consortium. The APPEC Consortium¹⁴ coordinates Astroparticle Physics research. ASTRONET and ASPERA/APPEC continuously update comprehensive studies of all the present and future activities based on scientific goals and merit.

The ASTRONET and ASPERA/APPEC Infrastructure Roadmaps, which include ESFRI Roadmap facilities, are being implemented in spite of the serious impact of the recent financial restrictions. The suite of ground-based telescopes is delivering new science. The European Southern Observatory's Very

10. _____
European Southern Observatory
<http://www.eso.org/public/>

11. _____
European Space Agency
<http://www.esa.int/ESA>

12. _____
ASTRONET
<http://www.astronet-eu.org/>

13. _____
ASPERA
<http://www.aspera-eu.org/>

14. _____
APPEC
<http://www.appec.org/>

15. _____
European Southern Observatory's Very Large Telescope (VLT)
<http://www.eso.org/public/unitedkingdom/teles-instr/paranal-observatory/vlt/>

Large Telescope (VLT)¹⁵ is the world-standard. The ALMA¹⁶ millimetre/sub millimetre array in the Atacama Desert (Chile), the largest such facility in the world, is in full operation. The International LOFAR Telescope (ILT)¹⁷ and the Joint Institute for VLBI ERIC (JIVE)¹⁸ in the European VLBI Network¹⁹, are pathfinders for the **ESFRI Landmark SKA** (Square Kilometre Array). SKA, a global collaboration with Europe in a leading role, has established a dual location in Australia and South Africa. High-energy gamma-ray Cherenkov telescopes HESS²⁰ and MAGIC²¹ developed the observation of TeV scale photon sources into a full-fledged astronomy. The **ESFRI Landmark ELT** (Extremely Large Telescope) – ESO's giant optical-infrared telescope – was approved in 2012 and is now under construction in Chile. The **ESFRI Landmark CTA** (Cherenkov Telescope Array) is setting up the infrastructure of its two hosting sites at ESO Paranal in Chile and at the IAC La Palma, Spain. The **ESFRI Project KM3NeT 2.0** (KM3 Neutrino Telescope 2.0) is installing the first set of strings at the two Mediterranean sites of Capo Passero (Italy) and Toulon (France), aiming at higher luminosity than the IceCube²². The European ground-based solar community successfully proposed the **ESFRI Project EST** (European Solar Telescope) to the 2016 update of the ESFRI Roadmap.

Two ASTRONET panels, the European Telescope Strategy Review Committee and the European Radio telescope Review Committee, respectively recommended

16. _____
ALMA
<http://www.almaobservatory.org/en/home/>

17. _____
LOFAR
<http://www.lofar.org/>

18. _____
Joint Institute for VLBI ERIC
<http://www.jive.eu/>

19. _____
European VLBI Network
<http://www.evlbi.org/>

20. _____
HESS
<https://www.mpi-hd.mpg.de/hfm/HESS/>

21. _____
MAGIC
<https://www.magic.mpp.mpg.de/>

22. _____
IceCube
<https://icecube.wisc.edu>

to optimize the science impact and cost effectiveness of small and medium size facilities²³, and reviewed the existing European radio telescopes in the context of the **ESFRI Landmark SKA**. The optical/infrared, radio, planetary and solar communities are federated respectively by OPTICON, RADIONet, EuroPlaNet and PREEST, succeeding SOLARNET-I3 in 2017. The APPEC 2017-2026 resource-aware roadmap recommends a strong coordination among the EU agencies involved in Astroparticle Physics in the four main research areas of *multi-messenger* astronomy, neutrino physics, dark matter searches and cosmology (CMB, dark energy). Four European networks focus on gravitational wave antennas, underground laboratories, ultra-high energy cosmic rays and dark energy.

The global network of gravitational wave interferometers (GWIC) includes advanced VIRGO²⁴ (EU), advanced LIGO²⁵ (US) and KAGRA²⁶ (Japan) and the forthcoming INDIGO²⁷ (India); all are sharing data, analysis and publications. A European FP7 design study was carried out for a novel underground 10 km-arm interferometer concept called the Einstein Telescope. The first direct observation in September 2015 of gravitational waves from the merger of a black-hole pair at LIGO and furthermore the possibility of studying the direction of the signals thanks to joining VIRGO with LIGO in data taking, set the course for a new era of gravitational and *multi-messenger* astronomy.

The network of *underground laboratories* hosts increasingly large detectors, the Gran Sasso (Italy) being the largest equipment world-wide. The ultrahigh energy cosmic ray community is gathered in Europe around the Auger Observatory in

Argentina. Finally, there is a large European ground-based dark energy community with major participation in the US-led Large Synoptic Survey Telescope (LSST)²⁸, which is complementary to the EU-led EUCLID²⁹ space mission.

Excellent science continues to emerge from space missions. Herschel³⁰ and Planck³¹ provided truly spectacular far-infrared/sub-millimetre mapping of the cold Universe and of the cosmic microwave background. Gaia performs a 3D-image of our galaxy and of star velocities. In addition, the ESA Cosmic Vision selection process has set the scene for small, medium and large projects covering: the study of the Sun (Solar Orbiter³², launched in 2019), of Mercure (BepiColombo³³, 2018) and of Jupiter's icy moons looking for biology markers (JUICE³⁴, 2022), exoplanetary studies (CHEOPS 2019, PLATO 2026, ARIEL 2028), the search for dark energy (EUCLID), the study of the hot and energetic universe (ATHENA) and the study of the gravitational wave Universe (LISA)³⁵, this last planned to be launched by 2034, with in addition the Exomars programme (Trace Gas Orbiter³⁶ 2016, robotic exploration 2020). There is also an important European participation in space missions through bi- or multilateral agreements, for instance for searching for antimatter in space (AMS on the ISS) and gamma-rays (FERMI). Europe's premier space astrophysics research is planned out into the distant future thanks to the

substantial stability in funding for ESA that allows maximising returns for the agencies and structuring the community as well as industry. International collaboration is also well established, in particular on the James Webb Space Telescope (WEBB/JWST)³⁷ near-infrared telescope, which will be launched in 2018.

The Astronomy ESFRI & Research Infrastructure Cluster project (ASTERICS) develops the cross-cutting synergies and common challenges shared by the Astronomy and Astroparticle ESFRI RIs: the **ESFRI Landmarks ELT, SKA, and CTA**, and the **ESFRI Project KM3NeT 2.0**, with liaison building up with the **ESFRI Project EST**.

A summary of the main Research Infrastructures in Astronomy and Astroparticle Physics field is shown in **Figure 1** and ESFRI contribution is depicted in **Figure 2**.

GAPS, CHALLENGES AND FUTURE NEEDS

The programme of development of new facilities is basically on track, but timelines get longer as the cost and complexity of projects increase. One challenge is to propose projects which remain doable while at the forefront to fulfil science needs. Moreover, the funding of backend instruments for the large facilities and of data science is not always included in the Research Infrastructure cost estimate, whereas the field already feels *Big Data* challenges.

The evolution of Astronomy and Astroparticle Physics projects clearly goes towards internationalisation in the construction as well as the operation of Research Infrastructures. ALMA and the **ESFRI Landmark SKA** have been the first global astronomy infrastructures. The novel *multi-messenger* paradigm implies the observation and interpretation of transient phenomena alerts and follow up by a network of telescopes and underground or underwater/ice detectors. The first detection of gravitational waves sources by the LIGO-VIRGO Consortium led to their astrophysical interpretation and their astronomical follow-up. Interest

23. Report by the European Telescope Strategic Review Committee on Europe's 2-4 m telescopes over the decade to 2020
http://www.astronet-eu.org/sites/default/files/plaquette2_4m-final-2.pdf

24. VIRGO
<http://www.virgo-gw.eu/>

25. LIGO
<https://www.ligo.caltech.edu/>

26. KAGRA
<http://gwcenter.icrr.u-tokyo.ac.jp/en/>

27. INDIGO
<http://gw-indigo.org/tiki-index.php>

28. Large Synoptic Survey Telescope
<https://www.lsst.org/>

29. EUCLID
<http://sci.esa.int/euclid/>

30. Herschel space mission
<http://sci.esa.int/herschel/>

31. Planck space mission
<https://www.cosmos.esa.int/web/planck>

32. Solar Orbiter
<https://www.asi.it/en>

33. BepiColombo
<http://sci.esa.int/bepicolombo/>

34. JUICE
<http://sci.esa.int/juice/>

35. LISA
<https://www.elisascience.org/>

36. Trace Gas Orbiter
<http://exploration.esa.int/mars/46475-trace-gas-orbiter/>

37. WEBB/JWST
<https://www.jwst.nasa.gov/>

in gravitational-wave astroparticle/astrophysics is growing fast with the approved ESA LISA mission, the Pulsar Timing Arrays with LOFAR and in the future with **ESFRI Landmark SKA**, and developments of the Einstein Telescope.

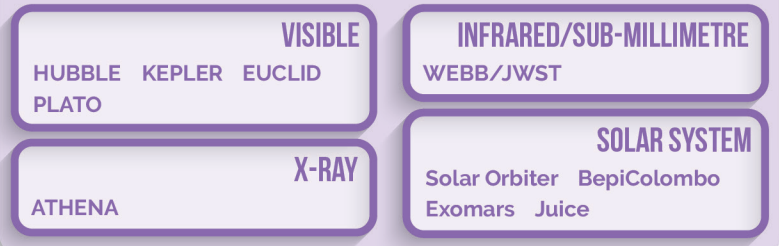
A key topic for the future is the search for early life signature in exoplanet studies, the expansion of astrochemistry to this field and the development of astrobiology. ASTRONET and APPEC representing the major EU agencies/institutions operating in Astrophysics and Astroparticle Physics respectively have large overlaps in the Research Infrastructures they deal with. They are establishing contacts trying to develop a more solid coordination to fully exploit the synergy present in their roadmap visions.

The ASTERICS Cluster supports and accelerate the implementation of the ESFRI telescopes, to enhance their performances beyond the state-of-the-art, and to see them interoperating as an integrated, multi-wavelength and *multi-messenger* facility. It demonstrates the power of building synergies and common endeavours between the ESFRI RIs, and the necessity to establish a framework to continue to do so beyond the current Cluster projects.

GROUND-BASED TELESCOPES



SPACE-BASED TELESCOPE



GRAVITATIONAL WAVES INTERFEROMETERS

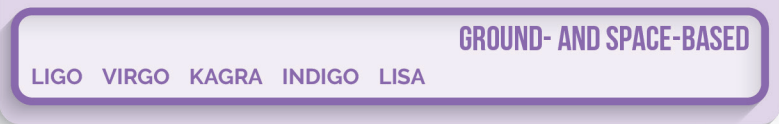


FIGURE 1.
Main Research Infrastructures in Astronomy and Astroparticle Physics

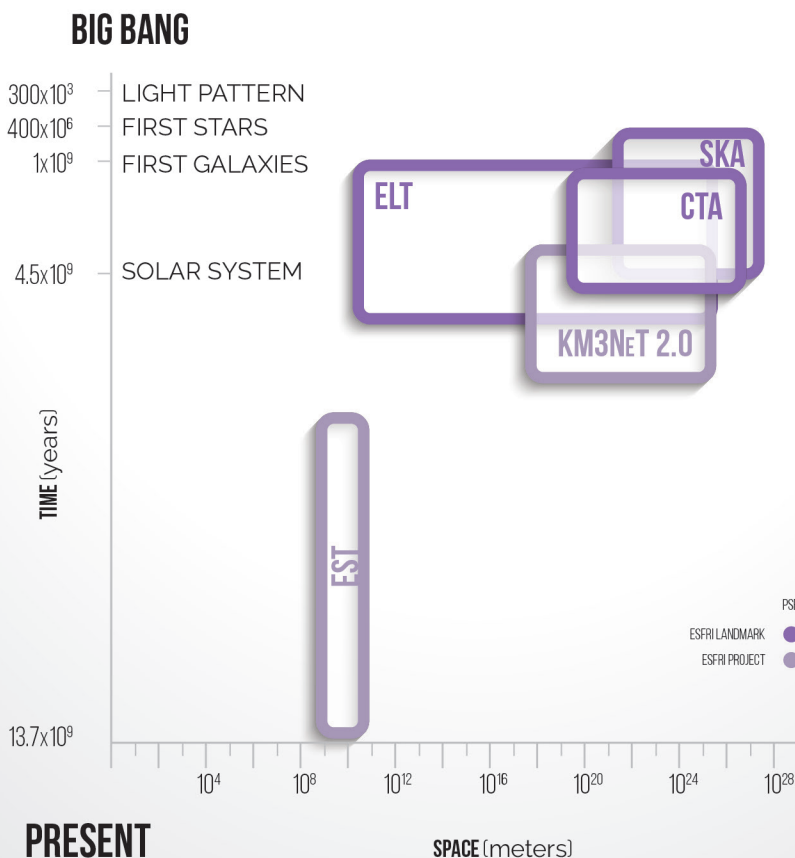


FIGURE 2.
Space and time domain of investigation of ESFRI Projects and Landmarks in Astronomy and Astroparticle Physics

PARTICLE AND NUCLEAR PHYSICS

During the last 10 years, major discoveries have shaped our vision of the building blocks of matter, their properties, their interactions and their role in the evolution of the Universe. With the discovery of the Higgs boson, the Standard Model of **Particle Physics** provides an internally consistent picture of the known elementary particles which is nevertheless known to be incomplete, since it leaves several major questions unanswered. The presence of Dark Matter in current cosmological models, and the fact that gravity is not included in the Standard Model, are two examples which push searches for physics beyond the Standard Model.

New physics models which address these questions can, for example, lead to deviations Standard Model in consistency tests or in the properties of the Higgs boson at the sub per cent level, and/or predict new particles or forces which manifest at the higher energies than currently accessible. Reach-

ing high precision and extending the energy range are therefore crucial.

Searches for Dark Matter continue at colliders, direct detection experiment and via indirect observation via astrophysics. So far none of these have revealed any signature of new particles, though theoretical as well as experimental efforts are continuously pushing the limits. Other promising areas to look for deviations from the Standard Model include high precision measurements in flavour physics in the quark and charged lepton sectors, and the search of broken symmetries in the neutrino sector.

A key goal for **Nuclear Physics** is to develop a comprehensive understanding and a predictive theory of complex nuclei. Worldwide, this goal has driven the development of various cutting edge facilities for experiments with short-lived rare isotopes in order to provide data and discover new phenomena against which theoretical predictions

have to be tested. Rare isotope beams (RIB) are obtained by complementary techniques, either through the isotope-separation-on-line (ISOL) process or through in-flight production. Such beams will allow for nuclear physics research studies aiming at answering several fundamental questions related to the phases of strongly interacting matter and their role in astrophysics, the nature of the strong force that binds protons and neutrons into stable and rare isotopes, the nature of neutron stars and dense matter, the nuclear reactions that drive stars and stellar explosions. Nuclear structure and dynamics have not only reached the discovery frontier, but are also entering into a high precision frontier with higher beam intensities and purity, along with better efficiency and sensitivity of instruments, in order to focus on essential observables to validate and guide our theoretical developments.

II CURRENT STATUS

The current Particle Physics landscape is guided by the 2013 European Strategy for Particle Physics (ESPP)³⁸, which has been closely followed providing a coherent and broad scientific programme. The Large Hadron Collider (LHC) at CERN³⁹ is the major infrastructure for particle physics, with more than 7,000 physicists working on its different experiments. By the end of 2018, the LHC is in its second running period and will have accumulated an integrated luminosity of 150 fb^{-1} , corresponding to acquiring the data of roughly 10^{25} collisions and a stored data volume well in excess of 250 PB. In 2019-2020 a long shutdown is foreseen with major detector upgrades of the LHC experiments. It is foreseen to accumulate another 150 fb^{-1} in this configuration until the high-luminosity phase of the LHC will start around 2025. The **ESFRI Landmark HL-LHC** (High-Luminosity Large Hadron Collider) requires an upgrade of the accel-

erator complex, which has already started, and also refurbishment of the ATLAS and CMS detectors in order to maximise their scientific output in a much harsher environment.

In the field of flavour physics, the measurements provided by the LHCb experiment will be complemented and cross-checked by the results from the BELLE-2 experiments at the SuperKEKB⁴⁰ collider at KEK in Japan. Data taking of this experiment will start in 2019 and use rather low energy electron-positron beams yet at the highest intensities with the aim to accumulate an integrated luminosity of 50 ab^{-1} .

The CERN neutrino platform is a framework that allows European physicists to work on neutrino detector development. In this context, collaboration is ongoing with the next generation long baseline accelerator-based neutrino experiments: DUNE in the US (Fermi National Accelerator Labora-

tory FNAL⁴¹ and Sanford Underground Research Facility⁴²) and Hyper-Kamiokande⁴³ in Japan.

These experiments with increased beam intensities, and improved detectors, will allow unprecedented precision in measurements of neutrino oscillations and CP violation. Detector R&D as well as prototype construction for these experiments is ongoing. Accelerator based neutrino experiments are complemented by the upcoming reactor-based experiment, JUNO located in China, and measurements with atmospheric neutrinos by the ORCA-site of the **ESFRI Project KM3NeT 2.0** collaboration. Other neutrino properties are measured in Europe by smaller infrastructures, such as KATRIN at KIT for aiming at a direct neutrino

38. European Strategy for Particle Physics (ESPP)
<https://cds.cern.ch/record/1567258/files/esc-e-106.pdf>

39. HL-LHC
<https://home.cern/topics/high-luminosity-lhc>

40. SuperKEKB
<http://www.superkekb.kek.jp/index.html>

41. Fermi National Accelerator Laboratory (FNAL)
<http://www.fnal.gov/>

42. Sanford Underground Research Facility
<https://sanfordlab.org>

43. Hyper-Kamiokande
<http://www.hyperk.org>

mass measurement, and GERDA, CUORE at LNGS or SuperNemo (LSM) for determining the Dirac or Majorana nature of neutrino. European particle physicists are also pursuing precision measurements in the charged-lepton sector, at PSI and at infrastructures in other regions (US, Japan).

Complementing the searches for new physics at the LHC, experiments directly searching for Dark Matter based on various techniques such as liquid noble gas or cryogenic detectors are hosted in underground laboratories. The most stringent limits are currently provided by the XENON collaboration (LNGS), with developments ongoing on large liquid Argon based detectors (DARKSIDE) and low mass searches with cryogenic detectors.

The first generation of radioactive beam (RIB) facilities based on the complementary methods of, in flight separation (GANIL and GSI) and the ISOL approach (ISOLDE and SPIRAL1) have enabled tremendous progress in the study of exotic nuclei to be made. Both in-flight separation and the ISOL approach, combined with different post-processing of the radioactive nuclei, will form the pillars of the RIB facility network in Europe.

Major advances in the field are expected to come through the studies of extended reach in proton-to-neutron ratio of new or upgraded facilities, including the Radioactive Isotope Beam Factory (RIBF) at Rikagaku Kenkyusho (RIKEN), the **ESFRI Landmark FAIR** (Facility for Antiproton and Ion Research) at Darmstadt, the HIE-ISOLDE facility at CERN, the **ESFRI Landmark SPIRAL2** (Système de Production d'Ions Radioactifs en Ligne de 2e génération) at Grand Accélérateur National D'Ions Lourds (GANIL), the facility for the Study and Production of Exotic Species (SPES) at INFN-Legnaro, the Isotope Separation and Acceleration II (ISACII) at TRIUMF, and the Facility for Rare Isotope Beams (FRIB, USA) with capabilities for fast, stopped, and unique reaccelerated beams. All these facilities provide or will provide new and important insights into the structure of nuclei and are expected to discover new phenomena that will lead to major progress towards a unified description of nuclei. Other accelerator-based probes are also important for nuclear physics research in Europe. The ELI-NP (Extreme Light Infra-

structure - Nuclear Physics) facility is one of the three pillars of the pan-European **ESFRI Landmark ELI** aiming at the use of extreme electromagnetic fields for nuclear physics research.

Investigation of nuclei produced at the upcoming nuclear physics research facilities requires development of state-of-the-art detectors and detection techniques. The Advanced Gamma Tracking Array (AGATA)⁴⁴ represents a revolution in the way gamma-ray spectroscopy is performed and it will have a wide range of uses in nuclear physics from studying how elements are synthesised in stars to the understanding of the underlying shell structure of the newly discovered super-heavy elements. The basic technology of the array will also bring developments in medical imaging and diagnostic machines that produce three-dimensional images of people's bodies, providing information about the functioning of internal organs and detecting disease and tumours.

The production of exotic nuclei is closely linked to the availability of separators and spectrometers in order to select and identify the nuclei or reactions of interest. Addressing these objectives is a driving force for existing or future facilities, such as the Japan Proton Accelerator Research Complex (J-PARC), the international **ESFRI Landmark FAIR** at Darmstadt, the 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF) Upgrade at the Jefferson Lab, the Mainz Microtron (MAMI), A Large Ion Collider Experiment (ALICE) at CERN, and RHIC II at Brookhaven National Laboratory (BNL), the Nuclotron-based Ion Collider fAcility (NICA) or The Super Heavy Element Factory (SHE Factory) at the Joint Institute for Nuclear Research (JINR) in Dubna (Russia).

A summary of the main Research Infrastructures in Particle and Nuclear Physics field is shown in **Figure 3** and ESFRI contribution is depicted in **Figure 4**.

44. Advanced Gamma Tracking Array (AGATA)
<https://www.agata.org/>

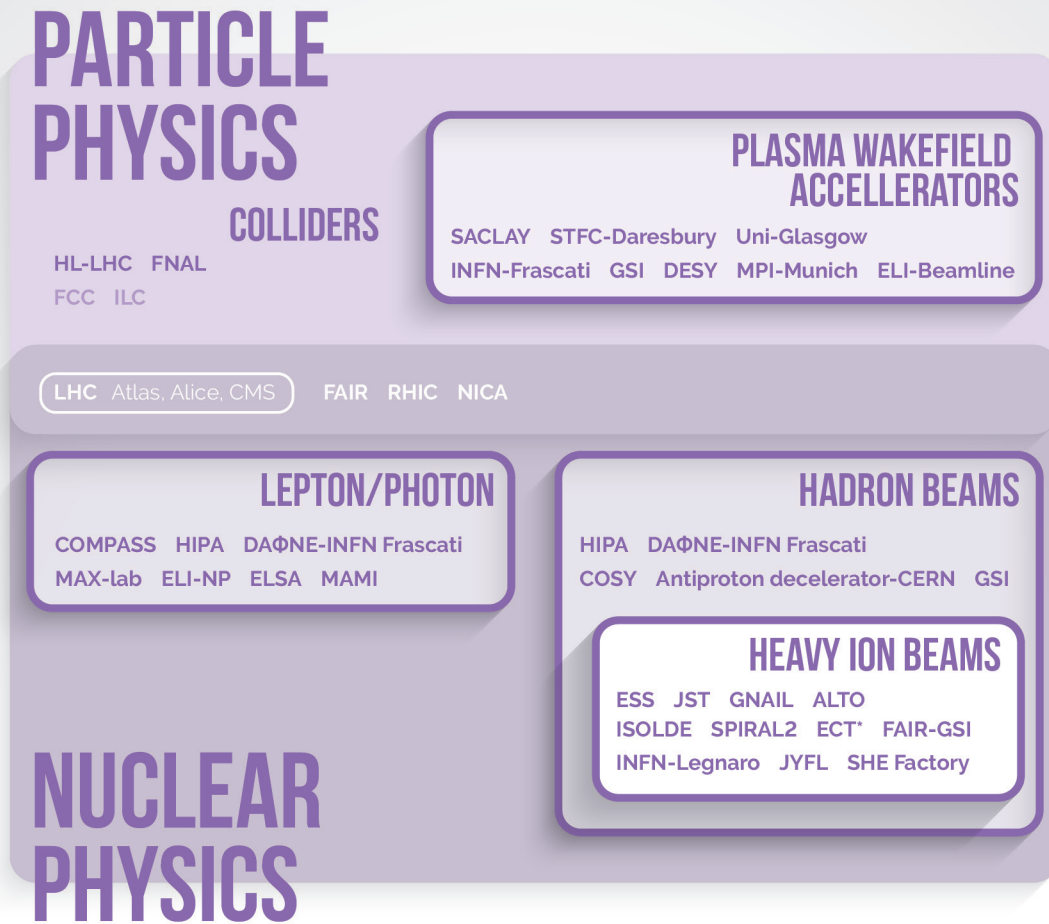


FIGURE 3. Major Research Infrastructures in Particle and Nuclear Physics

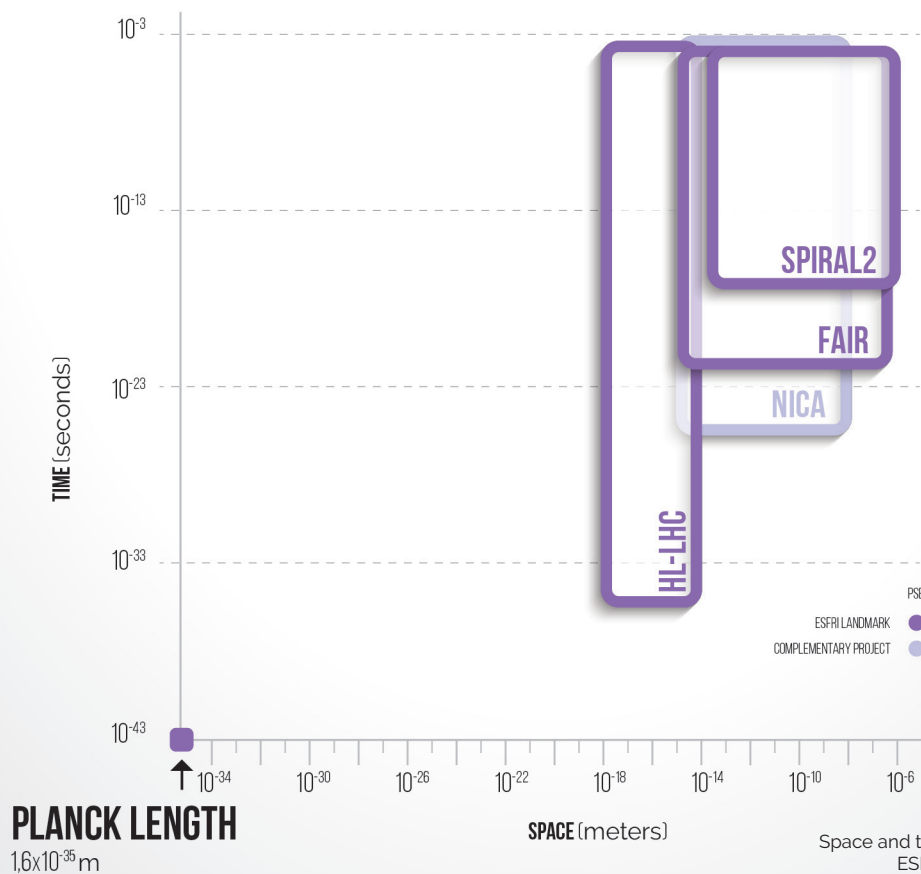


FIGURE 4. Space and time domain of investigation of ESFRI Projects and Landmarks in Particle and Nuclear Physics

GAPS, CHALLENGES AND FUTURE NEEDS

For the near term future, the HL-LHC will be the main particle physics accelerator infrastructure, allowing detailed study of the Higgs sector and searches for new physics with 3000 fb^{-1} of data expected for ATLAS and CMS by 2035. On a similar timescale an International Linear Collider (ILC)⁴⁵ providing electron-positron collisions at a few hundred GeV energy, is a possible project to be hosted in Japan as a worldwide international collaboration. This would allow important studies of the Higgs sector and other precision measurements complementary to the HL-LHC. The ILC has long been on the strategic list of projects foreseen in particle physics, and a signal from the Japanese community indicating whether or not Japan would host such a project is expected by the end of 2018.

Further future projects would address the two main requirements for particle physics: an increase in precision and in energy. Several initiatives in accelerator R&D are addressing these challenges. In order to reach higher energies for an electron-positron linear collider, R&D for the CLIC concept using beam driven acceleration has been pursued at CERN initially aiming at energies in the multi-TeV range. However, the highest reach in energy is obtained from proton colliders, where the big challenge is the development of high field magnets, currently part of an ambitious R&D programme. Conceptual studies for a 100 km collider with about 100 TeV collision energy – the Future Circular Collider Study (FCC)⁴⁶ are underway at CERN. Such a collider would open a new window on searches for new physics and allow a conclusive study of the Higgs self-coupling. A possible stepping stone could be to install the required high field magnets in the LHC tunnel to double the LHC collision energy (HE-LHC), or to have an electron-positron collider in the FCC tunnel (FCC-ee), both of which are included in the FCC studies. There may also be interesting options to combine these technologies to collide electrons with protons, which may provide significant improvement in Higgs coupling measurements. Beyond these studies, innovative R&D programmes are ongoing on the concept of laser-plasma acceleration. Several techniques are studied in major European laboratories (Germany, Italy, UK, France and Portugal) and through the EUPRAXIA⁴⁷ design study as well as through the AWAKE⁴⁸ project at CERN.

45. International Linear Collider
<http://www.linearcollider.org/>

46. Future Circular Collider Study
<https://fcc.web.cern.ch/Pages/default.aspx>

47. EUPRAXIA
<http://www.eupraxia-project.eu/>

48. AWAKE
<https://cds.cern.ch/record/2221183/files/SPSC-SR-194.pdf>

Given the lack of theoretical guidance on where new physics could be realized, it is important to, as much as possible, cover all options. A new Physics Beyond Colliders⁴⁹ initiative is looking at ways of profiting from the CERN infrastructure and expertise to leave no stone unturned in the search for new physics. For example, studies include searches for axion-like particles in beam dump based experiments benefitting from the upgrade of the LHC injectors. By the end of 2018 documents on all the above projects will be available for the next ESPP discussion, from which a set of recommendations will be released in 2020 to define the strategy for particle physics research for the proceeding 5-10 years.

For Nuclear Physics on a long term perspective a novel ISOL facility in Europe (EURISOL) is needed, which will provide wide range of beams with much higher intensities compared to what is available at present. Meanwhile, by integrating the ongoing efforts and developments at the major ISOL facilities of HIE-ISOLDE, SPES and SPIRAL2, the planned ISOL@MYRRHA facility, and the existing JYFL and ALTO and COPIN facilities and the planned ELI-IGISOL facility an advantage should be taken use the synergies and complementarities between them and build a programme of research to bridge the gap between present facilities and ultimate EURISOL facility.

Based on the collaboration between nuclear physicists and plasma physicists, the ELI project will develop laser-plasma electron accelerators, based on the wakefield principle, and ion beams accelerators. Such devices have the potential to accelerate a range of particle and ion species in table-top distances. These innovative acceleration methods will open new perspectives for a range of applications such as: more efficient production of radioisotopes required for nuclear medicine and beams for testing the latest designs of sensors for use in medical imaging, new methods for identification and remote characterization of nuclear materials with applications in homeland security and nuclear material management, testing of materials for space science.

Research and development programmes, are being pursued to investigate the concept of precision storage rings to search for charged particle electric dipole moments (EDM), based on the ongoing studies at COSY; the design of a polariser ring to produce high intensity polarized antiproton beams as one upgrade option for HESR at FAIR; the implementation of sympathetic laser cooling techniques to cool systems like the proton, antiproton and highly charged ions to temperatures as low as a few mK; the design of advanced high intensity lasers for precision spectroscopy of exotic atoms, such as antihydrogen, muonic hydrogen, pionic helium, and muonium.

49. Physics Beyond Colliders
<http://pbc.web.cern.ch/>

ANALYTICAL PHYSICS

Analytical Research Infrastructures primarily comprise powerful sources of photon or particle beams. Light sources based on electron accelerators with storage rings for **Synchrotron Radiation** or **Free-Electron Lasers** provide brilliant soft to hard X-ray beams enabling nanoprobe of the structure and chemical composition of materials, including trace analysis down to ppb concentration, over many length scales – from atomic to macroscopic (10^{-10} – 10^{-1} m) – and time scales – from femtoseconds (fs, 10^{-15} s for FELs) or picoseconds (ps, 10^{-12} s for SR) to milliseconds (ms, 10^{-3} s) or steady states. **Neutron Scattering** sources based on proton accelerators or nuclear reactors provide unique and complementary probes of the structure of materials, particularly for light elements such as H and subtle magnetism, and lower energy scales for slow dynamics – typically $\sim\mu$ s. Moreover, the neutrons constitute, because of their high penetration power, a single probe for analysis on large volumes, or non-destructively on small internal volumes in an industrial piece for example.

The broadly distributed laser spectroscopy, high resolution **Electron Microscopy** and **High Magnetic Field** facilities also operate as ARIs. EM complements SR, FELs and NS, probing down to 50 picometers (pm, 10^{-12} m) spatial resolutions with element specificity, comparable energy resolution (10 meV or less) and temporal resolutions that can approach 10 fs. **Laser RIs** probe or manipulate matter with ultra-short or ultra-high intensity pulses from ~ 100 attoseconds (as, 10^{-18} s) to 100 fs with millijoule (mJ) to tens of joule (J) energies, or cover the complementary time-energy region up to 10 kilojoule (kJ) and 10 nanosecond (ns, 10^{-9} s). Materials may also be manipulated using HMFs to provide unique insights into electronic and magnetic phenomena.

The very broad range of analytic capabilities provided by ARIs provides an equally broad range of drivers across many areas of fundamental and applied science: structure and function of biological macromolecules implicated in disease and therapy; materials for cleaner, greener transport, energy and chemical synthesis; complex electronic and magnetic materials, for next generation ICT; synthesis and performance of materials during manufacture and under *operando* conditions; environmental systems and planetary science; and climate, natural and cultural heritage artefacts.

Integration of European ARIs is occurring at different levels, impacting materials science and nanoscience both for fundamental research and for innovation: the CERIC-ERIC⁵⁰ is a distributed RI providing access to fine analysis with complementary methods – electrons, neutrons, X-rays, synchrotron-light; the EU IA Initiative NFFA-Europe⁵¹ offers integrated access to nano-foundry, characterization, theory and fine analysis at major European facilities and research institutions.

50. Central European Research Infrastructure Consortium CERIC-ERIC
<http://www.ceric-eric.eu/>

51. NFFA-Europe
<http://nffa.eu>

CURRENT STATUS

SYNCHROTRON RADIATION AND FREE ELECTRON LASER FACILITIES

There are currently twelve SR facilities and six FELs open for transnational access across Europe (Table 1 and Table 2). Among SR facilities most have storage ring energies of 3 GeV and are among the best in class in the world – while the **ESFRI Landmark ESRF EBS** (European Synchrotron Radiation Facility Extremely Brilliant Source) have helped maintain it as best in class of any SR facility in the world and the 6 GeV facility PETRA III has also undergone extensive upgrades⁵². Most recently, Europe has seen first operations of the MAX IV Facility⁵³ based on novel, disruptive MultiBend Achromats (MBA) technology for the storage ring that will offer unprecedented brightness and coherence. The **ESFRI Landmark ESRF EBS** will provide 100-fold increase in brilliance and coherence – significantly closer to the physical (diffraction) limit for hard X-rays – by 2019 through a MBA upgrade, several other national facilities also plan MBA upgrades in the period 2020–2025. Complementary improvements in detector technology have also been transformative, while accelerated throughput and increased remote access in techniques such as crystallography, and construction of more beamlines at some national facilities helps meet the increasing demand for access.

52. PETRA
http://photon-science.desy.de/facilities/petra_iii/index_eng.html

53. MAX IV
<https://www.maxiv.lu.se/>

FACILITY	LOCATION	ELECTRON ENERGY (GeV)	EMITTANCE (nm rad)	FULLY SCHEDULED BEAMLINES (CONSTRUCTION/COMMISSIONING)	START OF USER OPERATIONS
ESRF (EBS)	GRENOBLE (FR)	6	4 (0.13)	30+14 CRGS*	1994 (2020)
PETRA III	HAMBURG (DE)	6	1.1	16 (24)	2010
ALBA	BARCELONA (ES)	3	3.6	7	2012
DIAMOND	HARWELL (UK)	3	2.7	31 (33)	2007
MAX IV	LUND (SE)	3	0.34	16 (29)	2016
		1.5	9	0 (5)	2016
SOLEIL	ST. AUBIN (FR)	2.75	3.74	29	2008
SWISS LIGHT SOURCE	PSI, VILLIGEN (CH)	2.4	4.4	16	2001
ELETTRA	TRIESTE (IT)	2.0/2.4	7.0/9.7	26 (2)	1994
BESSY II	BERLIN (DE)	1.7	6.4	47 (31)	1998
SOLARIS	CRACOW (PL)	1.5	6	2	2018
ASTRID2	AARHUS (DK)	0.58	12	10	2014
MLS	BERLIN (DE)	0.24-0.6	100	11	2008

*Collaborating Research Groups managing quota of access

TABLE 1.
Summary of European SR facilities

FACILITY	FELS LINES OPERATING IN PARALLEL	LOCATION	START USER OPERATION	ELECTRON ENERGY	PHOTON ENERGY	PULSE PROPERTIES	NUMBER OF END STATIONS
European XFEL	SASE-1	HAMBURG / SCHENEFELD, GERMANY	2017	8.5-17.5 GeV	3.0 to >20 keV	1-100 fs 10x2.700 pulse/s	2
	SASE-2		2018		3.0 to >20 keV		2
	SASE-3		2018		0.25-3.0 keV		2
SwissFEL	ARAMIS	VILLIGEN, SWITZERLAND	2018	2.1-5.8 GeV	4.0-15 keV	5-100 fs 100 Hz	2
	ATHOS		2020		0.25-2.0 keV		2
FERMI	FERMI-1 FERMI-2	TRIESTE, ITALY	2012 2016	1.5-1.8 GeV	15-90 eV 80-400 eV	20-90 fs 10-50 Hz	5
FLASH	FLASH	HAMBURG, GERMANY	2005	1.25 GeV	30-300 eV	20-150 fs 10x800 pulses/s	4
	FLASH-2		2016		30-300 eV		3
CLIO	CLIO	PARIS, FRANCE	1993	40 MeV	10-400 meV	0.5-5 ps 60 MHz pulsed: 25 Hz	
ELBE	FELBE	DRESDEN, GERMANY	2005	40 MeV	0.5-250 meV	0.5-30 ps	7
	TELBE		2016			13 MHz cw	1
FELIX	FELIX 1/2	NIJMEGEN, NETHERLANDS	1993	15-50 MeV	8-400 meV	0.5-200 ps	12
	FLARE		2013	10-15 MeV	0.8-12 meV	1/3 GHz	4
	FELICE		2007	15-50 MeV	12-250 meV	pulsed: 20 Hz	2
TARLA		ANKARA, TURKEY	2019	40 MeV	5-400 meV	0.5-30 ps 13 MHz cw	

TABLE 2.
Summary of European FELs, in operation or under construction

The **ESFRI Landmark European XFEL** (European X-Ray Free-Electron Laser) and SwissFEL⁵⁴ are hard X-ray FEL facilities that saw their first experiments in 2017, complementing a suite of complementary IR, UV or soft X-ray FEL user facilities already in operation. The TARLA facility is being built in Turkey and further projects are planned (MAX IV-FEL, POLFEL).

CALIPSOplus⁵⁵ supports co-ordinating activity for SR and FEL facilities, overlapping with the remit of the European Cluster of Advanced Laser Light Sources (EUCALL)⁵⁶. The League of European Accelerator-based Photon Sources (LEAPS)⁵⁷ co-ordinates activity for SR and FEL facilities, FEL activities join forces in the consortium FELs of Europe⁵⁸ and the EC funded the PaNdata⁵⁹ initiative for integrated data infrastructure for European photon and neutron facilities, and for the future EOSC is under discussion.

NEUTRON SCATTERING FACILITIES

Thirteen NS facilities operate in Europe, comprising two world-leading sources – the **ESFRI Landmark ILL** (Institut Max von Laue-Paul Langevin), and the accelerator-based ISIS neutron and muon Facility⁶⁰ – and an array of high quality medium flux facilities (**Table 3**). This landscape will change greatly in the next decade: the future neutron source for Europe, the **ESFRI Landmark European Spallation Source ERIC** begins its user program on world-leading instruments initially planned for 2023 while two reactor-based facilities – BER-II⁶¹ and Orphée-LLB⁶² – will stop in 2019. ILL whose current agreement between the partners expires in 2023, is one of the key facilities to maintain at a very high level the European community of neutron scientists and users, especially before ESS reaches its nominal operation. These evolutions of the European neutron landscape will lead to a significant shortfall in the provision of neutron facilities relative to needs from the start of the next decade⁶³. EC currently supports such facilities, including integrating activity, through SINE2020⁶⁴.

FACILITY	LOCATION	SOURCE	POWER (MW)	FULLY SCHEDULED INSTRUMENTS	START (END) USER OPERATIONS
ILL	GRENOBLE (FR)	REACTOR	57	30+10 CRGs*	1971
ISIS	HARWELL (UK)	SPALLATION	0.2	21+10 CRGs*	1984
LLB	SACLAY (FR)	REACTOR	14	21	1981 (2020)
FRM-II (MLZ)	GARCHING (DE)	REACTOR	20	25	2004
BER-II	BERLIN (DE)	REACTOR	10	10	1973 (2019)
SINQ	VILLIGEN (CH)	SPALLATION	1	13	1996
JEOP II	KJELLER (NO)	REACTOR	2	2	1967
REZ	REZ (CZ)	REACTOR	10	8	1957
BNC	BUDAPEST (HU)	REACTOR	10	15	1959
DELFT	DELFT (NL)	REACTOR	2	4	1963
SACAVEM	SACAVEM (PT)	REACTOR	1	3	1961 (2016)
VIENNA	VIENNA (AT)	REACTOR	0.25	4 CRGs*	1962
ESS	LUND (SE)	SPALLATION	5	15**	2023

* Collaborating Research Groups managing quota of access

** Instruments under design and construction to be operational in the period 2022-2028

TABLE 3.
Summary of European Neutron Scattering facilities

54. SwissFEL
<https://www.psi.ch/swissfel/>

55. CALIPSOplus
<http://www.calipsoplus.eu/>

56. EUCALL
<https://www.eucall.eu/>

57. LEAPS
<https://leaps.desy.de/>

58. FELs of Europe
<https://www.fels-of-europe.eu/>

59. PaNdata
<http://pan-data.eu/>

60. ISIS Muon and Neutron Source
<https://www.isis.stfc.ac.uk/Pages/home.aspx>

61. Research Reactor BER II
https://www.helmholtz-berlin.de/quellen/ber/ber2/index_en.html

62. Orphée-LLB
http://www-llb.cea.fr/en/Web/hpr_web/HPRWEB1.php

63. Neutron scattering facilities in Europe - Present status and future perspectives Author: ESFRI Physical Sciences and Engineering Strategy Working Group - Neutron Landscape Group, ESFRI Scripta Volume 1, 2016
http://www.esfri.eu/sites/default/files/u4/NGL_CombinedReport_230816_Complete%20document_0209-1.pdf

64. ENSA Brochure, 2017
<https://www.sine2020.eu/news-and-media/ensa-brochure---second-edition.html>

ELECTRON MICROSCOPY FACILITIES

About 100 mid- to high-end EM instruments operate in Europe (most of which include aberration correction of the probe forming or imaging optics). From these 15 leading laboratories and some SMEs form a networked infrastructure, ESTEEM2 (FP7)⁶⁵, to be replaced by ESTEEM3 (H2020). An EU Design Study (DREAM) to explore the creation of a pan-European Research Infrastructure for advanced EM at a scale similar to SR and Neutron facilities is being planned, including two of the highest spatial resolution microscopes in the world (at Juelich⁶⁶ and Harwell^{67,68}) and several instruments capable of providing sub 10 meV energy resolution (Daresbury⁶⁹ and Orsay⁷⁰). The recent development of direct electron detectors has helped to revolutionise the use of cryo-EM in structural biology, with an exponential growth in installations that increasingly complement X-ray protein crystallography, and in the physical sciences through faster frame-rates and significantly improved detector resolution.

HIGH PERFORMANCE LASERS

Laser RIs are distributed across Europe with user access and joint R&D coordinated mainly through the EU integrated Initiative Laser-Lab IV (LLIV)⁷¹ with 33 organisations from 16 countries and also part of EUCALL. The **ESFRI Landmark ELI**, which aims to host the highest performance laser systems worldwide, is currently developing at three sites with complementary capability to each other and the rest of LLIV: the ELI-ALPS⁷² pillar combines USP and UHI at very high repetition rates; the ELI Beamlines pillar⁷³ will provide ultra-short secondary radiation (X and γ -rays) and particle (electrons, ions) sources; ELI-Nuclear Physics⁷⁴ offers a unique combination of the most powerful laser sources worldwide (2 x 10 PW) with a fully tuneable γ -ray source (up to 19.5 MeV).

HIGH MAGNETIC FIELDS

All high magnetic field activities in Europe are organised through the **ESFRI Landmark EMFL** facilities, with a common user access program, outreach, training and technical developments. Maximum field strengths are increasing, with two hybrid magnets designed to exceed 43 Tesla (T) field, under commissioning in 2018 (Grenoble and Nijmegen) while in Toulouse, a semi-destructive pulsed field installation now offers fields of 100-200 T. All HMF facilities have been either fully renewed since 2000 or have had major upgrades and are internationally competitive. Two of them are directly coupled to a THz FEL (Nijmegen and Dresden), allowing unique joint operation.

GENERAL

European activity should also be considered as part of a network of global partnerships, both among our nearest neighbours (for example Russia, which has a number of existing and planned facilities available for international users such as the IBR-2 reactor⁷⁵ and the support of the Commission through the Cremlin project⁷⁶, as well as the middle East with initiatives such as SESAME⁷⁷).

A summary of the main Analytical Research facilities representing the Analytical Physics Landscape is reported in **Figure 5** and ESFRI contribution in **Figure 6**.

65.

ESTEEM 2

<http://esteem2.eu/>

66.

ER-C

<http://www.er-c.org/centre/centre.htm>

67.

Harwell ePSIC

<http://www.diamond.ac.uk/Science/Integrated-facilities/ePSIC.html>

68.

Harwell eBIC

<http://www.diamond.ac.uk/Science/Integrated-facilities/eBIC.html>

69.

SuperSTEM-Daresbury

<http://www.superstem.com/>

70.

LPS-Orsay

<http://www.lps.u-psud.fr>

71.

LASERLAB

<https://www.laserlab-europe.eu/>

72.

ELI-ALPS

<https://www.eli-hu.hu>

73.

ELI-BEAMS

<https://www.eli-beams.eu>

74.

ELI-Nuclear Physics

<http://www.eli-np.ro/>

75.

IBR-2 reactor

<http://ibr-2.jinr.ru/>

76.

Cremlin project

<https://www.cremlin.eu/project/>

77.

SESAME

<http://www.sesame.org.jo/sesame/>

ANALYTICAL FACILITIES

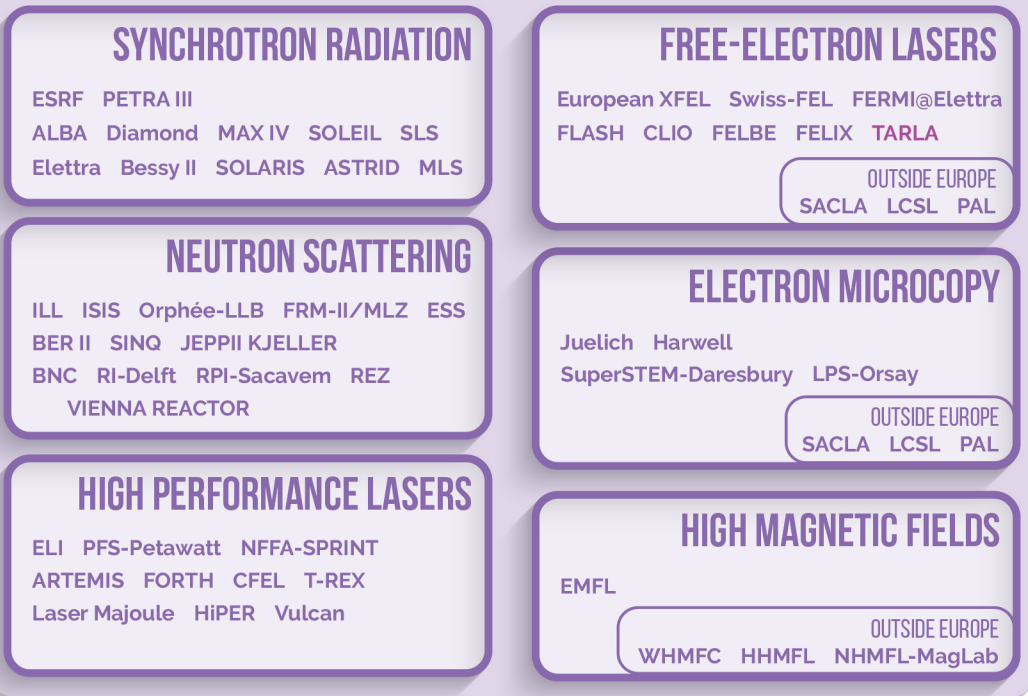


FIGURE 5.
Main Research Infrastructures in
Analytical Physics

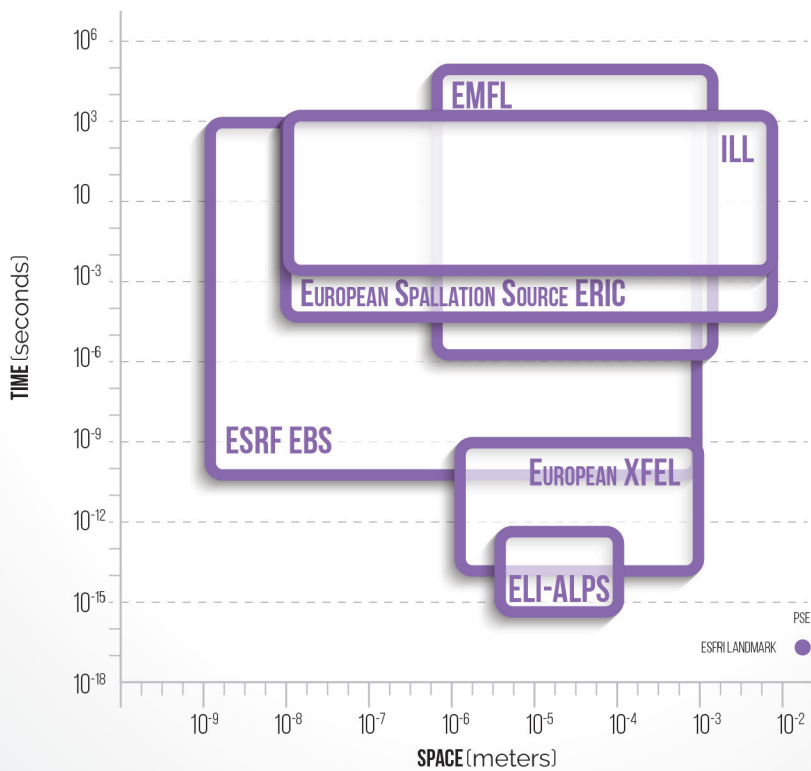


FIGURE 6.
Space and time domain of investigation of
ESFRI Projects and Landmarks in
Analytical Physics

▶ GAPS, CHALLENGES AND FUTURE NEEDS

Brighter sources and faster detectors produce larger, often more complex data sets that are becoming more challenging to process and analyse, both during the experiment to make informed decisions about how best to proceed, and afterwards, increasingly across multiple probes. This requires not only significant investment in hardware to transfer, store and process data but also coherent development of software with greater exploitation of AI techniques, and many more people – data scientists – expert in such methods.

Many ARIs require more powerful, compact accelerator sources and better detectors, both of which could involve highly synergic collaborations across types of RIs. There are technical challenges specific to individual types of ARI: diffraction limited storage rings for SR for harder X-rays offering coherent imaging down to 10's of nm, and study of fluctuations to 100 ps; new medium-power high-brilliance NS installations; coherent pulsed sources for EM that operate in both stroboscopic and single shot modes, also requiring detector development. Improvements to high performance lasers will require new materials for robust optical components, a new generation of online, single-shot, *in situ* diagnostics of the laser fields, to control the experimental environment fully, and increase laser peak power at least 100 times by shortening pulses or superposing beams from several sources to create and study electron-positron pairs from the vacuum. For HFM, co-ordinated development across RIs (CERN, NS, etc.) is needed to develop a 30+ T high T_c superconducting (HTSC) magnet and address the very high electricity costs of operation, as well extend fields to the region 55-60 T, closer to the point where charge carriers in HTSC materials decouple.

Increasing demand for SR facilities could be met over the next decade through the upgrade of existing facilities and building additional national or regional facilities. Exploitation of complementary FEL facilities is still at a relatively early stage but likely to grow strongly in this period. A co-ordinated European plan to provide sufficient NS capacity before the ESS ramps up should be developed. The very strong growth in demand for Cryo-EM will require an increase in the number of instruments and the development of higher throughput methods. For high-performance lasers a key challenge is to transform existing networks into more robust and reliable user-oriented operations at or approaching 24/7.

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PART2

LANDSCAPE ANALYSIS - SECTION1

SOCIAL & CULTURAL INNOVATION

SOCIAL & CULTURAL INNOVATION

Research Infrastructures that support research across and within the Social & Cultural Innovation domain are among the first known infrastructures: libraries, museums and archives are the most obvious examples of this legacy. In today's digital age, Research Infrastructures in the Social Sciences and Humanities (SSH) enhance research into the historical, social, economic, political and cultural contexts of the European Union, providing data and knowledge to support its strategies.

The data collected and provided by SCIRIs contribute to research that offers new insights into Europe's cultural heritage, its creative industries, education, health and well-being of its citizens, as well as the workings of social and economic policies and societal trends in and across Europe. These insights are fundamental to understand European society and to answer to emerging challenges moving forward.

Data from social sciences and structures that create, collect, assemble and curate such relevant data are fundamental to the further development of the social science research community of Europe. The statistical literacy and research potential of the next generation of social scientists is nurtured using the resources of networked social science data archives and cross-national surveys. The research outputs of Europe's social scientists have impact on Europe's politics and map the social and economic conditions of the continent. Developing better measures of well-being and progress is supported, at the international level, by the Organisation for Economic Cooperation and Development (OECD), the Global Science Forum (GSF) and the European Commission (EC), with important contributions arising from the social sciences.

Public statistics, major scientific surveys, management data and data from opinion polls represent essential sources of knowledge for the social sciences. The development of European indicators on society via longitudinal surveys is a challenging goal to provide a key instrument for constructing Europe.

Research in the humanities provides a better understanding of our society, both diachronically through historical research to answer questions of how we become what we are – by which mechanisms was this driven – and how we can elaborate this knowledge for shaping the future development of our society; and synchronically by monitoring the media to detect what is currently happening in our society – how we react to the major challenges – how societal challenges beside us can be addressed. There is economic impact from this knowledge, as well as a solid base for developing politics and society at large. The increased availability of digital resources in the humanities, and the development of advanced digital methods for research, have prompted remarkable changes in the scale and scope of research in these disciplines. In the area of the humanities, collaboration between the RIs and the GLAM sector – galleries, libraries, archives and museums – will lead to an enhanced impact on culture and society.

Future surveys of the impact of SSH research and RIs will make use of the Social Impact Open Repository (SIOR)¹ allowing researchers to upload qualitative and quantitative testimonies of the social impact of their research, making use of specific indicators². This sys-

tem also enables funding agencies and citizens to monitor the way in which research impacts society positively, for instance through the reduction of early school leaving. It shows especially the directions of innovation in SSH research are going and how these are integrating with other sciences. The availability of this information will also provide guidelines for SSH research groups and projects to increase political and social impact, as well as a body of evidence to demonstrate the results.

The SSH target community is substantial: according to available data, SSH area accounts for over 40% of the students in Europe. Eurostat³ reports that 34% of the students are in social sciences – including journalism, business and law – and 11% in arts and humanities. The ISSC World Social Science Report 2016 estimates that more than 30% of the researchers in the higher education system are in SSH disciplines, however with substantial variation among countries. This accounts for more than 500.000 researchers employed – Full Time Equivalent (FTE) – in higher education in the European Union. In contrast, the spending for SSH is substantially lower than 30% of the overall research spending and often lower than 20% in many countries, according to figures given in the same report⁴.

1. Social Impact Open Repository
<http://sior.ub.edu/jspui/>

2. Social impact: Europe must fund social sciences. Flecha R., Soler-Gallart M., Sordé T. – Nature, 2015, Vol. 528 (7581): 193.
<http://www.nature.com/articles/528193d>

3. Eurostat – Tertiary education statistics
http://ec.europa.eu/eurostat/statistics-explained/index.php/Tertiary_education_statistics#Fields_of_study

4. ISSC World Social Science Report 2016
<http://unesdoc.unesco.org/images/0024/002458/245825e.pdf>

EMERGING DRIVERS

BIG DATA

The speed and versatility of electronic communication and the growth of digital media and tools, as well as their accessibility, is underlying the success of the five ESFRI Landmarks in the SCI domain. From large-scale databases to virtual museums, the tools that these developments have fostered are changing the way in which research is carried out. From the old model of *theorise/hypothesise/collect data/test/refine/conclude*, scientific enquiry has now become much more data-driven and, at the same time, more theory- and method-dependent. The ability to rapidly access large bodies of texts in different languages, to examine music archives, to compare three-dimensional images, to analyse census and survey data from around the world provides research possibilities that were inconceivable 20 years ago and redefine Social Sciences and Humanities research.

The term *Big Data* started to be used to describe assemblages of data – data files, datasets, databases or data streams – that, in terms of their volume, their variety, and the velocity of creation, pose severe challenges for many conventional analytical and computational methods in SSH. Such data may be generated by machines through the operation of sensing and imaging devices – e.g. Radio-Frequency Identifiers, imaging equipment; by robotic analysis – e.g. genome wide scans; by social media interactions – e.g. Twitter feeds; mass-recordings of video magnetic tapes – e.g. video cassettes from last centuries art projects; or from the recording of administrative processes – e.g. hospital records, tax and benefit claims. In 2012, digital content grew to over 2.8 Zettabytes (ZB, 10^{21} bytes) to 8.5 ZB by 2015⁵. *Big Data* technologies, tools, and services that turn this information overload into information gains are the next opportunity for competitive advantage, and Language Technology (LT) is a core *Big Data* technology. Growth in the volume and variety of data is mostly due to the accumulation of unstructured text data; in fact, up to 80% of all data is unstructured text data⁶. Moreover, the translation technology segment will continue to dominate the European LT market. RIs in LT are indispensable in breaking new ground. A common characteristic of *Big Data* in SSH is that they have significant research value in terms of the information contained either in its own right or when linked to other data sources. They can, for example, be used to extract information about preferences, or undiscovered relations between people, and therefore provide important snapshots of human activities and orientations. When data are collected over time, such collections will also contain information about how culture and society develop.

While data types are many and varied, their value for research relates to the depth of their content and the extent of their coverage and the possibility to link data from different sources, which in turn is a func-

tion of the processes by which such data are generated. For example, supermarket store card data derived from specific and self-selecting customers who shop at particular stores and feel motivated to use a store card to gain a loyalty bonus. With data from millions of shoppers, in particular when linked to social surveys or administrative sources, the information generated can be used to explore dietary patterns and to relate these information to geographical indicators of social deprivation. Data generated by social media interactions can be used to gauge the mood of users, their political affiliations, or to document popular interpretations of significant events – e.g. migration, riots, and virus outbreaks. Biosocial data, such as a genome-wide scan linked to longitudinal life course survey data, represent a special form of *Big Data*, with the potential to demonstrate the links between our health, well-being and lifestyles. These data are evidence bases as well as indicators of the effects of public policies.

Before the research value of *Big Data* for SSH can be realised, three important conditions must be met. First, the data must be accessible for research purposes, often through their availability, digitalisation and normalisation; second, the best possible metadata and methods need to be used to extract and interpret the information; and third, there should be clarity about how the data have been generated. While the first condition seems obvious to researchers, data holders may place restrictive conditions on research when individual-related data or commercial interests are involved. In addition, linking data from different sources substantially increases their scientific potential but raises many practical issues to be addressed: technical connected to data integration, and legal related to data protection.

5. _____
The Forum for Europe's Language Technology Industry
https://www.lt-innovate.org/sites/default/files/LT|presentation_European_Data_Forum100413_0.pdf

6. _____
Unstructured Data and the 80 Percent Rule
<http://breakthroughanalysis.com/2008/08/01/unstructured-data-and-the-80-percent-rule/>

NEW MEANS FOR COMMUNICATING AND DISSEMINATING RESEARCH

The mechanism for dissemination of research results emerges as one of the most important predictors of extra-academic impact. Open Access has gained momentum with the involvement of Governments from different countries and the support of funding agencies for research in order to create a strong Open Access Landscape in Europe.

Open Access is just one component of Open Science – the movement to give access to data, research and publications and open up the whole research cycle for participation and collaboration. Initiatives such as the European Open Science Cloud (EOSC)⁷, or the Open Access mandate that goes along with the Horizon 2020 Framework⁸, are strong messages to the whole scientific community. Yet, the development of Open Access for publications in SSH seems to lag behind other scientific disciplines. For example, the Directory of Open Access Journals indicates that only 41% of the journals⁹ – representing 23% of the articles – belong to the SSH area. One of the reasons explaining this divergence could be that a large part of the scientific production in SSH disciplines is published in books and not journals. Even if quantitative social research is often coming closer to other sciences in terms of methodological approaches, books still play an important role in the dissemination of knowledge for those disciplines. Open Access for academic books in SSH develops under different conditions than those we know for articles in the natural or hard sciences. The challenges are different in technical and economic terms as well as in usage, and there are many initiatives in different European countries, by the publishers, the libraries or the scientific communities themselves, which need to be better coordinated in the future.

The dissemination is increasingly not limited to the publications but to the data underlying publications. The request to make primary sources of SSH data available is increasing, both from funding agencies and publishers. This trend in open science not just for publications, but for data as well, requires new and enhanced capabilities to store and access different type of data in the future.

The EOSC aspires to become the European stakeholder-driven infrastructure for science and innovation. It will not only be a data repository, but will also comprise technical elements of connectivity, hardware, repositories, data formats and Application Programming Interfaces (APIs) and it will offer access to a wide range of user-oriented services, data-management, associated HPC analytics environments, stewardship services and, notably, expertise.

7. European Open Science Cloud
<https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-cloud>

8. H2020 Programme Guidelines to the Rules on Open Access to Scientific Publications and Open Access to Research Data in Horizon 2020
http://ec.europa.eu/research/participants/data/ref/h2020/grants_manual/hi/oa_pilot/h2020-hi-0a-pilot-guide_en.pdf

9. Directory of Open Access Journals
<https://doaj.org/>

NEW FORMS OF INTERDISCIPLINARITY

Recently there has been an increase in the value and practice of interdisciplinary SSH research.

INTERNAL INTERDISCIPLINARITY. The traditional fragmentation of the area is being overcome: social sciences and humanities makes way for promising interactions. Disciplinary boundaries are gradually fading to make room for integrative and transversal research methods concerning the entire field of Social Sciences and Humanities. On the one hand, a large body of digitised texts allows Humanities to use quantitative methods that were previously confined to the Social Sciences. On the other hand, a *linguistic turn* within the Social Sciences, makes room for new types of discourse and conversation analysis. Media Studies, which connect the Social Sciences and Humanities, are an eloquent example of that evolution. In particular, the scientific study of the web, which has become an integrated part of society, culture, business, and politics, is a burgeoning field of research activity, with enormous potential for contributing to societal challenges related to the evolution of communication, solidarity or security issues.

EXTERNAL INTERDISCIPLINARITY. The increase of the interaction between SSH and other sciences is one of the most salient features of the recent period. There is now a more acute perception that many causal chains that are the object of natural sciences have their determinants in human action and behaviour. To cite just one example, the extraction of oil from bituminous sands and shales in Canada is expected to move every year more than two times the total mass of annual river sediments in the whole world. While the environmental impact of such extraction can be estimated by natural sciences, it requires the social sciences to analyse and understand the decision-making processes that lead to or can avoid such massive changes in the environment. This change has been accentuated by recent developments in the way of managing science. Horizon 2020, which is not structured by disciplinary fields, but by societal challenges – e.g. health and well-being, climate changes – is the paradigmatic example of this transformation of the science system in Europe. This new approach poses the question of hybrid infrastructures, aggregating data arising from different domains or, alternatively, new forms of collaboration and interchange between existing infrastructures. A good example of this hybridization is provided by the **ESFRI Project E-RIHS** (European Research Infrastructure for Heritage Science) which combines material science methods with interpretative schemes of history of art to rejuvenate the field of heritage studies.

II CURRENT STATUS

The digital aspect of the currently most prominent ESFRI Landmarks and ESFRI Projects is outlined below to testify the progress in the use of digital techniques throughout SSH research methodologies.

Scientific databases are a crucial part of the pan-European infrastructures and more generally in the global science system. Effective access to research data, in a responsible and efficient manner, is required to take full advantage of the data and the possibilities offered by the rapidly evolving digital technology. Accessibility to research data is an important condition for maximising the research potential of new digital technologies and networks. An open and democratic access policy not only provides scientific advantages to the whole academic community, it also provides greater returns from public investments in research activities.

The **ESFRI Landmark CESSDA ERIC** (Consortium of European Social Science Data Archives) is a distributed Research Infrastructure that provides and facilitates researchers' access to high quality social science data and supports their use of this data. The CESSDA Work Plan 2017 informs about significant improvements in information retrieval across the range of relevant service providers and other sources. In this regard, the CESSDA Product and Service Catalogue (PaSC) will be made fully operational in 2018, and a new retrieval tool is under development. Other improvements are in the areas of metadata management, technical architecture, PID policy, and outreach to new scientific cohorts through workshops on data discovery, collaborative data management, etcetera. CESSDA does not disseminate data itself, it coordinates the activities of the national data service providers across Europe. In total it holds, curates and provides access to several thousands of separate data collections, supporting a European-wide user community. CESSDA operates within a global data environment, with reciprocal data access arrangements and agreements established with other data holding organisations worldwide.

The **ESFRI Landmark ESS ERIC** (European Social Survey) is an academically driven long-term pan-European survey designed to chart and explain the interaction between Europe's changing institutions and the attitudes, beliefs and behaviour patterns of its diverse populations. ESS recently announced 100k registered

users. The ERIC updated its Multilevel Data resource in June 2017. Italy, Slovakia and Spain were the final countries to confirm that they will take part in Round 8 (2016/17) of the European Social Survey alongside 21 other European countries. ESS has a broad scientific network and is widely used for academic publications: 109,063 users were registered by the end of August 2017; 76,677 users have downloaded ESS data from all over the world by end of August 2017. Bibliometric data from a google scholar analysis shows 3,140 ESS publications and citations based on ESS data recorded in the period 2003-2015; 2,821 outputs and publications are registered in the ESS online bibliography as of 5 September 2017¹⁰. In addition, HypeStat¹¹ states: europeansocialsurvey.org receives about 650 unique visitors and 2,210 (3.40 per visitor) page views per day.

The **ESFRI Landmark SHARE ERIC** (Survey of Health, Ageing and Retirement in Europe) is the upgrade into a long-term Research Infrastructure of a multidisciplinary and cross-national panel database of micro data on health, socio-economic status and social and family networks of about 110,000 Europeans aged 50 or over. SHARE covers 27 European countries and Israel. The main data collection of Wave 7 is under way in all these countries. As the largest pan-European Social Science Panel Study, SHARE broke a new country record – there have never been more countries in one wave. 6,400 SHARE users were recorded in February 2017. Furthermore, new country teams in Romania, Cyprus and Slovakia were established between 2016 and 2017. SHARE had more than 7,000 users by July 2017. Overall 1,836 publications were produced with SHARE data, 815 were peer reviewed articles¹².

The **ESFRI Landmark CLARIN ERIC** (Common Language Resources and Technology Infrastructure) provides easy and sustainable access to digital language data – in written, spoken, video or multimodal form – and advanced tools to discover, explore, exploit, annotate, analyse or combine them, wherever they are located.

10. _____
ESS User Statistics
http://www.europeansocialsurvey.org/about/user_statistics.html

11. _____
HypeStat
<https://hypestat.com/>

12. _____
SHARE Project
<http://www.share-project.org/>

In 2018, CLARIN has 20 Members, two Observers and one third country institution (Carnegie Mellon University, USA). CLARIN has a global vision, although the focussed user community is European (EU and Associated States). In 2018, CLARIN has more than 40 centres and more than 160 institutes. Europeana¹³ has 800,000 resources listed in CLARIN's Virtual Language Observatory (VLO). The number of monthly visits to the CLARIN website is slowly growing since January 2015. In addition, there is a steady increase in the number of visits to the Discovery Service – used during single-sign on to CLARIN service providers. This can most probably be explained by the increase of the number of services available and their growing popularity.

The **ESFRI Landmark DARIAH ERIC** (Digital Research Infrastructure for the Arts and Humanities) is aiming at enhancing and supporting digitally enabled research and teaching across the Arts and Humanities. During 2017, DARIAH launched its Teaching Platform in Digital Arts and Humanities.

The **ESFRI Landmarks CLARIN ERIC** and **DARIAH ERIC** have collaborated on the relaunch of the Digital Humanities Course Registry. Recent workshops have focused on Data Management, Software Sustainability, Research Ethics, Access, Staff Training, Impact, etc. Numerous universities and libraries joined as cooperating partners in the first half of 2017.

The **ESFRI Project E-RIHS** supports research on heritage interpretation, preservation, documentation and management. It connects researchers in the humanities and natural sciences and facilitates a trans-disciplinary culture of exchange and cooperation. E-RIHS enables the provision of state-of-the-art tools and services to cross-disciplinary users and communities. It aims at the advancement of knowledge about heritage and the division of innovative strategies for its preservation. Based on the preliminary work done in the framework of the H2020 IPERION-CH project started in May 2015, the **ESFRI Project E-RIHS** is currently in the Preparatory Phase which will be used to address legal status and governance/management organization. This will lead to the foundation of an ERIC – or another suitable legal form – to be launched in 2020. Further developments are planned for connecting and including partners and facilities outside the EU, and gradually reaching the status of a global distributed Research Infrastructure.

13. _____
Europeana
<https://www.europeana.eu>

▶ GAPS, CHALLENGES AND FUTURE NEEDS

The development of high speed data connection together with storage capacities and information processing software has provided access to massive amounts of data, as well as new ways of analysing analogue resources of cultural heritage. The disciplines in Social Sciences and Humanities are thus confronted with a momentum that is transforming the entire profession of the researcher. Research Infrastructures in this area must enable the creation and manipulation of large and very heterogeneous bodies of data, of a qualitative or quantitative nature, opening up new research possibilities and encouraging interdisciplinary work. RIs contribute to the valorisation of scientific and cultural heritage.

Data storage and digital interactivity, have opened up new opportunities in terms of appropriation and handling of research resources. Consequently, we have seen a diversification in the locations of digital resource production which have resulted in the creation of many platforms. They form clusters for bringing together disciplinary and technological skills that offer many services to support researchers in the humanities who use ICT either directly because the research data is digital or as an environment allowing for access to new processing tools.

Exponential growth in the amount of data, their increasing use by SSH scholars, as well as the rapid evolution of technology, opens up new opportunities for SSH research. The use of *Big Data* also bears new methodological challenges with implications for empirical research: the implementation of surveys on emerging social trends in longitudinal perspectives can lead to important advances in epistemological and methodological fields. In particular, *Big Data* raises some important issues for the SCI domain, among which we point out the following.

THE PREDICTIVE CAPACITY OF BIG DATA. The challenge is to understand if and how a large amount of data can improve and enhance predictive capacity regarding social phenomena. One concern is that *Big Data* might lead to causality being overlooked, since this perspective relies on correlations and trends whose underlying cause may not be clear.

BIG DATA AND THE ROLE OF THEORY. The advent of *Big Data* has often been accompanied by concerns about the end of theory and about a kind of knowledge that is only data-driven. The question is to understand if the use of *Big Data* can contribute to the generation of interpretative patterns of past, present and future social, political or cultural reality, or identification of the limits of machine learning for humanist and sociological knowledge.

BIG DATA AND DATA PROTECTION ISSUES. The use of *Big Data* in research does not only refer to the issues of privacy protection, but also concerns about access and possession of such data and in many cases also copyright issues. Solutions at national and European level must be found in order to enable researchers to use *Big Data*, given the ethical and legal challenges.

METHODOLOGICAL CHALLENGES OF BIG DATA. The scientific community has some concerns about the validity and the reliability of *Big Data*: the discussion is how to use them in a controlled way in order to produce scientifically relevant inferences.

BIG DATA ANALYSIS. Especially in the field of opinion mining and sentiment analysis, treatment and analysis of *Big Data* rely on automatic procedures more or less monitored by the researcher and on algorithms of machine learning through which the software is able to classify a large amount of textual information. This raises classic methodological problems in a new form: the inspection and thus the control and evaluation of data analysis procedures.

In light of the changes outlined in the preceding section, new forms of Research Infrastructures combining storage and state-of-the-art information extraction methods and services are required if the research community is to utilise all potential research opportunities. This section identifies a number of areas in which the changing research landscape needs to foster new research opportunities in SSH and at the disciplinary boundaries with other scientific communities.

INTEGRATION OF BIO-SOCIAL DATA

Interdisciplinary research cutting across SSH has the potential to supply increasingly rapid insights into the influence of socio-economic and environmental conditions on biological changes. These have long-lasting consequences for our behaviours, health and socioeconomic well-being through the life cycle. There is a need to understand the pathways and mechanisms involved in these reciprocal feedbacks over the range from cells to society. Bringing together interdisciplinary teams to address these research issues and ensuring that our longitudinal and cohort studies are augmented and enhanced to enable such research, provides new opportunities for scientific discovery.

Bringing together data from diverse sources, spanning genomics, blood analyses and biomarkers, health and other administrative records, and business or transaction data, and linking all of these into the rich longitudinal cohort and panel studies presents several major challenges to ensure accessibility and usage. Many researchers would benefit enormously from having complex data pre-processed and summarised in useful ways.

Existing RIs, such as the **ESFRI Landmark ELIXIR** (A distributed infrastructure for life-science information, H&F) and **ESFRI Landmark SHARE ERIC**, indicate that there is significant potential at the pan-European level to integrate a range of biomedical and socio-economic data resources during the lifecycle. In the same way, the surveys and data provided by the emerging project GGP will contribute to the analysis of generational differences in values and gender roles that are highly relevant for policy debates.

Further development in this area of the European research landscape will provide fertile ground for trailblazing research with huge potential benefits for the health and well-being of populations.

PROMOTING AN INTERNATIONAL APPROACH TO REAL-TIME DATA ANALYTICS

Historically, data that have been used for research in the social, economic and behavioural sciences have been designed and/or collected specifically for that purpose. In recent years, however, new forms of data not originally intended for research use, such as transactional and administrative data, internet data (derived from social media and other online interactions), tracking data (monitoring the movement of people and objects), and image/video data (aerial, satellite and land-based), have emerged as important supplement resources and alternatives to traditional datasets. In quantitative humanities, however, the analysis of resources that were not created for specific research questions has a long tradition. The problem of non-tailored resources arises newly since large amounts of digital resources are available to researchers. The troubling gap is emerging in our ability to capture and explore these new forms and amounts of data for the purposes of research. This gap is arising because:

- the prevalence of new forms of data will increase exponentially as technologies and digital capabilities evolve and it is imperative for the SSH community to take a leading role in establishing a robust, quality assuring, secure and sustainable infrastructure for utilising them;
- technological and methodological advances must be made in order to realise the potential of real-time analytics for research in SSH;
- much of the value of new forms of data lies in the potential for linkage and calibration with other data and the derived opportunities for addressing novel research questions as well as re-examining open questions through a new lens;
- current training and capacity-building provisions are insufficient to meet the growing demand from researchers at all stages of their careers to utilise new forms of data;
- new forms of data and their subsequent uses pose novel ethical, quality and privacy

questions that must be explored to ensure that these technologies are deployed in a responsible way.

Europe has to implement standards with respect to privacy and security issues in Research Infrastructures. The recently established General Data Protection Regulation (GDPR) could bring clarity and benefit to research across the SSH and associated disciplines – e.g. medical sciences, health research etc. The new GDPR is an opportunity to develop and establish a lead in regard to privacy and security issues concerning Research Infrastructures.

RIS FOR SOCIAL MEDIA – ARCHIVING WEB

Since the mid-1990s the web has become an integrated part of society, culture, business, and politics, and national web archives have been established to preserve this part of the digital cultural heritage. But for the scholar who wants to study the web across borders, national web archives become an obstacle since they delimit the borderless information flow on the web by national barriers. Thus, a transnational Research Infrastructure should be established with a view to: i) developing a more efficient and attractive European Research Area; ii) ensuring the researcher free access to the digital cultural heritage from different nations; and iii) increasing the potential for fostering innovative partnerships with the software development industry for studies of *Big Data*.

RIS FOR HUMANITIES AND CULTURAL INNOVATION

Contemporary technologies offer great opportunities to revitalize and make available on a large scale cultural items which represent a collective treasure for Europe in terms of identity, citizenship, diversity, cultural growth, and economic potential. The effort in that direction should be conceived in two different ways:

- Cultural items – manuscripts, papyri, books, movies, music, paintings, monuments, etc. – in their material reality, are complex physical objects that are in need of material

analysis, dating, preservation and restoration. Viewed in this way, they are relevant for RIS which aim to support the analysis of physical objects in general.

- Making a material object part of our cultural heritage largely depends on the collective awareness of its existence and on the value vested in it. In this respect, RIS devoted to the dissemination (digitisation, 3D-reconstitution, etc.) of those objects are crucially needed to the maintenance of our cultural heritage.

An enormous amount of diverse materials is widely distributed across Europe: they are often difficult to access from outside local communities, and sometimes at risk of deterioration. The main challenge of RIS is to provide users access (educators, museums and exhibition curators, public) to such treasures and heritage, and to the state-of-the-art analysis carried out by experts and researchers, also by exploiting digital media and archives.

National museums and integrating Research Infrastructures such as the European Cultural Heritage Online (ECHO)¹⁴ and Europeana¹⁵ have made important efforts to digitize libraries and collections. ECHO was established in 2002 to create a research driven IT infrastructure for the humanities. It works on digitisation of cultural heritage and develops research driven tools and workflows for analysis and publication of scholarly data linked to primary sources. ECHO features more than 70 collections from more than 24 countries worldwide. Europeana is a European network representing more than 3,300 institutions and aggregators and provides cultural heritage collections to all in the form of more than 30 million digitised objects and descriptive data.

However, making these treasures accessible in digital form is only the first step in ensuring their uptake by the target audience. The vast bulk of the cultural heritage accumulated through centuries of European history is a formidable resource of rich material for new and far-reaching analyses, typically in languages no longer spoken. Therefore, the mere availability of this heritage no longer

14. European Cultural Heritage Online (ECHO)
<http://echo.mpiwg-berlin.mpg.de/home>

15. Europeana
<http://www.europeana.eu/portal/>

guarantees that current scholars, let alone the general public, will be able to internalise it through conventional methods, i.e., reading about this heritage and annotating it. Thus, new methods of intelligent information mining and text analytics are needed that should be capable of automatically processing the content of the massive amount of cultural heritage treasures and making them accessible to present day audiences. In response, initiatives have been made by setting up projects to record and possibly revitalize endangered languages, in which social media can also play an important role¹⁶. It may be noted that CLARIN has examples from a very large number of languages, and that more than 1,500 languages are represented with 5 examples or more.

Meeting this challenge requires significant interdisciplinary efforts to integrate competences from different expert fields, bring together the most advanced facilities and make their resources available on a large scale. Infrastructures such as the Cultural Heritage Advanced Research Infrastructure (CHARISMA) contributed to the development of joint activities in the field of conservation of cultural heritage. CHARISMA covers joint research, transnational access and networking of twenty-one organizations that provide access to advanced facilities, develop research and applications on artwork materials for the conservation of cultural heritage and open up larger perspectives to heritage conservation activities in Europe. It has defined and consolidated the background for the **ESFRI Project E-RIHS**.

Additionally, in the archaeological sciences the ARIADNE network developed out of the vital need to develop infrastructures for the management and integration of archaeological data at a European level. As a digital infrastructure for archaeological research ARIADNE brings together and integrates existing archaeological research data infrastructures so that researchers can use the various distributed datasets and technologies. ARIADNE has strong ties to the **ESFRI Landmark DARIAH ERIC**.

INCREASING THE GLOBAL REACH

Given that RIs in the Social Sciences and Humanities will be stably anchored in Europe in the future, further actions have to be undertaken to make them attractive and compatible on a global scale.

The accessibility of digital research data – e.g. survey data in the Social Sciences, digitized and annotated cultural heritage in the humanities – is obviously the key driver for increasing global research not only in the Social Sciences and Humanities but in the whole scientific system. It can be stated that not only is there still a possible gap between different standards for certain kinds of data – depending on the source from which they were derived – between European infrastructures and non-European infrastructures, there are also rather difficult challenges to meet that are inherently connected to the content types of data and research traditions between different parts of the world.

Digital tools and functions have to be potentially newly programmed when applied to sources in languages, scripts or symbols more recently encountered by the technology. The underlying understanding of text types, art classification systems and semantics would potentially have to be adjusted, complete methodologies would have to be newly negotiated. The same is true for political and sociological research terms and classification systems. In order to integrate and interconnect heritage and knowledge from and about societies and cultures from all over the world, their history and self-conception a lot of work has to be done to enable global infrastructures to offer a certain degree of consistency between these data and concepts.

SUSTAINABILITY AND GEOGRAPHICAL COVERAGE

There is an increased sustainability of the research data due to the fact that all RIs provide archives for storing data and state-of-the-art methods to analyse and interpret them. This is an important difference with respect to ten years ago where data could disappear when a researcher retired. Currently not only data are stored in sustainable, long-lasting and secure archives, but the current RIs – e.g. the **ESFRI Landmarks CLARIN ERIC** and **CESSDA ERIC** – also use innovative methods such as Persistent Identifiers for resources and data collections, so that the same version can always be retrieved and so that research based on their data can be replicated or extended. We also need to consider the sustainability of the RIs themselves. Research Infrastructures need to be sustainable: i) financially and organisationally; ii) technically; and iii) in terms of human resources. These three dimensions of sustainability are heavily interlinked and therefore require adequate financial resources. The organisational sustainability is supported through the use of the ERIC and other legal structures. The financial sustainability of the central and national operations may still be an issue worth considering. For all of the SSH Infrastructures, geographical coverage is crucial for the quality of the research they support and hence for their sustainability. Data from one country is not only of interest for the researchers of this country itself, but also for everyone else in Europe for comparison. To compare attitudes to different aspects of society, it is not enough to have one part of Europe if other parts are missing. For those Infrastructures where language plays an important role, it is obvious that a very good geographical coverage is needed, so that all types of languages, and preferably all languages, are described and will be the basis for the research developments. European data collecting infrastructures only have European Added Value, if they are able to provide data from all over Europe. Technical sustainability has to do with upgrading to new versions, following and updating standards, including new tools and possibilities, following international developments. All current SSH Research Infrastructures are heavily involved in and committed to continuous technical development.

16. The Endangered Languages Project
<http://www.endangeredlanguages.com/>

Sustainability in terms of human resources is at the heart of our infrastructures. There are three classes of activities where human resources are crucial:

- building and operating the infrastructure and keeping it up-to-date in the light of technological and methodological developments and evolving user needs (this is treated above under technological sustainability);
- instrumentation and population of the infrastructure with community specific data and services;
- education, training and research support for existing and future users.

There are various instruments to make these things happen in a sustainable way, and they are all implemented to some extent by the current ESFRI Landmark SSH RIs. For example, building knowledge about the availability of RIs within standard university curricula is a good, sustainable long-term investment. In the shorter term the obligation for infrastructures to build and maintain what could be called a *Knowledge Sharing Infrastructure* is important. Knowledge Sharing Infrastructure is a formalized way of recognizing and sharing knowledge among members. It is an acknowledgment that not all useful knowledge can be concentrated at the central level, and that the knowledge present at the national level is crucial for sustainability and has to be made visible and shared. This is particularly true for distributed Research Infrastructures like the SCI RIs.

HIGH STRATEGIC POTENTIAL AREAS OF RESEARCH IN THE FIELD OF SOCIAL AND CULTURAL INNOVATION

RELIGIOUS STUDIES

Religious studies have become very relevant not only for researchers, but also social actors and decision makers since positive knowledge on religions is a prerequisite to develop informed dialogue and effective policy in the evolving multicultural society. The economic and demographic crisis affecting Europe, as well as the concurrent immigration from other parts of the world, destabilizes the perception of the European society also in terms of an evolving religious landscape. New forms of orthodoxy appear and social discontent and radicalism are expressed frequently in religious terms which is also a threat to social cohesion in the EU. At the same time, religion has played a central role in social integration throughout the history of humankind and it is important to understand its evolution in a changing European society. In this context, specialized research in the broad field of religious and related sociological studies is of high potential strategic value for addressing the challenges of the evolving European societal landscape and dialogue with the neighbouring countries. To effectively address these challenges, scholars and other users who deal with issues related to religions need open access to libraries, archives, human and digital resources, as well as the dedicated services, at a higher level than typically available today at the existing national research centres and laboratories, or at excellence clusters. Cooperation of scholars in religious studies, like in the H2020-funded *Research Infrastructure on Religious Studies initiative (RelReS)*¹ project, can be of high potential strategic value for creating a diachronic understanding of the historical development of religions and for enabling the appropriate elaboration of tools to manage inter-religious stress.

DIGITAL SERVICES FOR OPEN SCIENCE

Scholarly communication practices in the social sciences and humanities need to be reinforced in order to implement Open Science principles. There is a fragmented and generally sub-critical level of activity corresponding to traditional university presses, other scholarly-led publishers, publication platforms, libraries, service providers and research networks that limits the high innovative potential of this area and its contribution to the effective implementation of the goals of Open Science. Specific challenges of the social sciences and humanities domain need to be addressed: publication typologies – research monographs, critical editions – multilingualism, strong connections of research with local communities. This generates a need of advanced interoperability across the sector and its perspective integration into the EOSC. The need of creating a robust open scholarly communication system capable of contributing to Open Science is evident as well as the opportunity to build it on existing know-how, technologies, infrastructures, business models and funding streams. Cooperation on the development of pan-European services in this field, like in the H2020-funded *Design for Open access Publications in European Research Areas for Social Sciences and Humanities (OPERAS-D)*² project, can be of high potential strategic value for promoting better accessibility and interoperability of SCI data and services.

1. [Research Infrastructure on Religious Studies – RelReS](https://cordis.europa.eu/project/rcn/213376_en.html)
https://cordis.europa.eu/project/rcn/213376_en.html

2. [Design for Open access Publications in European Research Areas for Social Sciences and Humanities – OPERAS-D](https://cordis.europa.eu/project/rcn/206231_en.html)
https://cordis.europa.eu/project/rcn/206231_en.html

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PART2

LANDSCAPE ANALYSIS - SECTION1

DATA, COMPUTING AND DIGITAL RESEARCH INFRASTRUCTURES

DATA, COMPUTING AND DIGITAL RESEARCH INFRASTRUCTURES

In research, as in all fields of society, Information and Communications Technology (ICT) has become a key enabling factor for progress. ICT is also changing the *modus operandi* of research by providing new possibilities for geographically distributed collaboration and sharing. Data-driven science, as well as more and more open access to data and scientific results, is transforming not only how research is conducted, but its overall reach.

Today, all large-scale Research Infrastructures are already dependent on ICT resources. This dependence has increased the need to find synergies and to develop ways to tackle the ICT challenges at a generic level, providing effective and cost efficient services that can be of wide and general use. The pan-European e-Infrastructures for networking, high-performance computing (supercomputing) and high-throughput computing (clusters built from more commodity-type hardware) are already well-established and provide production services used by international research and Research Infrastructures projects. Also, data and cloud infrastructures are developing fast and consolidation and integration of such initiatives is taking place, partly inspired by the description of the European e-Infrastructure *Commons* as proposed by the e-Infrastructure Reflection Group (e-IRG). The European Commission enforces the collaboration between researchers, Research Infrastructures and e-Infrastructures by the European Open Science Cloud (EOSC) declaration and the

Electronic Data Infrastructure (EDI) definition as a combination of very fast networking and exascale computing.

The e-Infrastructure landscape described below paves the way for common solutions for shared needs and requirements. Having a general, common layer of supporting e-Infrastructures – *horizontal* e-Infrastructures – also allows for a refocus on science for the disciplinary Research Infrastructures. *Horizontal* e-Infrastructures shared by thematic infrastructures are an important facilitator of cross-disciplinary work, thereby enabling the study of fundamentally new research questions. Here, it should be noted that the development of ICT is very fast and further innovation and development of e-Infrastructure services of all types is essential to make sure that the needs of the European research and Research Infrastructures communities can also be tackled in the future.

Beyond e-Infrastructures and digital devices for network, computation and data man-

agement, it is also of a major importance to develop specific Research Infrastructures in the domain of computer sciences, supporting the experimentation of disruptive systems including e-Infrastructures, hard-middle-sofwares, protocols, computing and cybersecurity issues. This is best done as a co-design effort between all stakeholders where new needs of the researchers lead the way to innovation efforts.

The European e-Infrastructure landscape includes a networking infrastructure, computing facilities and data infrastructures. The European e-Infrastructure ecosystem fully includes national, regional and institutional e-Infrastructures. It should be noted that the pan-European e-Infrastructure services are often being provided by national e-Infrastructures in a collaborative setting, and the European initiatives are dependent on the existence of strong, persistent and synergic national e-Infrastructure nodes.

In the subfields a brief introduction of the major pan-European *horizontal* e-Infrastructure initiatives is given and some examples of services provided are listed. The EOSC and EDI initiatives are highlighted in the corresponding sections. A more complete account of available services can be found in the e-IRG Guidelines Document 2017¹.

The subfields in the e-Infrastructures domain are **NETWORKING INFRASTRUCTURES** and **COMPUTING, DATA AND CLOUD INFRASTRUCTURES**.

1. Guide to e-Infrastructure requirements for European Research Infrastructures, e-IRG support document, 2017 <http://e-irg.eu/documents/10920/363494/2017-Supportdocument.pdf>

NETWORKING INFRASTRUCTURES

|| CURRENT STATUS

GÉANT² manages the pan-European research and education network which links together and offers transnational access to RIs and research resources by providing interconnectivity between National Research and Education Networks (NRENs) across 43 European countries. The NRENs connect universities, research institutes, and sometimes other public institutions in each country. The access to NREN resources is managed nationally and the policy differs slightly from country to country. In addition to pan-European connectivity, the GÉANT network has international connections to a large set of partner networks worldwide, enabling international collaboration on research and education. Most large-scale Research Infrastructures can connect to the local NREN and thus access GÉANT enabling worldwide communications. Projects can also work with their NREN and GÉANT for international point to point links to connect parts of the Research Infrastructures that are distributed over Europe or beyond. If the project or infrastructure is distributed across national boundaries, GÉANT can help coordinate with the relevant local NRENs and advise on appropriate technical solutions. GÉANT also provides important services for researchers, such as innovation test beds.

GÉANT delivers a range of networking services at the international level. Most of these services match those offered at national level by the NRENs. The GÉANT NREN Compendium³ gives an overview of all NRENs, their services and the contact information. The connectivity delivered by GÉANT is supported by a comprehensive range of network monitoring and management services for e.g. optimizing network performance and continuous monitoring. Users can also benefit from the range of GÉANT network monitoring, security and support services employed by NRENs to assure optimum performance for projects and institutions.

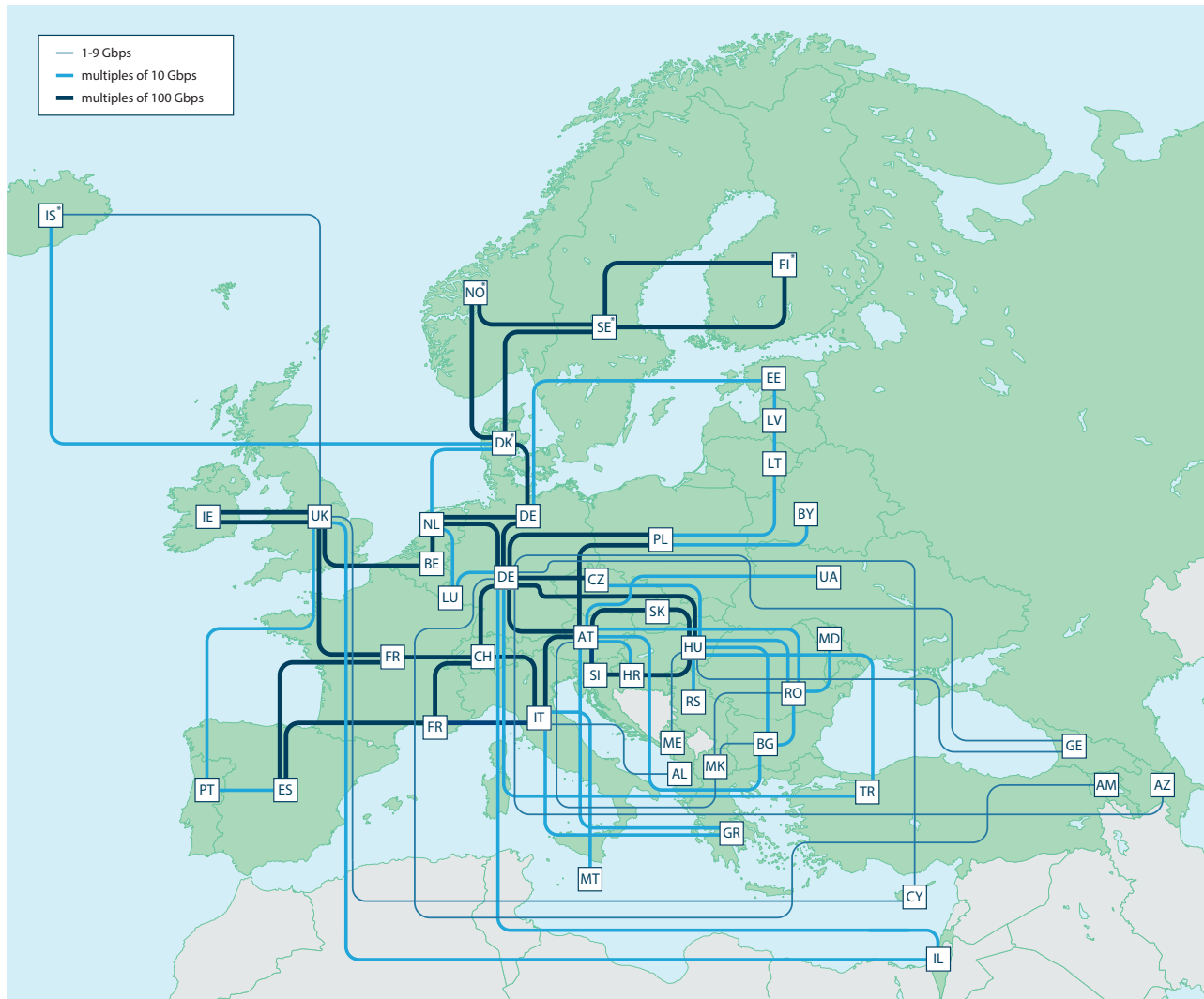
Leading research is today often conducted in a highly distributed and mobile environment where researchers freely collaborate across boundaries. The research communities need to manage access to their services from participants in many organisations and individual researchers need to easily and securely access multiple tools, services and datasets. Trust and identity therefore take up a pivotal position in the e-Infrastructure ecosystem. Here, federated authorization and authentication services simplify access to inter-organisational resources, allowing controlled and secure access. By forming a layer connecting the power of the network with computing, data and cloud infrastructures, such services enable safe and secure research throughout Europe and beyond. In this context, a number of services for the research community are provided to the research community by GÉANT. These services include eduroam that facilitates access to wireless networks in campuses around the world and eduGAIN that provides a framework for interoperation between digital identity federations.

2. GÉANT
<https://www.geant.org/>

3. GÉANT NREN Compendium
<https://compendium.geant.org/#/>



GÉANT's pan-European **research and education network** interconnects Europe's National Research and Education Networks (NRENs). Together we connect over **50 million users** at 10,000 institutions across Europe.



GÉANT's pan-European network is funded by the GÉANT Project (GN4-2), which received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement 731122. Connectivity to the Eastern Partnership countries (AM, AZ, BY, GE, MD, UA) is provided through the EaPConnect project, with 95% funding from the European Commission DG NEAR under grant agreement 2015-356353. The map shows topology as at January 2018. The GN4-2 and EaPConnect partners are listed below.

RASH AL Albania	Belnet BE Belgium	Cyprus CY Cyprus	EENet EE Estonia	RENA GE Georgia	HEAnet IE Ireland	LITHNET LT Lithuania	OMREN ME Montenegro	NORDUnet NO Norway*	AMRES RS Serbia	TURKNET TR Turkey
Asnet AM Armenia	BULNET BG Bulgaria	cesnet CZ Czech Republic	IRIS ES Spain	grnet GR Greece	ISIRI IL Israel	LUXNET LU Luxembourg	MARnet MK F.Y.R. Macedonia	PSNC PL Poland	NORDUnet SE Sweden*	Jisc UK United Kingdom
oconet AT Austria	BASNET BY Belarus	DFN DE Germany	NORDUnet FI Finland*	CARNET HR Croatia	NORDUnet IS Iceland*	LATVIANET LV Latvia	MALTA MT Malta	PT PT Portugal	SI SI Slovenia	UKRAINE UA Ukraine
AZERBAIJAN AZ Azerbaijan	SWITCH CH Switzerland	NORDUnet DK Denmark*	RENATER FR France	HUNGARIAN HU Hungary	GARR IT Italy	MOLDOVA MD Moldova	CURIE NL Netherlands	ROMANIA RO Romania	SLOVAKIA SK Slovakia	

*Connections between these countries are part of NORDUnet (the Nordic regional network)

FIGURE 1.

This map has been downloaded from the GÉANT website. Last update: January 2018
https://www.geant.org/Resources/Documents/G%C3%89ANT_Topology_Map_January_2018.pdf

COMPUTING, DATA AND CLOUD INFRASTRUCTURES

II CURRENT STATUS

The most well-established pan-European computing infrastructures are EGI⁴ in the area of high-throughput computing and cloud infrastructures, and the **ESFRI Landmark PRACE** (Partnership for Advanced Computing in Europe) in the area of High-Performance Computing (HPC) infrastructure. EUDAT⁵ and OpenAIRE are the initiatives that focus on data Infrastructures. Helix Nebula, GÉANT and EGI offer cloud services.

These e-Infrastructures represent the core of the European e-Infrastructures however this landscape may change in the coming years under the influence of the EOSC and EDI initiatives of the EC. The EOSC Declaration⁶ states that the EOSC infrastructure will be developed as a data infrastructure *Commons* serving the needs of scientists. It should provide both common functions and localised services delegated to community level. Indeed, the EOSC will federate existing resources across national data centres, European e-Infrastructures and Research Infrastructures; service provision will be based on local- to-central subsidiarity – e.g. national and disciplinary nodes connected to nodes of pan-European level; it will top-up mature capacity through the acquisition of resources at pan-European level by EOSC operators, to serve a wider number of researchers in Europe. Users should contribute to define the main common functionalities needed by their own community. A continuous dialogue to build trust and agreements among funders, users and service providers is necessary for sustainability. The EC has included a number of calls for proposals to build the EOSC in its Research Infrastructures and e-Infrastructures Work Programmes 2016-2017 and 2018-2020. It is anticipated that in the framework of these calls current e-Infrastructures, as mentioned here, will cooperate ever more closely, such as EGI and EUDAT in the EOSCHub project.

4. EGI
<https://www.egi.eu/>

5. EUROPEAN DATA INITIATIVE
<https://www.eudat.eu/european-data-initiative>

6. EOSC Declaration
https://ec.europa.eu/research/openscience/pdf/eosc_declaration.pdf

The supercomputing landscape will be enhanced in the coming years through the EuroHPC initiative. EuroHPC is part of EDI and aims at providing exascale computing in Europe. On 23rd March 2017, seven European countries signed an agreement to start a European HPC programme that will eventually lead to European exascale supercomputers called EuroHPC. Meanwhile, eight more MS have joined the declaration. Those Member States agreed to work together and with the European Commission in the context of a multi-government agreement called EuroHPC for acquiring and deploying by 2022/2023 a pan-European integrated pre-exascale supercomputing and a data infrastructure that will support data-intensive advanced applications and services. It is a response to the surging demand from scientists, industry and the public sector for access to leading-edge computing capacity to cope with vast amounts of data produced in almost all scientific and engineering domains. The EuroHPC joint undertaking will provide EU level coordination and adequate financial resources to support the development and procurement of such infrastructure. This infrastructure will be accessible to public and private users for research purposes; paying services to industry may also be provided (under conditions TBD). The EuroHPC has proposed, by the end of 2017, a legal instrument that provides a procurement framework for the exascale supercomputing and data infrastructure.

EGI is an international collaboration that federates the digital capabilities, resources and expertise of national and international research communities in Europe and worldwide. EGI's main goal is to empower researchers from all disciplines to collaborate and to carry out data- and compute-intensive science and innovation. EGI is coordinated by the EGI Foundation and has participants from national representatives (NGIs), EIROforums and ERICs. EGI provides open solutions offered through a service catalogue that has been evolving for many years. The EGI Federated Cloud Solution offers a standards-based and open infrastructure to deploy on-demand IT services that can manage and process datasets of public or commercial relevance, and can be flexibly expanded by integrating new providers. This is complemented by the EGI High Throughput Computing Solution which provides a global high-throughput data analysis infrastructure,

linking a large number of independent organisations and delivering computing resources and high scalability. The EGI Federated Operations Solution provides processes and tools to federate and manage distributed ICT capabilities. The EGI Community-Driven Innovation & Support Solution provides the processes, framework and experts so that research communities can co-create the new capabilities or adapt their existing applications or platforms for compute- or data- intensive science on EGI. Access to EGIs externally provided resources is provided through three different access modes: using free grant-based allocations, pay per use, and annual membership fees. The first two modes are applicable to the high throughput computing and cloud solutions and the policies depend on the service providers of choice and can vary nationally and regionally.

The **ESFRI Landmark PRACE** offers access to world-class high-performance capability computing facilities and services. PRACE is managed by the PRACE AISBL and is governed by governmental representative organisations. PRACE systems are available to scientists and researchers from academia and industry from around the world through the process of submitting computing project proposals based on scientific peer-review and open R&D. The PRACE 2 epoch that has been launched in the beginning of 2017 welcomes a new host hence making more computing cycles available to the research community and guarantees PRACE sustainability until 2020. PRACE is only briefly presented here, further details can be found in the dedicated card in the ESFRI Landmarks section of **Part3**.

In some countries, the national representatives are the same for EGI and PRACE. Both EGI and PRACE have already established contacts with consortia that operate or prepare European large-scale Research Infrastructures to understand needs and find out how these matches with available resources and existing policies.

The amount of digital information is growing rapidly. Large-scale Research Infrastructures, such as the initiatives on the ESFRI roadmap, produce and are dependent on a rapidly increasing amount of data. The importance of data management has emerged as a key element in many large-scale Research Infrastructures.

tures projects. It is recognised that specific efforts are needed for making data discoverable and reusable, but data sharing preparedness even within disciplines still differs a lot. The data infrastructures developed by disciplinary Research Infrastructures are often, for natural reasons, customised for the concerned project or research discipline domain and not primarily aimed at use beyond the project or discipline borders. In fact, several of the existing European large-scale Research Infrastructures could be classified as disciplinary e-Infrastructures focussing on disciplinary interoperability and access to data. Several ESFRI cluster projects have been studying similarities between the data needs of sets of ESFRI Research Infrastructures, considering common data standards and formats, data storage facilities, integrated access and discovery, data curation, privacy and security, service discovery and service market places.

For research and society to take full benefit of the major investments in Research Infrastructures and research, the data needs to be made openly and easily available for researchers, over wide spans of fields, in sustainable settings. Also, the data needs to be managed, stored and preserved in a cost-efficient way and the access to the data across borders and domain boundaries must be secured. To fully exploit the underlying potential value in the rapidly increasing amount of research data, interoperability between data infrastructures at all levels is becoming crucial. Efforts have been made to attain a common understanding on the realisation of an ecosystem of data infrastructures and related services, including producing a set of joint recommendations by ESFRI and e-IRG⁷. Many disciplines work at the European and international level to define the discipline-specific aspects of their data infrastructure, which then should be interfaced with the more generic data infrastructure components to provide cross-field interoperability.

Much effort is today going into the definition and development of common or interoperable data formats and metadata, which is necessary to fulfil the general requirement to provide data following the FAIR – Findable, Accessible, Interoperable and Reusable – principles. This requires significant engagement and work

from scientific communities at disciplinary level as a starting point to define standards and provide reusable data, as well as data management services to enable data interoperability and sharing, aiming at the realisation of an ecosystem with the appropriate technical and social channels for openly sharing of data at a multidisciplinary and global level. Here, an active role is played by the Research Data Alliance (RDA)⁸ initiative, a bottom-up organisation with constituents in different regions – such as RDA Europe – and countries. The goal of RDA is to accelerate international data-driven innovation and discovery by facilitating research data sharing and exchange, and the work is performed in Working and Interest Groups which tackle diverse sociological and technological aspects of research data sharing. At the European level, data infrastructures are not yet as well-established as the basic networking and computing infrastructures. However, significant steps have been made in the areas of basic data services (such as storage and replication) through the EUDAT projects and access to publications and other research results through the OpenAIRE projects.

EUDAT is the largest pan-European data infrastructure initiative and has now taken the necessary steps to move towards a sustainable data infrastructure. Covering both access and deposit, from informal data sharing to long-term archiving, and addressing identification, discoverability and computability of both long-tail and big data, EUDAT services aim to address the full lifecycle of research data. The current suite of EUDAT services include a secure and trusted data exchange service, a data management and replication service, a service to ship large amounts of research data between EUDAT data nodes and workspace areas of high-performance computing systems and a metadata catalogue of research data collections stored in EUDAT data centres and other repositories allowing to find collections of scientific data quickly and easily.

OpenAIRE enables researchers to deposit research publications and data into Open Access repositories and provides support to researchers at the national, institutional and local level to guide them on how to publish in Open Access (OA) and how to manage the long tail of science data within the institution environment. If researchers have no access to an in-

stitutional or a subject repository, Zenodo⁹, hosted by CERN, enables them to deposit their articles, research data and software. Zenodo exposes its contents to OpenAIRE and offers a range of access policies helping researchers to comply with the Open Access demands from the EC and the ERC. Zenodo has also been extended with important features that improve data sharing, such as the creation of persistent identifiers for articles, research data and software.

The Helix Nebula initiative is providing a public-private partnership by which innovative cloud service companies can work with major IT companies and public research organisations. The Helix Nebula Marketplace (HNX) is the first multi-vendor product coming out of the initiative and delivers easy and large-scale access to a range of commercial Cloud Services through the innovative open source broker technology. A series of cloud service procurement actions, including joint pre-commercial procurement co-funded by the EC, are using the hybrid public-private cloud model to federate e-Infrastructures with commercial cloud services into a common platform delivering services on a pay per use basis.

7. Summary of Policy Recommendations Drawn from the e-IRG Blue Paper on Data, e-IRG Blue Paper, 2013 <http://e-irg.eu/documents/10920/238805/BP-summary-policy-130227.pdf>

8. Research Data Alliance <https://www.rd-alliance.org/>

9. Zenodo <https://zenodo.org/record/7636#.W0yQfgUzaUk>

▶ GAPS, CHALLENGES AND FUTURE NEEDS

The e-IRG has identified the need for a more coherent e-Infrastructure landscape in Europe, in particular in its 2013 White Paper¹⁰. By now, this notion of a European e-Infrastructure *Commons* framework has been widely accepted and several steps have been taken towards its implementation, including the realisation of EOSC. The e-Infrastructure *Commons* framework has acted as the solid basis for designing the EOSC and its implementation program, already containing most of the ingredients needed for an integrated European platform for Open Science.

The e-Infrastructure *Commons* is the framework for an easy and cost-effective shared use of distributed electronic resources for research and innovation across Europe and beyond. An essential feature of the *Commons* is the provisioning of a clearly defined, comprehensive, interoperable and sustained set of services, provisioned by several e-Infrastructure providers, both public and commercial, to fulfil specific needs of the users. This set should be constantly evolving to adapt to changing user needs, complete in the sense that the needs of all relevant user communities are served and minimal in the sense that all services are explicitly motivated by user needs and that any overlap of services are thoroughly motivated. The *Commons* has three distinct elements:

- a platform for coordination of the services building the *Commons*, with a central role for European research, innovation and Research Infrastructures communities;
- provisioning of sustainable and interoperable e-Infrastructure services within the *Commons*, promoting a flexible and open approach where user communities are empowered to select the services that fulfil their requirements;
- implementation of innovation projects providing the constant evolution of e-Infrastructures needed to meet the rapidly evolving needs of user communities.

In summary, the ultimate vision of the *Commons* is to reach integration and interoperability in the area of e-Infrastructure services, within and between Member States, and at the European level and globally. It is the mission of e-IRG to support this vision through supporting a coherent, innovative and strategic European e-Infrastructure policy making and the development of convergent and sustainable e-Infrastructure services. This e-Infrastructure *Commons* is also a solid basis for building the EOSC already containing most of the ingredients needed for an integrated European platform for Open Science.

In its Roadmap 2016 document¹¹, the e-IRG provides the following key recommendations to attain this *Commons* or EOSC:

- 1) Research infrastructures and research communities should reinforce their efforts to:
 - elaborate on and drive their e-Infrastructure needs;
 - participate in the innovation of e-Infrastructure services;
 - contribute to standards and take care of their data.
- 2) e-Infrastructure providers should further increase their efforts to work closely together to fulfil the often complex user needs in a seamless way.
- 3) National governments and funding agencies should reinforce their efforts to:
 - embrace e-Infrastructure coordination at the national level and build strong national e-Infrastructure building blocks, enabling coherent and efficient participation in European efforts;
 - together analyse and evaluate their national e-Infrastructure funding and governance mechanisms, identify best practices, and provide input to the development of the European e-Infrastructure landscape.

4) The European Commission should provide strong incentives for cross-platform innovations and further support the coordination and consolidation of e-Infrastructure service development and provisioning at the national and the European level.

10. e-IRG White Paper
<http://e-irg.eu/documents/10920/11274/e-irg-white-paper-2013-final.pdf>

11. e-IRG Roadmap 2016 document
http://e-irg.eu/documents/10920/12353/Roadmap*2016.pdf





PART2

LANDSCAPE ANALYSIS

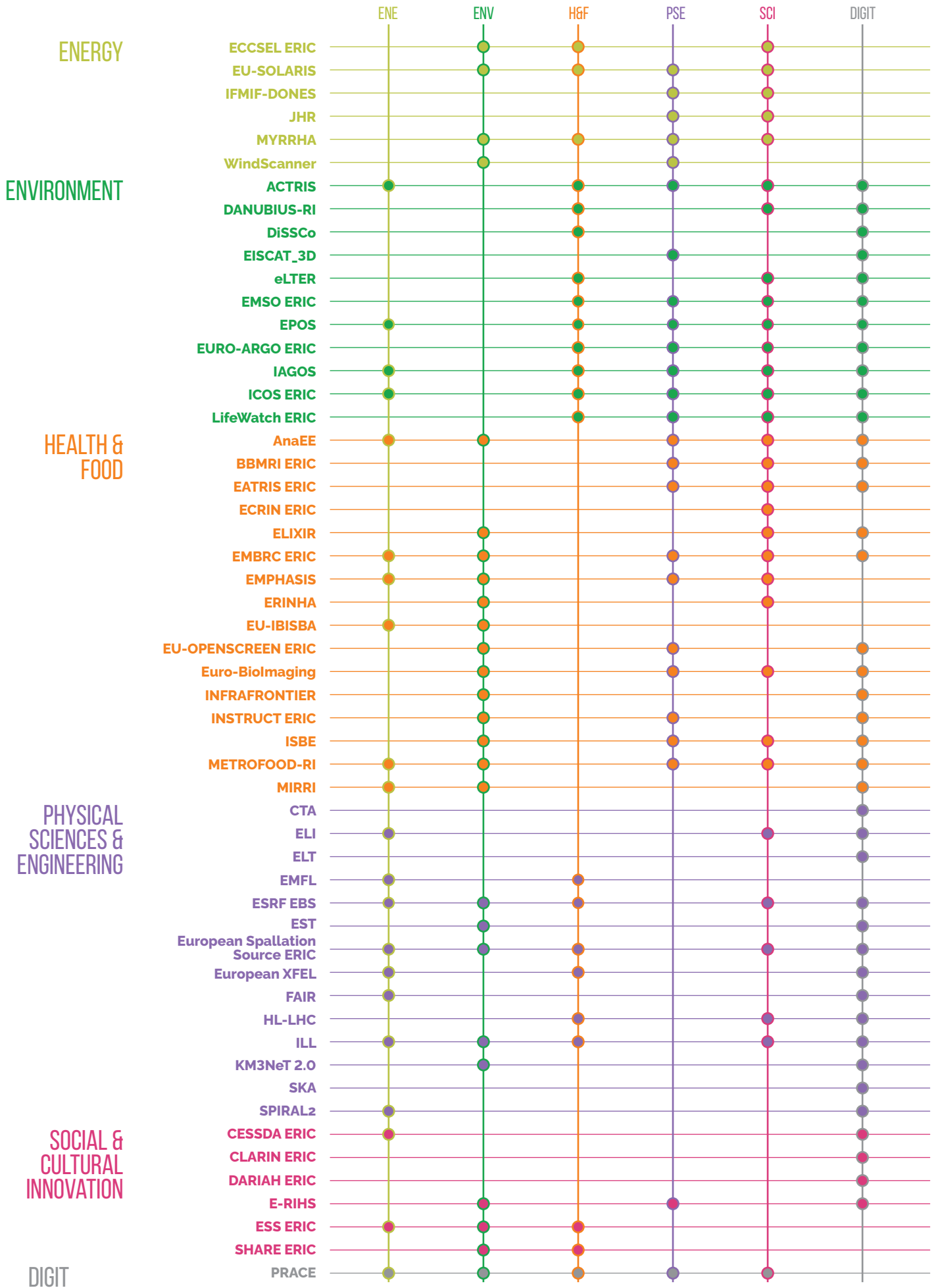
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INFRASTRUCTURES



ENERGY

ECCSEL ERIC

European Carbon Dioxide Capture and Storage Laboratory Infrastructure

ENV

Carbon dioxide Capture and Storage (CCS) research in environmental sciences

Carbon capture and storage verification and climate change

H&F

Carbon dioxide Capture and Storage (CCS) research in health and food

Study of the impact of CO₂ on benthic organisms and marine ecosystem; measurement on carbon cycle and impact on health and agriculture

SCI

Social and cultural aspects of Carbon dioxide Capture and Storage (CCS) research

Carbon capture and storage verification, climate change and impact on human wellbeing

EU-SOLARIS

European Solar Research Infrastructure for Concentrated Solar Power

ENV

Concentrating Solar Thermal (CST) technologies for energy supply and consumption

Concentrating solar thermal solutions for energy budget

H&F

Concentrating Solar Thermal (CST) technologies in health and food

CST impact on health and agriculture

PSE

New technologies and approaches for Concentrating Solar Thermal (CST) technologies

Material science and engineering for energy storage

SCI

Social and cultural aspects of Concentrating Solar Thermal (CST) technologies

CST, climate change and impact on human wellbeing

IFMIF-DONES

International Fusion Materials Irradiation Facility – DEMO Oriented NEutron Source

PSE

New technologies and approaches for nuclear fusion research

Irradiation of structural materials for nuclear fusion technology

PSE

New technologies and approaches for nuclear fusion research

Accelerator technology: high current CW particle beams

SCI

Social and cultural aspects of nuclear fusion research

Energy Security and social acceptance of nuclear fusion

JHR

Jules Horowitz Reactor

PSE

New technologies and approaches for nuclear fission research

Development and optimization of energy materials and components; irradiation of structural materials for nuclear fission technology

SCI

Social and cultural aspects of nuclear fission research

Energy Security and social acceptance of nuclear fission

MYRRHA

Multi-purpose hYbrid Research Reactor for High-tech Applications

ENV

Nuclear fission research in environmental sciences

Safe disposal of radioactive waste; safe operation of nuclear installations; natural radioactivity; transmutation of long-lived nuclear waste

H&F

Nuclear fission research in health and food

Medical radiation dose optimisation; radiological measurements and analyses; studies of the impact of radiation on humans and the environment; production of advanced radioisotopes for therapeutic and diagnostic applications

PSE

New technologies and approaches for nuclear fission research

(Subcritical) fast neutron source, accelerator technology; irradiation of structural materials for nuclear fission energy

PSE

New technologies and approaches for nuclear fission research

Research on matter with radioactive ion beams

PSE

New technologies and approaches for nuclear fusion research

Irradiation of structural materials for nuclear fusion technology

SCI

Social and cultural aspects of nuclear fission research

Energy Security and social acceptance of nuclear fission; transmutation of long-lived nuclear waste

WindScanner

European WindScanner Facility

ENV

Wind energy research in environmental sciences

Land use and landscape impact of wind energy

PSE

New technologies and approaches for wind energy research

Development of technologies for turbulence and aero-dynamical phenomena

ENVIRONMENT

ACTRIS

Aerosols, Clouds and Trace gases Research Infrastructure

- ENE** **Aerosol, clouds, and trace gases observations for energy supply and consumption**
Key atmospheric parameters and environmental assessments related to different energy production forms
- ENE** **Aerosol, clouds, and trace gases observations for energy supply**
Diagnostics development for wind and solar radiation energy applications
- H&F** **Aerosol, clouds, and trace gases observations for health and food**
Measurements of air quality parameters and impact on health
Measurements of air quality parameters and extreme weather events and impact on agriculture
- PSE** **New technologies and approaches for aerosol, clouds, and trace gases observations**
Development of laser optics and detectors
New techniques for atmospheric corrections and aerosol physics
- SCI** **Social and cultural aspects about aerosol, clouds, and trace gases observations**
Key atmospheric parameters, climate change and impact on human wellbeing
- DIGIT** **Open data resources and management for aerosol, clouds, and trace gases observations**
Data access and curation, standardisation of data and metadata, data and services interoperability
- DIGIT** **ICT tools for atmospheric research**
Virtual Research Environments (VRE) for data processing, trend analysis, and satellite cal/val
HPC for atmospheric global and regional models, data assimilation and processing of large volume of data

DANUBIUS-RI

International Centre for Advanced Studies on River-Sea Systems

- H&F** **Advanced studies on river-sea systems for health and food**
Surface waters analysis in global biogeochemical cycles, food and energy production, food security, aquaculture, environmental medicine
- SCI** **Sustainability scenario development for human societies in river-sea systems**
Integration of data from interdisciplinary Earth and Life sciences with social, economic and behaviour information on communities living in river-sea systems, aiming to support sustainable management plans at entire basin scale
- DIGIT** **Open data resources and management for interdisciplinary research on river-sea systems**
Development of DANUBIUS Commons – common set of standards, rules, methodologies supporting interdisciplinary research in freshwater, transitional and coastal marine environments

DiSSCo

Distributed System of Scientific Collections

- H&F** **System of scientific collections for health and food**
Natural science collections for bio- and geo-diversity information, climate change, food security, health and bioeconomy
- DIGIT** **Open data resources and management for scientific collections**
Multi-modal access to collections for a linked open data approach

EISCAT_3D

Next generation European Incoherent Scatter radar system

- PSE** **New technologies and approaches for monitoring of the atmosphere and ionosphere**
Development of new methods of radar coding, signal processing and data analysis
- PSE** **New technologies and approaches for monitoring of the atmosphere and ionosphere**
Sun-Earth interactions, radio astronomy, space security, plasma physics, magnetic field studies
- DIGIT** **Open data resources and management for monitoring of the atmosphere and ionosphere**
Collection and archive of basic data; data processing to describe the ionosphere and neutral atmosphere; selection of well-designed radar pulse schemes

eLTER Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure	H&F	Long-term ecosystem research for health and food Identification of drivers of ecosystem changes for climate, food security, health and bioeconomy
	SCI	Social and cultural aspects of long-term ecosystem research Understand the effects of global, regional and local changes on socio-ecological systems and their feedbacks to environment and society
	DIGIT	Open data resources and management for long-term ecosystem research Access to data across multi repositories
EMSO ERIC European Multidisciplinary Seafloor and water-column Observatory	H&F	Seafloor and water column observations for health and food Biogeochemical and physical parameters measurements to address natural hazards, climate change and marine species/ecosystems under anthropogenic change; biodiversity and ecosystem stability
	PSE	New technologies and approaches for seafloor and water column observations Development of instrument and technologies
	SCI	Social and cultural aspects of seafloor and water column observations Key hydrosphere observations, climate change and impact on human wellbeing
	DIGIT	Open data resources and management for monitoring of the Seafloor and water column
EPOS European Plate Observing System	ENE	Solid Earth science for energy supply and consumption Carbon capture and storage verification
	ENE	Solid Earth science for energy supply Geo-resources; geothermal heating; anthropogenic hazards
	H&F	Health impact of natural gas emissions and volcanic ashes Environmental impact of tsunamis, landslides, volcanic eruptions, lahar and gas emissions for food security
	PSE	New technologies and approaches for solid Earth science Development of instrument and new technologies
	SCI	Social and cultural aspects of solid Earth science Solid Earth observations for environmental changes and hazards and impact on human wellbeing Hazard assessment, risk communication and emergency management Increasing resilience of society to natural and anthropogenic hazards
	DIGIT	High Performance Computing for solid Earth science Integration of data and services – including data products, models and facilities HTC resources for data, metadata and services integration
	DIGIT	Open data resources and management for solid Earth science Access to quality controlled data from diverse Earth science disciplines, tools for analysis and modelling Data FAIRness in Solid Earth Science
EURO-ARGO ERIC European contribution to the international Argo Programme	H&F	Global array of oceans observing systems for health and food Measurements of physical and biogeochemical parameters of the oceans and influence on climate change and impact on health
	PSE	New technologies and approaches for oceans observing systems Development of instrument and technologies, e.g. new sensors to be mounted on autonomous platforms
	SCI	Social and cultural aspects of oceans observing systems Key ocean observations, climate change and impact on human wellbeing
	DIGIT	Open data resources and management for oceans observing systems Access to quality controlled data and data products for climate and oceanography
IAGOS In-service Aircraft for a Global Observing System	ENE	Global observations of atmospheric composition for energy supply and consumption Key atmospheric parameters and environmental assessments related to different energy production forms
	H&F	Global observations of atmospheric composition for health and food Measurements of air quality parameters and impact on health
	PSE	New technologies and approaches for atmospheric composition observations Development of instrument and technologies
	SCI	Social and cultural aspects of atmospheric composition observations Key atmospheric observations, climate change and impact on human wellbeing
	DIGIT	Open data resources and management for atmospheric composition observations Near real time data on atmospheric chemical species to weather and research services

ICOS ERICIntegrated Carbon
Observation System

- ENE** **Integrated Carbon Observation System for energy supply and consumption**
Large scale monitoring of atmospheric CO₂ around CCS
- H&F** **Integrated Carbon Observation System in health and food**
High precision measurement on carbon cycle in agricultural systems, support for climate-smart agriculture, evaluation of bioenergy, common analyses of plant and microbial adaptation to change in relation to carbon cycle
- PSE** **New technologies and approaches for integrated Global Carbon and GHG observations**
Development of instruments, new arrays for local (city) and regional emission verification, and technologies for satellite ground verification
- SCI** **Social and cultural aspects of integrated Carbon Observation System**
Key observations on carbon cycle and greenhouse gas budget and perturbations, climate change and impact on human wellbeing, common studies on behaviour related to climate change
- DIGIT** **Open data resources and management for Integrated Carbon Observation System**
Highly standardised quality control data archived for the long term, services for GHG model integration, comparison and visualisation

LifeWatch ERICe-Infrastructure for
Biodiversity and
Ecosystem Research

- H&F** **Biodiversity and ecosystems in health and food**
Advancement of scientific and technological research on human microbiota, vectors for diseases and parasites and impacts on human health and wellbeing
- H&F** **Biodiversity and ecosystems in health and food**
Advancement of scientific and technological research on conservation of biodiversity in species of agricultural interests, ecosystem impacts on/from agriculture, fisheries and aquaculture
- PSE** **New technologies and approaches for monitoring biodiversity and ecosystem**
Development of ICT instruments and technologies for the control of atmospheric and hydrosphere composition
- SCI** **Social and cultural aspects of biodiversity and ecosystems**
Development of ICT instruments and technologies on socio-ecological systems, past and future ecosystem services and human wellbeing
- DIGIT** **High Performance Computing for biodiversity and ecosystems**
Integration of biodiversity and ecosystem data and services – including data products, models and facilities
- DIGIT** **Open data resources and management for biodiversity and ecosystems**
Provide Virtual Research Environments (VRE) to run scientific experiments in cooperative environments

HEALTH & FOOD

AnaEE

Infrastructure for Analysis and Experimentation on Ecosystems

- ENE** **Managed and natural ecosystems for energy supply and consumption**
Bioenergy and bio-renewables – trade-offs between food supply, energy supply, biodiversity and ecosystem services
- ENV** **Managed and natural ecosystems in environmental sciences**
Land use and exploitation by agriculture change, food security and environmental sustainability
- ENV** **Managed and natural ecosystems in environmental sciences**
Bioenergy and bio-renewables – trade-offs between food supply, energy supply, biodiversity and ecosystem services
- ENV** **Managed and natural ecosystems in environmental sciences**
Health, environment and air/water/food pollution
- ENV** **Managed and natural ecosystems in environmental sciences**
Climate change, weather extremes, and epidemiology of pathogenic agents, in humans, animals and plants
- PSE** **New technologies and approaches for managed and natural ecosystems**
Internet of Things, new technologies – sensors, drones to satellites – to better predict and model agricultural systems, crop/livestock yield, and interactions with the environment
- SCI** **Social and cultural aspects of managed and natural ecosystems**
Land use and exploitation by agriculture change, food and non-food systems
- DIGIT** **Open data resources and management for managed and natural ecosystems**
Modelling platforms by providing the necessary hardware and software, as well as the access to expertise, datasets and modelling libraries

BBMRI ERIC

Biobanking and BioMolecular Resources Research Infrastructure

- PSE** **New technologies and approaches for biobanks and biomolecular resources**
Biomedical engineering and precision medicine: imaging, diagnostics and novel therapeutic approaches
- SCI** **Social and cultural aspects of biobanks and biomolecular resources**
Use of longitudinal studies and cohorts in the healthy population, e.g. life course studies, ageing
Use of longitudinal studies and cohorts in complex disease studies, e.g. obesity and food demand and consumption
- SCI** **Social and cultural aspects of biobanks and biomolecular resources**
Anthropological studies using resources in biobanks, omics, metabolomics, biomedical engineering and precision medicine: ethical implication
- DIGIT** **Open data resources and management for biobanks and biomolecular resources**
Metadata and public data information service about biobanks, sample and data collections, and services

EATRIS ERIC

European Advanced Translational Research Infrastructure in Medicine

- PSE** **New technologies and approaches for translational medicine and drug development**
High-end technologies to advance new products from target validation to early clinical trials
- SCI** **Social and cultural aspects of translational medicine and drug development**
Use of longitudinal studies and cohorts in the healthy population, e.g. life course studies, ageing
Use of longitudinal studies and cohorts in complex disease studies, e.g. obesity and food demand and consumption
- SCI** **Social and cultural aspects of translational medicine and drug development**
Anthropological studies using resources in biomedical engineering, clinical data and precision medicine: ethical implication
- DIGIT** **Open data resources and management for translational medicine and drug development**
Open access to clinical data

ECRIN ERIC
European
Clinical Research
Infrastructure Network

- SCI Social and cultural aspects of multinational clinical research and trials**
Use of longitudinal studies and cohorts in the healthy population, e.g. life course studies, ageing
Use of longitudinal studies and cohorts in complex disease studies,
e.g. obesity and food demand and consumption
- SCI Social and cultural aspects about of multinational clinical research and trials**
Trial management: ethical and cross border legal implication

ELIXIR
A distributed
infrastructure for life-
science information

- ENV Integrated bioinformatics resources and services in environmental sciences**
Sequencing of the DNA and RNA of crop and forest plants, as well
as their pathogens and pests; marine metagenomics
- SCI Social and cultural aspects of integrated bioinformatics resources and services**
DNA and RNA in medical and translational research, and rare diseases: ethical implication
- SCI Social and cultural aspects of integrated bioinformatics resources and services**
Use of longitudinal studies and cohorts in the healthy population, e.g. life course studies, ageing
Use of longitudinal studies and cohorts in complex disease studies,
e.g. obesity and food demand and consumption
- DIGIT High Performance Computing for integrated bioinformatics resources and services**
Data Resources for the life sciences and the long-term preservation of biological
data; repositories for publishing open data in the life sciences

EMBRC ERIC
European Marine
Biological Resource
Centre

- ENE Marine biological resources for energy supply and consumption**
Bioenergy and bio-renewables – bioenergy microbes, plants, crops, aquaculture
- ENE Marine biological resources for energy supply and consumption**
Bioenergy and bio-renewables – trade-offs between food supply,
energy supply, biodiversity and ecosystem services
- ENV Marine biological resources in environmental sciences**
Volcanic cold seeps, proxies for the future high CO₂/low pH oceans; polluted low-oxygen
sites, and artificial habitats such as renewable energy test sites for research on bio-fouling
- ENV Marine biological resources in environmental sciences**
Health, environment and air/water/food pollution on human health
- PSE New technologies and approaches for marine biological resources**
Satellite tag and sensor design for specialised services for tracking large
marine organisms, such as mammals and turtles in their natural habitat
- SCI Social and cultural aspects of marine biological resources**
Anthropological studies using resources in biobanks and omics
- SCI Social and cultural aspects of marine biological resources**
Marine and maritime education
- DIGIT Open data resources and management for marine biological resources**
Interoperability and standardisation of data generated by marine research
and bioinformatics; processing, curation and storage of large datasets of
sequences, metadata, historical time series and literature resources

EMPHASIS
European
Infrastructure for
Multi-scale Plant
Phenomics and
Simulation

- ENE Multi-scale plant phenotyping and simulation for energy supply and consumption**
Agriculture and land-use change, food and non-food systems
- ENE Multi-scale plant phenotyping and simulation for energy supply and consumption**
Development and optimization of specific energy plants;
competition of food supply and biomass for bioenergy
- ENE Multi-scale plant phenotyping and simulation for energy supply and consumption**
Bioenergy and bio-renewables – bioenergy microbes, plants, crops, biofuels
- ENV Multi-scale plant phenotyping and simulation in environmental science**
Precision agriculture and Internet of Things, new technologies – sensors,
drones to satellites - to better predict and model agricultural systems,
crop/livestock yield, and interactions with the environment
- ENV Multi-scale plant phenotyping and simulation in environmental science**
Land use and exploitation by agriculture change, food and non-food systems
- ENV Multi-scale plant phenotyping and simulation in environmental science**
Bioenergy and biorenewables – bioenergy microbes, plants, crops, biofuels, and the environment
- ENV Multi-scale plant phenotyping and simulation in environmental science**
Bioenergy and biorenewables – trade-offs between food supply,
energy supply, biodiversity and ecosystem services

- ENV Multi-scale plant phenotyping and simulation in environmental science**
Health, environment and air/water/food pollution on human health
- ENV Multi-scale plant phenotyping and simulation in environmental science**
Climate change, weather extremes, and epidemiology of pathogenic agents, in humans, animals and plants
- PSE New technologies and approaches for multi-scale plant phenotyping and simulation**
Internet of Things, new technologies – sensors, drones to satellites - to better predict and model agricultural systems, crop/livestock yield, and interactions with the environment
- SCI Social and cultural aspects for multi-scale plant phenotyping and simulation**
Land use and exploitation by agriculture change

ERINHA

European Research
Infrastructure on
Highly Pathogenic
Agents

- ENV Surveillance of highly pathogenic micro-organisms in environmental sciences**
Climate change, weather extremes, and epidemiology of pathogenic agents, in humans, animals and plants
- SCI Social and cultural aspects for surveillance of highly pathogenic micro-organisms**
Use of longitudinal studies and cohorts in infectious disease studies, with high risks for public health, society and the economy
- SCI Social and cultural aspects for surveillance of highly pathogenic micro-organisms**
Outbreak preparedness, surveillance and response

EU-IBISBA

European Industrial
Biotechnology
Innovation and
Synthetic Biology
Accelerator

- ENE Industrial Biotechnology Innovation for energy supply and consumption**
Bioenergy and bio-renewables – bioenergy microbes, plants, crops, biofuels
- ENV Industrial Biotechnology Innovation in environmental sciences**
Identification of genes, enzymes and regulation of the metabolic pathways to degrade the environmental contaminants and to synthesize chemical compounds by biotransformation/biorefinery processes – e.g. pharmaceuticals, biofuels, biomaterials, enzymes.

**EU-OPENSREEN
ERIC**

European
Infrastructure of Open
Screening Platforms
for Chemical Biology

- ENV High-capacity screening platforms for chemical compounds in environmental sciences**
Development of new and safer products – e.g. drugs to treat diseases, herbicides to protect crops, food additives for livestock
- PSE New technologies and approaches for high-capacity screening platforms for chemical compounds**
High-end technologies to advance new products from target validation to early clinical trials
Imaging, diagnostics and novel therapeutic approaches
- DIGIT Open data resources and management high-capacity screening platforms for chemical compounds**
Large-scale open-access data for computational data integration and prediction of drug-target interactions and networks, adverse effects and drug combinations; well-annotated, standardised, controlled datasets with great coverage of chemical space to external scientists

Euro-Biolmaging

European Research
Infrastructure for
Imaging Technologies
in Biological and
Biomedical Sciences

- ENV Biological and biomedical imaging in environmental sciences**
Studies on the bacterial response to environmental stimuli
- PSE New technologies and approaches for biological and biomedical imaging**
Access to range of state-of-the-art technologies in biological and biomedical imaging for life scientists; image data analysis support and training
- SCI Social and cultural aspects for biological and biomedical imaging**
Use of longitudinal studies and cohorts in the healthy population, e.g. life course studies, ageing
- SCI Social and cultural aspects for biological and biomedical imaging**
Biomedical engineering and precision medicine: ethical implication
- DIGIT Open data resources and management for biological and biomedical imaging**
Public data repository to store, integrate and serve image datasets from published scientific studies

INFRAFRONTIER

European Research
Infrastructure for the
generation, pheno-
typing, archiving and
distribution of mouse
disease models

- ENV Mouse functional genomics in environmental sciences**
Study of the genetic, environment and pharmacological components of human disease
- DIGIT Open data resources and management for mouse functional genomics**
Data resources of EMMA, the non-profit repository for the collection, archiving (via cryopreservation) and distribution of relevant mutant mouse strains essential for basic biomedical research

INSTRUCT ERIC
Integrated Structural
Biology Infrastructure

- ENV Integrated structural biology in environmental sciences**
Suddenly shapes, sizes and assemblies of molecules assigned to various compartments in cells and put into context with their surrounding environment
- PSE New technologies and approaches for integrated structural biology**
Analytical facilities at molecular scale – i.e. protein production, cryo-electron microscopy, NMR, nanobody drug discovery, protein crystallisation, X-ray approaches
- DIGIT Open data resources and management for integral structural biology**
Data analysis: bioinformatics, computational software, image processing

ISBE
Infrastructure for
System Biology
Europe

- ENV System biology in environmental sciences**
Approached at the multiscale level to provide solutions to protect our environment; advances in bio-based products research, bioremediation, biofuels, and ecosystem health
- PSE New technologies and approaches for system biology**
Analytical facilities at molecular scale – i.e. protein production, cryo-electron microscopy, NMR, nanobody drug discovery, protein crystallisation, X-ray approaches
- SCI Social and cultural aspects for system biology**
Use of longitudinal studies and cohorts in the healthy population, e.g. life course studies, ageing
Use of longitudinal studies and cohorts in complex disease studies, e.g. obesity and food demand and consumption
- DIGIT Open data resources and management for system biology**
Computational approaches and software development for data and model management, model and data analysis, and model simulation

METROFOOD-RI
Infrastructure for
promoting metrology
in food and nutrition

- ENE Metrology in food and nutrition for energy supply and consumption**
Agriculture and land-use change, food and non-food systems
- ENE Metrology in food and nutrition for energy supply and consumption**
Bioenergy and bio-renewables – trade-offs between food supply, energy supply, biodiversity and ecosystem services
- ENV Metrology in food and nutrition in environmental sciences**
Agriculture and land-use change, food and non-food systems
- ENV Metrology in food and nutrition in environmental sciences**
Health, environment and air/water/food pollution
- PSE New technologies and approaches for metrology in food and nutrition**
New devices and technologies to exploit alternative sources of food; advanced digital solutions for food production and waste management
- SCI Social and cultural aspects for metrology in food and nutrition**
Better use of longitudinal studies and cohorts in complex disease studies, e.g. obesity and food demand and consumption
- SCI Social and cultural aspects for metrology in food and nutrition**
Agriculture and land-use change, food and non-food systems
- DIGIT Open data resources and management for food metrology**
Collection, dissemination and sharing of information about principles, terminology, tools
Harmonization and integration of food composition databases
Development of new standardized tools for food quality, safety & authenticity.

MIRRI
Microbial Resource
Research
Infrastructure

- ENE Microbial resources for energy supply and consumption**
Bioenergy and bio-renewables – bioenergy microbes, plants, crops, biofuels
- ENV Microbial resources for environmental sciences**
Bioenergy and bio-renewables – bioenergy microbes, plants, crops, biofuels
environmental microbiology, food microbiology and safety, in biotechnology
- DIGIT Open data resources and management for microbial research**
Interoperability of data: facilitated data mining and availability of trusted data

PHYSICAL SCIENCES & ENGINEERING

<p>CTA Cherenkov Telescope Array</p>	<p>DIGIT Open data resources and management for ground-based observatory for gamma-ray astronomy Metadata and gamma-ray data openly available, after proprietary period. On-line data analysis tools for <i>multi-messenger</i> approach</p>
<p>ELI Extreme Light Infrastructure</p>	<p>ENE High intensity and short time light pulses impact on the research of fusion technologies Development of alternatives of fusion technologies by inertial confinement, characterization of the plasma</p> <p>SCI Intense and coherent light sources with different time structure for social and cultural sciences Spectroscopy, imaging; analysis of samples of the cultural and natural heritage</p> <p>DIGIT Open data resources and management for investigation of light-matter interactions Metadata and data on extremely powerful laser sources, atto-second pulses, nuclear spectroscopy and particle acceleration by the intense optical field</p>
<p>ELT Extremely Large Telescope</p>	<p>DIGIT Open data resources and management for ground-based astronomy Metadata and astronomy data openly available, after proprietary period. On-line data analysis tools for <i>multi-messenger</i> approach</p>
<p>EMFL European Magnetic Field Laboratory</p>	<p>ENE High magnetic field facilities in energy materials Development and optimization of energy materials and components; experiments on materials behaviour in extreme magnetic fields</p> <p>H&F High magnetic field facilities in new and high precision imaging techniques for health and food Development and optimization of new technologies for magnetic resonance under extreme magnetic fields for medical imaging and diagnostic. NMR high field-high frequency for protein crystallography and structural biology</p>
<p>ESRF EBS European Synchrotron Radiation Facility Extremely Brilliant Source</p>	<p>ENE Synchrotron radiation facility in energy materials Development and optimization of energy materials and components: analysis of materials in extreme conditions and <i>in operando</i> conditions</p> <p>ENV Synchrotron radiation facility in spectroscopy and analysis of contaminant components Reflectometry on the interactions on contaminants in the atmosphere and liquid systems. Analytical tools</p> <p>H&F Synchrotron radiation facility in health and food Protein crystallography and spectroscopy; high resolution structural biology, X-ray imaging, mammography</p> <p>SCI Synchrotron radiation facility in social and cultural sciences Materials structure, spectroscopy, imaging; analysis of samples of the cultural and natural heritage</p> <p>DIGIT Open data resources and management for synchrotron radiation facility Large sets of metadata and data on physics, chemistry, material science, life sciences, heritage science, palaeontology, nanotechnology, engineering; data analysis tools</p>
<p>EST European Solar Telescope</p>	<p>ENE Large-aperture solar telescope observations in environmental sciences Sun observations for the understanding of auroras and other reflections of magnetic phenomena on Earth</p> <p>DIGIT Open data resources and management for large-aperture solar telescope observations Metadata and astronomy data openly available, after proprietary period</p>
<p>European Spallation Source ERIC European Spallation Source</p>	<p>ENE Spallation neutron source for energy materials Development and optimization of energy materials and components: analysis of materials in extreme conditions and <i>in operando</i> conditions</p> <p>ENV High flux neutron beams facility in spectroscopy and analysis of contaminant components Reflectometry on the interactions on contaminants in the atmosphere and liquid systems. Analytical tools</p>

	H&F	Spallation neutron source in health and food Protein crystallography and spectroscopy: high resolution structural biology, microscopy, spectroscopy
	SCI	Spallation neutron source in social and cultural sciences Materials structure, spectroscopy, imaging: analysis of samples of the cultural and natural heritage
	DIGIT	Open data resources and management for neutron science and technology Large sets of metadata of physics, chemistry, material science, life sciences, heritage science, palaeontology, nanotechnology, engineering; data analysis tools
European XFEL European X-Ray Free-Electron Laser Facility	ENE	X-ray Free Electron Laser facility in energy processes and materials Development and Optimization of Energy Materials and Components: analysis of materials in extreme conditions and <i>in operando</i> conditions, time resolved methods
	H&F	X-ray Free Electron Laser facility in health and food Protein crystallography and spectroscopy: single-protein X-ray diffraction, time resolved spectroscopy
	DIGIT	Open data resources and management for X-ray Free Electron Laser radiation facility Large sets of metadata and data on physics, chemistry, material science, life sciences, heritage science, palaeontology, nanotechnology, engineering; data analysis tools
FAIR Facility for Antiproton and Ion Research	ENE	Nuclear physics in energy materials Development and Optimization of Energy Materials and Components
	DIGIT	Big data management and high through computing analysis for exotic nuclear reactions Large sets of metadata and data on nuclear physics, instable isotopes, nuclear spectroscopy and particle acceleration; data analysis tools
HL-LHC High-Luminosity Large Hadron Collider	H&F	Large hadron collider in health and food Developing accelerators and radio-isotope for medical treatments
	SCI	Large hadron collider in social and cultural sciences Global collaboration: example of world laboratory
	DIGIT	Big data management and high through computing analysis for large hadron collider GRID and cloud management of data analysis and storage
ILL Institut Max von Laue-Paul Langevin	ENE	Neutron science and technology in energy materials Development and optimization of energy materials and components: analysis of materials in extreme conditions and <i>in operando</i> conditions
	ENV	High flux neutron beams facility in spectroscopy and analysis of contaminant components Reflectometry on the interactions on contaminants in the atmosphere and liquid systems. Analytical tools
	H&F	Neutron science and technology in health and food Protein crystallography and spectroscopy: high resolution structural biology, microscopy, spectroscopy
	SCI	Neutron science and technology in social and cultural sciences Materials structure, spectroscopy, imaging: analysis of samples of the cultural and natural heritage
	DIGIT	Open data resources and management for neutron science and technology Large sets of metadata of physics, chemistry, material science, life sciences, heritage science, palaeontology, nanotechnology, engineering; data analysis tools
KM3NeT 2.0 KM3 Neutrino Telescope 2.0	ENV	Neutrino telescope in environmental sciences Deep-sea technology and science: measurement of water optical and oceanographic properties, behaviour of bioluminescent organisms; measurement of sea currents, and identification of acoustic noise sources
	DIGIT	Open data resources and management for under water observatory for neutrino and high energy particle detection Metadata and neutrino detection data openly available, after proprietary period. On-line data analysis tools for <i>multi-messenger</i> approach
SKA Square Kilometre Array	DIGIT	Big data management and high through computing analysis for radio-astronomy telescope Very large data sets, curation, storage and access. On-line data analysis tools for <i>multi-messenger</i> approach
SPIRAL2 Système de Production d'Ions Radioactifs en Ligne de 2e génération	ENE	Nuclear physics in energy materials Development and Optimization of Energy Materials and Components
	DIGIT	Big data management and high through computing analysis for exotic nuclear reactions Large sets of metadata and data on nuclear physics, instable isotopes, nuclear spectroscopy and particle acceleration; data analysis tools

SOCIAL & CULTURAL INNOVATION

CESSDA ERIC

Consortium of
European Social
Science Data Archives

ENE

European social science data archives in energy

Data sets providing detailed evidence about behaviour with respect to energy issues and policies

DIGIT

Open data resources and management for data archives and digital preservation

Data catalogue for software tools and services to provide trustworthy, sustainable, and efficient preservation of data; metadata harvesting from Service Providers and other sources

CLARIN ERIC

Common Language
Resources and
Technology
Infrastructure

DIGIT

Open data resources and management for common language resources

User-friendly overview of the available resources from digital humanities, social sciences and human language technologies – e.g. corpora, lexica, audio and video recordings, annotations, grammars, etc. Archives for language resources and depositing services

DARIAH ERIC

Digital Research
Infrastructure for the
Arts and Humanities

DIGIT

Integration of national digital arts and humanities initiatives

Platforms for data sharing and digital publishing alongside technical systems for persistent identification, authentication and long-term preservation

E-RIHS

European Research
Infrastructure for
Heritage Science

ENV

Environmental sciences for cultural heritage

Measurement of key atmospheric parameters, air pollution impact on cultural heritage

PSE

New technologies and approaches for cultural heritage

Analytical tools used directly in cultural heritage, better understanding of artefacts and insights into preservation

DIGIT

Open data resources and management for cultural heritage

Virtual access to data and tools for heritage research; searchable registries of multidimensional images, analytical data and documentation from large academic as well as research and heritage institutions

ESS ERIC

European Social
Survey

ENE

Cross national survey data in energy issues and policies

Data sets providing detailed evidence about behaviour with respect to energy issues and policies

ENV

Environmental sciences for social and cultural innovation

Climate change impact on human wellbeing, common studies on behaviour related to climate change
Citizens' perception of environment and air/water/food pollution

H&F

Cross national survey data in health and food

Use of surveys in the healthy population in biomedical life course studies and ageing, and in complex disease studies, e.g. obesity and food demand and consumption

SHARE ERIC

Survey of Health,
Ageing and
Retirement in Europe

ENV

Environmental sciences for social and cultural innovation

Climate change, pollution and extreme events impact on human life

H&F

Connecting surveys to health and food

Use of surveys in the healthy population in biomedical life course studies and ageing, and in complex disease studies, e.g. obesity and food demand and consumption

DATA, COMPUTING AND DIGITAL RESEARCH INFRASTRUCTURES

PRACE

Partnership for
Advanced Computing
in Europe

ENE

High Performance Computing for energy

Modelling of Energy Systems (high-resolution, real time)
Modelling of Energy Materials and Components
Modelling of the interaction between Energy and Environment

ENV

High Performance Computing for environmental sciences

Modelling of complex dynamical systems (oceans, atmosphere, climate, weather forecast)
Modelling of earth and ocean dynamics

H&F

High Performance Computing for health and food

Modelling and simulation of biological processes

PSE

High Performance Computing for physical sciences and engineering

Modelling and simulation of condensed matter behaviour
Modelling and simulation of out of equilibrium phenomena
Computing theoretical models in HEP, hydrodynamics etc.

SCI

Social and cultural aspects of advanced computing

High-impact scientific discovery and engineering research and development across
all disciplines to enhance European competitiveness for the benefit of society





PART2

LANDSCAPE ANALYSIS

SECTION3

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EDUCATION AND TRAINING

RIs are key elements in the higher education and training for European researchers in all domains as well as for technology developers and innovators. RIs from all scientific domains invest important resources in Education & Training integrating the academic disciplinary culture with multi-disciplinary research methodologies, advanced data technologies and skills to perform research on complex problems.

EDUCATION

In the framework of the study on Long-Term Sustainability of RIs it has been pointed out the need to optimize the role of RIs in higher education by establishing structured collaborations – e.g. credits – and mobility exchange programmes between universities and RIs.

RIs can provide education services and advanced education at master or doctoral level that are complements to the advanced academic education. In the **PSE** domain, one example is the Hercules European School¹ that concentrates on synchrotron and neutron radiation methods of research in a broad range of disciplines, from the life sciences including health, materials science, nanoscience, physical chemistry, archeometry and palaeontology to physics. Hercules is in fact a well established complement of PhD and post-doctoral level education for young researchers in these sciences.

In the **DIGIT** domain, digital infrastructures are expected to boost research, growth, innovation and job creation, and it is clear that education of digital scientists and practitioners is a priority for Europe as this can effectively give people the knowledge, skills and competences to critically use and benefit from scientific data, to contribute creating the European identity, building on common values and cultures. Education on newly emerging technologies for data collection, compression, preservation, and analysis can be realized in collaboration with Digital Infrastructures. The e-learning programs complement and enhance traditional learning, support existing teaching methods and provide a valuable reference point, which can be accessed anytime, anywhere. These programs cover computer science, data and statistics, engineering, life sciences, social sciences and humanities and more, providing proper platforms and, which is extremely important, sharing the knowledge and data stored by all RIs connected via networks.

In the **SCI** domain, the **ESFRI Landmarks CLARIN ERIC** and **DARIAH ERIC** are Digital Humanities RIs that jointly maintain a registry of about 150 courses on Humanities and Computer Science. A more formal integration of educational initiatives between RIs and universities could shape attractive options for advanced-level student to identify possible research and career paths.

1. Hercules European School
<http://hercules-school.eu>

TRAINING

Training initiatives are practiced at all operational levels of RIs, from management to maintenance, from in-house research to technology upgrade, as well as specific training of the users. RIs managerial skills need to address the complexity of international undertakings characterized by challenging technical and organizational structures and to create advanced services for both the very demanding scientific community and trust by the institutional stakeholders and supporting governments – e.g. RITrain Research Infrastructure Training Programme *Executive Masters in Management of Research Infrastructures* hosted by the University of Milano-Bicocca². Training of users cover laboratory safety and research good practices as well as technical skills to operate the RI facilities or the scientific data services.

RIs may represent prototypes for new solutions adapted to changing boundary conditions that have general technological and societal perception implications: specific training needs concern also the optimization of the mix of energy sources that may contribute to sustainability – economic, environmental and social. The integration in the electricity grid of renewables and novel nuclear plants – IV-G or fusion – with currently operational sources requires a high level of knowledge of all technologies and their complementarity. Examples in the **ENE** domain are: the **ESFRI Landmark ECCSEL ERIC** which runs a programme for the development of a capacity building and provides training to the prospective users by webinars and conferences; the **ESFRI Landmark JHR** which relies on a dedicated simulator to train future operators.

In the **ENV** domain, education and training activities focus on the cross-fertilisation and knowledge transfer of new technologies, best practices, approaches and policies of the involved RIs via specific training courses and staff exchange programs for RIs personnel. In addition, an e-training platform developed by the **ESFRI Landmark LifeWatch ERIC** supports the training activities, giving sustainability and re-use to the course materials and offers specific e-training tools for RIs users.

In the **H&F** domain examples are: the **ESFRI Landmark ECRIN ERIC** with a course on *Clinical evaluation of medical devices: from the restrictions and obligations to the means and levers*, focused on requirements

2. Executive Masters in Management of Research Infrastructures
<http://www.emmri.unimib.it/en/>

for clinical investigations, clinical data, decision analytic modelling and financial instruments; the **ESFRI Landmark BBMRI ERIC** course on *How to build a biobank*; the **ESFRI Landmark EATRIS ERIC** online course *The Landscape of Translational Medicine* covering target validation, predictive models, biomarkers, personalized medicine, and regulatory environments; the **ESFRI Landmark ELIXIR** provides training to life science professionals to deal with the exponential growth of bioinformatics tools and data, and filling the training gap left by transformative data technologies in medicine and the life sciences, including how *Big Data* are generated, analysed and interpreted.

In the domain of **SCI** training activities by RIs help scholars to find the appropriate data and access norms to personal datasets. An example is given by the **ESFRI Landmark DARIAH ERIC** which provides supporting platforms to the researchers for the access and the use of the data-sets generated by RIs. A remarkable initiative is the training programme organized by the Synergies for Europe's Research Infrastructures in the Social Sciences (SERISS)³, which aggregates the six major European RIs for Social Sciences. The reference organization in information technology and data services that supports research, training and teaching in the social sciences at international level is the International Association for Social Science Information Service and Technology (IASSIST)⁴.

EU-funded RIs consortia in the **PSE** subdomain of Analytical Physics like CALIPSO⁵ (Synchrotrons), SINE2020⁶ (Neutrons), ESTEEM⁷ (Electron Microscopy), and more in the PSE domain, organize workshops and advanced training.

The training in data sharing, on how to make data FAIR – Findable, Accessible, Interoperable, Reusable – and on the broad implications of Open Science should be substantially supported jointly by Digital and Research Infrastructures. The users of data intensive infrastructures – as the **ESFRI Projects ACTRIS, DANUBIUS-RI, EMPHASIS, ISBE**, and the **ESFRI Landmarks CTA and SKA** – need specifically tailored education and training programs for data acquisition, usage and interoperability.

OUTREACH

Outreach activities are important in several aspects: to communicate with other fields of science that can benefit from the services offered by a given RI, to communicate correctly with Government administrations and stakeholders, to reach industry and civil service operators, to diffuse scientific culture to the students at all levels – from primary education on – and to the general public.

Outreach initiatives by RIs in all domains are aimed at reducing barriers between science and citizens providing evidence of the direct benefits to society in many aspects of life, from health to communication, from environment and energy to cultural heritage and to economic competitiveness. All RIs practice outreach initiatives in form of public events often conducted by well-known journalists, site visits – open door days, general media hard and software products including interactive virtual experiences.

3. _____
Synergies for Europe's Research Infrastructures in the Social Sciences (SERISS)
<https://seriss.eu>

4. _____
International Association for Social Science Information Service and Technology (IASSIST)
<http://www.iassistdata.org>

5. _____
CALIPSOplus
<http://www.calipsoplus.eu/>

6. _____
SINE2020
<https://www.sine2020.eu>

7. _____
ESTEEM 2
<http://esteem2.eu/>

INNOVATION

RIs are important innovation drivers for the development of a competitive knowledge-based economy providing competences and data to – for example – society and industry. They are mission-driven open innovation centres – knowledge hubs – where advanced technologies are created for serving the RI's specific mission and for maintaining the RI's scientific excellence by involving industry and services in public/private partnerships, spin-offs or start-ups therefore realizing an effective knowledge-transfer to industries that raises their standards. Conversely, RIs are test beds of innovative equipment and instrumentation.

Among the solutions developed at RIs and successfully transferred to industrial or civil applications one can quote, within the **PSE** domain, detectors of electromagnetic fields from terahertz to X-rays, neutrons, electrons, high energy particles, and the associated signal electronics; adaptive optics and advanced integration of mechanics and nanomechanics from telescopes; extremely stable power lasers and ultra-short laser pulses; stable hadron beams; imaging; irradiation; high throughput signal processing, data reduction and distribution; visual or textual pattern recognition; efficient archiving and more. All the above yielded innovation in medical, environmental, information, production monitoring, security, computing applications.

Industrial Liaison Offices and Industry Advisory Boards of RIs are the typical interfaces to industry as user-supplier-partner. On the market side a central European portal should inform thoroughly on calls for tenders, RI needs and Technology Transfer (TT) opportunities, upcoming procurements concerning all major RIs.

Research data represents significant financial assets and business opportunities: RIs manage the full chain of data from production and provision of metadata, data curation, long-term preservation to open data services for research and, when appropriate, pay-services for commercial re-use of data. Ensuring research data availability across disciplinary borders, and data han-

dling and portability of results are increasingly important in many industrial and service sectors.

Distributed RIs in the **H&F**, **ENV**, and **SCI** areas are seeds for research and innovation hubs of excellence throughout Europe, also offering services to SMEs, from quality control to new product development and training. Overall IPR issues for cooperation with industry for the development of new devices, the commercial use of scientific data, and ethical considerations are sensitive issues across the fields.

Innovation along the whole value-chain for electrical energy production, from structural materials to components and devices and their integration into the energy system, is supported in the **ENE** domain by the ESFRI RIs that address cutting edge research in this field within a governance scheme that includes industrial advisors.

ENV RIs foster innovation for new measurement concepts and technologies for environmental monitoring in all compartments of the Earth system. The transfer of cutting edge solutions to industry is often realized by spin-off companies and start-ups linked to the RIs.

SCI RIs contribute to innovation articulating aspects as Innovation in service industries, creating new services based on Natural Language Processing, machine learning and semantic technologies based on knowl-

edge graphs, design, game development and social media. Societal and cultural innovation detects spontaneous, emerging changes in society – e.g. co-housing practices among seniors or evolution of ideas and aspirations among citizens and helps innovative policies with evidence-based guidelines about appropriateness and acceptability of rules and norms.

The European Open Science Cloud (EOSC)⁸ is an emerging Digital Infrastructure with structuring impact on European science and beyond, setting up a European Data Infrastructure, underpinning high-capacity cloud solutions with super-computing capacity, federating its services to RIs and community produced ones and widening the user base to the public sector and industry. As such, the EOSC will be a fundamental enabler of the digital transformation of science, offering access and reuse of research data in Europe, across disciplines and borders. EOSC has the potential to leverage past investment in research data infrastructures to add value in terms of scale, interdisciplinary, and faster innovation. ESFRI recognised the Research Infrastructures and their users will enable a successful start of the EOSC providing high quality controlled data and data analytics. A suitable organization of work should be designed to optimize the roadmap towards the realization of the EOSC goals by fully exploiting the ESFRI contribution, as recommended by the European Council in May 2018.

By covering different aspects of key future digital technologies, innovation is driven forward by ESFRI data-intensive RIs. Given the service-oriented nature of the field, innovation support to the industry and business is inherent for the ESFRI RIs, which are data-intensive.

8. [The European Open Science Cloud \(EOSC\)
https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-cloud](https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-cloud)

SOCIO-ECONOMIC IMPACT

RIs contribute to accelerate the transition to a knowledge based economy. Capacity building, high-level training, provision of innovative technologies, and implementation of know-how, methods and standards to national and international stakeholders, training and education, and advising on policies do impact the European society and economy. Socio-economic impact (SEI) is an element of the ESFRI Roadmap assessment procedures and it is central in the networking activities of the ESFRI RIs. It remains challenging to elaborate a robust model and metrology to quantitatively estimate the SEI.

The contemporary results of *Big Science* from space-missions like Cassini or the detection of gravitational waves demonstrating the genesis of heavy elements in the collapse of binary systems, contribute to broadening attraction to science and rational scientific research efforts, as well as the results of genomics and related medical research addressing common and rare diseases. High-quality research, as generated by RIs, develops a large SEI, and a baseline for pursuing a truly knowledge-inspired societal policy.

The assessment of SEI stemming from RIs' activities is a standardized way to evaluate the effective use of public resources, to inform future decision and policy-making and to secure funding for the continuous operation of RIs. The SEI assessment is relevant along the whole lifecycle of RIs, from design to termination, and may require *ex ante* as well as *ex post* assessments. Dedicated studies of SEI of large single-site facilities in the ENE and PSE areas were published, but we lack proven models for SEI in the case of distributed RIs typical of the **ENV**, **H&F** or **SCI** domains. Here we list some elements that contribute to SEI for all ESFRI RIs areas.

The geographical coverage, complementary resources and concerted approach of **H&F** RIs represent unique assets for accelerating drug discovery and production, testing of new diagnostics and therapies, supporting the development of personalised or stratified medicine, identifying new models of human rare diseases, and facilitate the

emergence of new biomedical applications. These concerted actions accelerate socio-economic competitiveness and foster an equitable healthcare in Europe. **H&F** RIs will provide data in strategic areas for Europe such as marine bio-resources, good environmental status, circular economy, therefore supporting the efforts to address challenges as the increasing demand for food connected to population growth, the increasing use of biomass for non-food purposes and the competition for arable land. Research in the **H&F** domain has direct impact on society and helps strengthening public awareness and support to science, including attraction for the youths towards science and technology careers.

The SEI of **ENV** RIs is based on the knowledge contribution to society for educating and preparing people to environmental hazards therefore increasing the resilience to natural and anthropogenic risks – e.g. the **ESFRI Landmarks EPOS** and **EMSO ERIC**. Moreover, long-term observation data on the changing Earth system help triggering new technology development and innovation in the field of mitigation and adaption to climate change – e.g. the role of the **ESFRI Landmarks ICOS ERIC**, **IAGOS**, **EURO-ARGO ERIC** and the **ESFRI Project ACTRIS** in Copernicus.

The SEI of the Analytical Research Infrastructures (ARIs) in the **PSE** domain – synchrotrons, FELs and neutrons facilities – include the multi-disciplinarity generating societal benefits from technology to her-

itage preservation. Competitive research hubs do qualify the host territory by attracting highly skilled human resources and generating jobs of higher knowledge content in the local economy.

The SEI of RIS in **SCI** is easily perceived as these infrastructures provide information that relates to our cultural heritage, preserves art, uncovers our past, informs political thinking and decision making and supports our social and economic well-being. An important SEI indicator is the effect of **SCI** RI-supported research on evidence-based public policy. The data from the **ESFRI Landmark SHARE ERIC**, for example, revealed a strong correlation between early retirement and the loss of cognitive abilities with strong policy implications both at European and national level. The EU Commission as the single largest user of **SHARE ERIC** data, uses the data for economic and social benchmarking exercises. The social and longitudinal surveys deal with values, representations, beliefs and subjective conditions such as well-being that drive human behaviour, proved their SEI with a better common understanding across Europe. RIs on common language and cultural heritage, its richness and diversity, strengthening cultural citizenship and linking with the most advanced technologies producing a high SEI for Europe. Working with complex questions as contemporary societal challenges requires a system that is capable of giving access to and handle large amounts of data from a wide variety of sources covering many scientific areas.

DIGIT RIs create a safe and seamless environment for sharing research data, accessing to new platforms and software tools do contribute to increase the scientists' productivity and enable data reuse with the aim of generating new science and science services, ultimately generating major economic benefits. The net effect is a more efficient usage of the existing infrastructures and attracting new resources to the European science sector, creating a circle that fuels investment in innovative businesses, new public services, higher quality scientific information.

BIG DATA AND e-INFRASTRUCTURE NEEDS

Science and Technology of Information and Communication (STIC) and RIs must develop the maximum synergy to produce, communicate and diffuse the culture of high quality data in all areas of science. Frontier research generates high-quality data and extracts knowledge from them. Raw data are generally unstructured flows that are effectively usable only by the scientists who generated them, or by a specialized scientific community. Open Data science requires large cohorts of structured and well documented data: only a special effort pushing ahead the state-of-the-art of e-Infrastructures can enable this goal by realizing advanced standards of accessibility, quality control of data and analysis tools.

The multi-disciplinarily character of data-intensive themes imposes the scalability of the digital infrastructures with increasing e-needs, calling for a coordinated effort of all RIs. ESFRI foster adoption of FAIR – Findable, Accessible, Interoperable and Reusable – data principles plus data Reproducibility and Openness by all RIs of the Roadmap. ESFRI RIs generate massive data and have often developed own standards and metadata formats, developed data analysis and computational resources available to users, as well as data repositories for storage facilitating data sharing and re-use optimized for their reference scientific communities. High throughput (HTC) and high performance computing (HPC) are key services for the RIs activities. RIs in different domains face similar data management challenges – e.g. validation and access – and this gives high evidence of the urge of concerted actions towards innovative data policies as well as for the training of data scientists.

The European Open Science Cloud can realize a framework of *Commons* – good practices and instruments of interdisciplinary value – to organize a consistent system of RIs and e-Infrastructures, assuring data preservation and protection, Virtual Research Environments (VREs) data in-

teroperability, and suitable data analytics and computational resources across all disciplines, with proper solutions for ethical and IPR issues. EOSC will federate the most advanced data and service infrastructures, often directly built and supported by the RIs. ESFRI RIs – among other European, national and international – represent a major investment in data infrastructure. In contributing to the EOSC the RIs should retain control over the quality of their data, its persistence in time, and over the quality of the data services that might eventually be also provisioned by others to the general scientific users and for innovation purposes.

Important efforts are being developed for coordinating a harmonized contribution to all e-Infrastructure European initiatives – e.g. EOSC, EDI and HPC, in tune with the most recent recommendation of the European Council. Notably HPC applications for data analysis are expected to have a multiscale integrating character and contribute filling gaps with regard to databases and research platforms. Distributed RI platforms and a rising number of national hubs have the potential to advance the digital RIs in the ecosystem.

RIs producing *Big Data* need, for example, pre-exascale computing technology – e.g.

green computing, data and streaming, nano-photonics, etc. – that requires an important R&D effort. Green computing will radically reduce the power needed to do computationally intensive work on large amounts of data. Data & streaming technologies are needed to process data on-the-fly and to efficiently archive data – e.g. time series that need perpetual conservation. Nano-photonics research addresses technologies to drastically reduce the energy cost of data transport over long distances as well as inside computing devices.

In the **PSE** domain, astronomy has pioneered a global framework for FAIR data sharing, which is operational and intensively used by the international community: ground and space-based observatories provide access to their data, which can be reused for scientific aims different from the initial motivation of the research; a Virtual Observatory (VO) defines the relevant data standards as well state-of-the-art data analysis tools. The VO shows the power of interoperability *within a discipline* to enable data and *Commons* to become an integrated Research Infrastructure. The International VO Alliance (IVOA)⁹ is expanding with the inclusion of Astroparticle Physics needs through the Astronomy ESFRI & Research Infrastructures cluster (ASTERICS)¹⁰ and planetary physics by the Virtual Atomic and Molecular Data Centre (VAMDC)¹¹. The rate at which data-handling is required at analytical facilities exceeds Moore's Law and will further accelerate as new-generation detectors and brighter sources come online – ARIs' instruments produce PBs of data a year, e.g. in imaging and tomography. Advanced ARIs need to process data in near-real-time to enable the users to steer their

9. International VO Alliance (IVOA)
<http://www.ivoa.net>

10. Astronomy ESFRI & Research Infrastructures cluster (ASTERICS)
<https://www.asterics.eu>

11. Virtual Atomic and Molecular Data Centre (VAMDC)
<http://www.vamdc.org>

experiments and optimize the costly and scarce beam time availability. An example are Free Electron Laser facilities requiring large computing power and advanced analytics at hand during the experiment sessions. The RDA is developing reference criteria and methods and a broader concept of virtual observatory/laboratory enabling remote access to RIs spanning over the **PSE** domain.

ENV RIs are distributed with nodes/sites acquiring data with a range of spatial and time coordinates so that data standardization and quality control are built-in activities to provide exploitable information and data services for research and society. The **ENV** RIs involve *Big Data* as collections of many different kinds of environmental data and share common challenges such as data capture from distributed sensors, management of high volume data, data visualization and web-casting of data nearly in real time.

Europe is the most environmentally monitored continent, there is however an urgent need to develop a more advanced approach to environmental observation capable of integration across diverse science domains, temporal and spatial scales, space-based observations and *in situ* measurements, data and analysis performed by researchers, industry and governments. A priority and a key driver for **ENV** RIs is to implement a federated approach to IT resources for greater integration and interoperability building on the examples of earth observation – e.g. the role of the **ESFRI Landmarks EPOS** and **Lifewatch ERIC** in the Global Earth Observation System of Systems (GEOSS)¹²– and meteorology – e.g. the role of the **ESFRI Projects ACTRIS** and the **ESFRI Landmark IAGOS** in the World Meteorological Organization (WMO)¹³.

H&F RIs data and knowledge output, as well as the technologies to manage and integrate with other research data in this field, will extend the frontiers of research and generate opportunities to respond to the health and food challenges. **H&F** RIs have a long track record on generating the conditions to share data. In the Health domain,

12. _____
Global Earth Observation System of Systems (GEOSS)
<https://www.earthobservations.org/geoss.php>

13. _____
World Meteorological Organization (WMO)
<https://public.wmo.int/en>

there are special requirements in the Data management, concerning protection, anonymization, identification, storage and data analytics to keep data public and confidential. This expertise can be translated into other fields in order to align and to extract knowledge from **H&F** data in combination with data from other domains, including the development and application of AI and machine learning.

The multi-disciplinarity intrinsic to **ENE** domain requires developing and applying scale-bridging approaches to the design of new materials and to study energy related processes. The study of energy networks and systems from local to macroscopic scales needs handling large volumes of data and intensive model-based processing. New initiatives as the Energy oriented Centre of Excellence for computing applications (EoCoE)¹⁴ are expected to have a multiscale integrating character and to contribute filling gaps between databases and research platforms. Distributed RI platforms such as the European Distributed Energy Resources Laboratories (DERlab)¹⁵ and European Real-time Integrated Co-simulation laboratory (ERIC-Lab)¹⁶ and a rising number of national living laboratories collecting and processing data of real energy systems have the potential to advance the digital real-time integration of distributed and volatile energy resources into advanced and sustainable energy systems.

An important element that needs special mention in e-needs is Human Resources (HR). HR are at the core of all aspects of the overall e-infrastructure and *Big Data* ecosystem at institutional, national, European (EOSC, EDI, EU-HPC etc.) and global level. Sustainability of the RIs and e-Infrastructures must be approached simultaneously with an unprecedented effort in training of data scientists as a specialised profession and of broad data literacy to enable more and more users of the data system.

14. _____
Energy oriented Centre of Excellence for computing applications (EoCoE)
<https://www.eocoe.eu>

15. _____
European Distributed Energy Resources Laboratories (DERlab)
<http://der-lab.net/about/>

16. _____
European Real-time Integrated Co-simulation laboratory (ERIC-Lab)
<http://www.eric-lab.eu>

Finally, it is important to say that there is a clear need to bring together data from multiple platforms to solve increasingly complex problems, and this requires more open access and transferability of data, but the ethical issues and those related to industrial confidentiality need to be properly addresses by all the concerned RIs aiming at developing well based rules.

REGIONAL IMPACT

RIs strongly characterize the territory that host them as drivers for regional development in terms of scientific production and culture, higher education services, innovation in procurement and services and the promotion of supplying industries including SMEs and start-ups oriented to innovation. Enforcing the cooperation between the research sector and economic activities through RIs is central to driving innovation, which typically emerges at local and regional level before spreading globally.

RIs impact the local and regional development: they attract highly internationally qualified staff, the best researcher users from all over the world, students and trainees, and reflect excellence on the local educational system, on the job market and overall regional economy. The role of the regional and local authorities is, thus, fundamental from the preliminary stage of declaring their smart specializations as background for the RI and for the possibility of benefiting of EU structural and investment funds or other financial support facilities at national or European level. Further stimulus role should foster collaboration of RIs with universities and local research institutions.

ENV RIs have a prominent role for addressing the global scientific challenges related to environmental and climate change which impact our society on all levels up from the local, regional, national, to the continental and global scale. The majority of these are of distributed nature, and constitute pan-European hubs of scientific excellence that are, by definition, regional - Think regionally, but work together internationally. The sustainability of **ENV** RIs involves regional investment among others. Various showcases particularly in Southern and Eastern Europe have demonstrated the beneficial effect and proper use of European Structural and Investment Funds and of collaboration with regional governments to improve our environment - i.e. the **ESFRI Landmark LifeWatch ERIC** and the **ESFRI Project DANUBIUS-RI**.

The distributed **H&F** RIs provide opportunities for regional development of the entire

EU-28. The objective is to increase active participation of all Member States in RIs, to support regional research output, to offer new capacities and expertise, prevent brain drain and regional unbalance and ensure coherence and synergy of resources throughout Europe, overall reinforcing cooperation and the formation of EU-wide centres of expertise.

Electron Microscopy laboratories are ubiquitous at universities and research laboratories, but the few that operate as users' facilities have been developed at regional scale, or in conjunction with large ARIs. CEITEC in the Czech Republic is an example of the strategic use of EU Structural Funds for infrastructure development in science, with a strong cryo-EM component. Another example of regional funding is the support from Regione Toscana for the Italian node of the **ESFRI Landmark INSTRUCT ERIC**, the Centre CERM/CIRMMP.

ENE RIs are drivers for regional development in terms of scientific knowledge, innovation and the promotion of supplying industries including SMEs and start-ups with their often special competences in innovative technologies. For Energy RIs, this is especially true for innovative materials, components and devices as well as for high-level characterization technologies, engineering equipment and technical plant construction.

PSE RIs substantially contribute to the regional economy as they represent large investments and create conditions for collaboration and partnership schemes. Regional

facilities are increasingly networked thanks to strategic initiatives like ASTRONET or APPEC. New schemes and initiatives with impact at regional level emerge: the LEAPS initiative - league of electron acceleration driven photon sources - brings together 12 national facilities with the **ESFRI Landmarks ESRF EBS** and the **European XFEL** - aiming to strengthen the network of the analytical facilities and support the free open access to all national resources. Medium power nationally-funded neutron sources and the pulsed sources ISIS (UK) and SINQ at PSI (CH) are open to international users and develop collaboration/funding schemes. The high flux sources - the **ESFRI Landmarks ILL** and the **European Spallation Source ERIC** - are governed under international ownership schemes. The regional dimension of an international source is measured by the impact of the large investment in construction and long-term operation on local economy, society, University and broader educational system, as demonstrated by the competition for hosting large RIs.

The EU FP measure *Integrating Activities* contributes to the Regional impact supporting the networking of national/regional facilities for common research and infrastructure service including transnational access.

RIs and Digital Infrastructures create regional opportunities to compete for Structural and Cohesion Funds in RI investments which in turn can be seeds for the development of innovation nodes within distributed RI. The increasing synergy and complementarity of ESFRI and national roadmaps will create a facilitator for a coherent development of RIs and e-RIs in Europe from the pan-European to the regional scale.

PAN-EUROPEAN DIMENSION

Pan-European relevance is the rationale of ESFRI RIs in terms of the resources involved – competences, financial, human resources, services – and of the EU-wide research users' community needing such unique facility. The entire ESFRI assessment, coaching and monitoring activity has as a reference the criteria for effective pan-European relevance. The e-Infrastructure aspects are assessed against indicators adopted in cooperation with e-IRG¹⁷.

H&F RIs and their services are crucial to offer solutions to the provision of sustainable food options for Europe and the world in the context of a changing climate and limited land availability. Extreme climatic events observed in several European countries have led to a marked decrease in the growth trends of major crop yields – such as wheat – over the past two decades, thus also affecting health, welfare and quality of life of Europeans. The well integrated and synergetic **H&F** RIs landscape is key to understand the best strategy towards sustainable and safe food development, i.e. producing goods and services while minimising the consumption and waste of raw materials, water and energy sources. The **ESFRI Projects AnaEE, EMPHASIS and METROFOOD-RI** are important RIs in the context of these challenges. **H&F** RIs are also very relevant to state-of-the-art healthcare in Europe for the implementation of personalised medicine and for tackling global infectious diseases. The implementation of personalised medicine requires *Big Data* and data sharing. Omics data – the **ESFRI Landmark ELIXIR**; biobanking – the **ESFRI Landmark BBMRI ERIC**; translational medicine – the **ESFRI Landmark EATRIS ERIC**; and clinical trial platforms – the **ESFRI Landmark ECRIN ERIC** – are key RIs to achieve this. It is also necessary to foster collaborations with the International Consortium on Personalized Medicine (IC PerMed) and ERAPerMed, and with the European ecosystem of supercomputing facilities. The Multi-disciplinary HPC-BD infrastructure for Personalized Medicine data analysis and clinical diagnosis in Europe, a

part of IPCEI HPC initiative, is an example. Research and clinical infrastructures in the hadron oncologic therapies, like the CNAO and HIT facilities are coordinated by the ENLIGHT network, and new initiatives are emerging in the Balkans. The ageing population in Europe has led to a rising demand for advanced healthcare, especially in the context of the current shift towards complex multi-morbidity patterns and chronic illnesses, monitoring by longitudinal studies – the **ESFRI Landmark SHARE ERIC** – is very important. The Human Brain Project FET Flagship is also relevant in this context. Climate change is projected to greatly affect public health in Europe, particularly in the elderly and chronic disease patients, as well as by shifting the pattern of spread of some mosquito borne diseases – e.g. Zika virus vector has reached central European countries such as Switzerland. Again similar collaborations, including the **ESFRI Landmark ERINHA** with GloPID-R (International Consortium for Global Infectious Diseases Preparedness) are important. The developing RI landscape offers a unique opportunity to exploit inter- and cross-disciplinary research models and the latest technological advances to foster the development of safe and effective approaches for the screening, prevention, early diagnosis and therapies and therapy monitoring, thus bridging scientific research with tangible benefits for the European society.

Within Europe the **ENV** RIs already operate and collaborate across borders for a long time being the RIs thematic areas of global interest by nature. So the collaboration at global scale is already in their DNA. This makes also easier for European initiatives to

extend their collaborations outside Europe. Moreover, the pan-European dimension of **ENV** RIs is necessary to ensure peer and balanced collaborations both with other developed and emerging world areas. ESFRI helped consolidating integration of **ENV** RIs with the further effect of advancing technological developments to provide users services, making possible to bring **ENV** RIs to the next level of service provision. The **ENV** RIs were able to learn from their own problems/issues/efforts, and they have today a leading position for global collaborations. Better awareness of the EU RIs outside EU can attract more scientific talent.

All **ENE** RIs aim at providing solutions for the transformation of the energy system as one of the major scientific, economic and societal challenges of Europe. To this purpose, they either gather a number of distributed RIs and expertise in different EU countries in order to combine and accelerate efforts in form of platform-building decentralized RIs – the **ESFRI Landmark ECCSEL ERIC**, and the **ESFRI Projects EU-SOLARIS and Windscanner**– or they provide technology-related R&I services to the European and worldwide community – e.g. the **ESFRI Project MYRRHA** and the **ESFRI Landmark JHR**.

PSE RIs are pan-European with relevance expanding to the global scale as emphasized by the Membership and Usage indicators. Astronomy and astroparticle physics are well organised at European level, with world-leading ESFRI RIs, and other major facilities of global interest such as the EGO/VIRGO gravitational telescope part of the LIGO-VIRGO GW-Detector global network. The strategic vision of ASTRONET and APPEC provides a pan-European and international vision and strategy for the field. Transnational Access programmes in EC-funded networks such as OPTICON and RADIONET give a pan-European dimension to national and multilateral facilities. The open access to astronomical data allows researchers from all European countries to access and use the best data-sets and data-analysis tools, contributing powerfully to a better integration in the European Research Area.

17. Evaluation of e-Infrastructures and the development of related Key Performance Indicators, ISBN 978-90-823661-4-3.

About 30.000 scientists in Europe perform their research using some 15 synchrotron radiation facilities and Free Electron Lasers either at national facilities or at ESFRI RIs, and about 5.000 scientists in Europe are users of neutron beams at the 10 European sources (see the Neutron Landscape) that are presently operational. An overall number as high as 10.000 researchers needing neutron spectroscopy, mainly from academia, have been estimated by the network of European neutron facilities, SINE2020. The **ESFRI Landmark European Spallation Source ERIC** has adopted the ERIC framework and explores options for international collaborations at global scale. Supporting user programmes and excellence-based access, especially for researchers from countries without neutron sources, is a very critical point at the present level of development of the neutron landscape and a necessary investment to manage properly the evolving neutron scenario¹⁸.

Estimates arising from ESTEEM, ESTEEM 2 projects, the **ESFRI Landmark INSTRUCT ERIC** and the European Microscopy Society indicate a user base of more than 5.000 scientists skilled in TEM and a broader base of scientists who will benefit from access at advanced TEM RIs indicating the need of further investment, integration-standardisation and inter-operability in this field.

In the case of the **SCI** RIs the complete European coverage is a key strategy goal for the efficient construction of instruments and services enabling research on cultural, linguistic, social, political and economic life in Europe in its variety and complexity. The large membership of **SCI** RIs proves their importance for research community as well as confidence of decision makers in the

18. 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

efficiency of established services, but the remaining gaps in European coverage limit their pan-European impact. Some areas of Europe, e.g. eastern and southern parts, are less represented in ESFRI **SCI** RIs than others. This may have negative implications: the creation of biases in understanding of Europe, the undermining of European comparative research, less comprehensive standards, reduced possibilities because of missing languages and language families, persistent inequality in scientific research among European countries.

The aim of all ESFRI RIs is the transformation of their data intensive feature to address one of the major scientific and societal challenges of Europe – digitalization of science and industry to introduce the open science and open access paradigm. To achieve the goal, RIs collect expertise in different EU countries in order to combine and accelerate the efforts.

GLOBAL DIMENSION

European competitiveness in research is strengthened by RIs with prominent role in the global landscape. The long tradition of Physics RIs sees Europe as a global player in the High Energy Particle (HEP) and ion/nuclear research with colliders, in the detection of all the cosmic messengers – Electro Magnetic radiation, High Energy Astroparticles, Neutrinos, Gravitational Waves – and in the Analytical RIs and extreme optical pulse sources. But globalization is a need and an opportunity in all other fields of research, from solid Earth, ocean and atmosphere observation to H&F, SCI, ENE and DIGIT domains.

Promotion of global consortia of advanced facilities and novel Global Research Infrastructures (GRIs) are needed to enhance the role of European RIs and science in the global context. The Group of Group of Senior Officials (GSO)¹⁹ has defined a frame-

19. Group of Senior Officials (GSO) on global Research Infrastructures <https://ec.europa.eu/research/infrastructures/index.cfm?pg=gso>

work for GRIs and the considered case studies have already involved ESFRI RIs and other leading European research facilities.

Global cooperation on RIs is strategic to Europe for maintaining leadership in standardization of data protocols and the sharing of best practices all over the world. The role of electronic infrastructures is central on this playground. The electronic infra-

structures providing services to global RIs like the **ESFRI Landmarks SKA, HL-LHC, EURO-ARGO ERIC**, and **ELIXIR** ensure the opening of these infrastructures to the world fostering cooperation between European RI and other international world class RIs. Developing a staff exchange programme at the global level, including the organisation of thematic courses and workshops for staff managing and operating Research Infrastructures, is largely facilitated by the electronic platforms available via electronic infrastructures.

In the **SCI** domain the context of globalisation implies that public authorities and companies have a vital need to better know and understand cultural diversity. It is essential to analyse factors of social cohesion, economic development and well-being, by looking at the roles and forms that risk acceptance or risk avoidance take. Of particular importance will be those RIs that support the understanding of the driving forces that can enable our society to offer a better framework for integration, to fight inequality

and to promote social and economic development. It is important to *go beyond Europe* because much can be learned from sharing data, best practices and know-how, in addition to ensuring harmonization and interoperability. All of the existing ESFRI Landmarks in the **SCI** domain have a policy for international collaboration and partnership.

The **ESFRI Landmark CESSDA ERIC** has a close cooperation with the Inter University Consortium for Political and Social Research in the US and with relevant institutions in India, Japan and Australia and South Africa among others. The **ESFRI Landmark ESS ERIC** has informal collaborative links with a number of global research programs such as the International Social Survey Program (ISSP)²⁰, Eurobarometer²¹, AfroBarometer²², Comparative Survey of Electoral Systems (CSES)²³, East Asian Social Survey (EASS)²⁴, Gallup World Poll²⁵, EU-SILC²⁶, Latinobarómetro²⁷, World Values Survey (WVS)²⁸ and the EU Household Budget Surveys (HBS)²⁹. The **ESFRI Landmark SHARE ERIC** has a long-standing cooperation with the United States sister survey Health and Retirement Study sponsored by the National Institute of Ageing which is also providing funding to SHARE. Further sister surveys exist in China, Korea, Japan, India, Mexico and Brazil. In terms of users the US is ranked second – after Germany – in the user statistics of the SHARE data, which is also a strong proof of the international impact. The **ESFRI Landmark CLARIN ERIC** is actively becoming more global. Across the world, there is an obvious need for access to data for cross-lingual and cross-cultural research, and collaborative research can only be fruitful if researchers have access to the same data and tools and are prepared to share them. At present CLARIN

is actively discussing partnership with South Africa, it is exploring possibilities with other African languages, and Arabic speaking countries. In the US, Carnegie Mellon University has a recognised CLARIN centre, and they are now beginning to create a US consortium for CLARIN relations. There are links to other networks and actors in North and South America and Japan. CLARIN collaborates with the RDA. The **ESFRI Landmark DARIAH ERIC** participates to the creation of sustainable platforms for Digital Humanities, from the US Bamboo project (2008-2012) to the Australian Humanities Network Infrastructure HuNi. DARIAH ERIC together with CLARIN ERIC and Bamboo established in 2009 the international CHAIN initiative (Coalition of Humanities and Arts Infrastructures and Networks). The DARIAH node in Italy, co-organised in 2014 events and meetings around the theme of Fostering Transatlantic Dialogue on Digital Heritage and EU Research Infrastructures which were held at the Library of Congress in Washington DC. There have been expressions of interest from Israel, Canada and Australia, regarding the possibility of DARIAH Membership. Data and resources of other current and former projects should be interlinked for open access and interoperability, as in the case of the *Digital Preservation of Cultural Heritage*, funded under FP7 or projects of the Societal Challenge 6.

The **ENV** domain is of global dimension by nature and close collaborations on Earth system research are already established worldwide. Few **ENV** RIs – the **ESFRI Landmarks EPOS** and **IAGOS** – are already listed as candidate Global Research Infrastructures by the GSO. Global cooperation on RIs is strategic to Europe for maintaining leadership in environmental research on UN Sustainable Development Goals³⁰ – i.e.

the **ESFRI Landmarks EURO-ARGO ERIC** and **ICOS ERIC** – as well as standardization of data protocols and the sharing of best practices all over the world. **ENV** RIs play also a crucial role in developing areas in the world, as ICOS ERIC which is supporting the development of a climate and greenhouse gas observation system in Africa.

The cluster of **ENV** RIs (ENVRI) is working on positioning the **ENV** RIs in the global playing field through its presence in GEO, various international fora, participating in projects to enhance global collaboration (COOP+, GLOBIS-B) and the AGU conference for instance.

In fields like **H&F**, the opportunities generated by global RIs for the worldwide scientific communities are crucial to address the global challenges of the area. Global impact of the ERA emphasises the role of **H&F** RIs in providing a sustainable world-class quality infrastructure environment and services to serve the **H&F** research community and to assist in attracting top scientists and collaborations worldwide from public research as well as industry. RIs like the **ESFRI Landmark ELIXIR** and the **ESFRI Landmark BBMRI ERIC** have been proposed to the GSO list of potential GRIs that indicates those RIs who seek interest by other RIs to coordinate with or other Countries to participate. The **ESFRI Landmark INFRAFRONTIER** is an important partner of the International Mouse Phenotyping Consortium (IMPC), which aims at creating a comprehensive catalogue of mammalian gene functions, this was a Case Study of GSO, considered to be in an advanced status of development. **H&F** RIs have established numerous connections internationally, e.g. the **ESFRI Landmark EATRIS ERIC** established links with NIH, USA; the **ESFRI Landmark INSTRUCT ERIC** continues developing relationships with China, Brazil, Argentina and India. The European Virus Archive (EVA), including the **ESFRI Landmark ERINHA** partners, has been very visible at international level on the occasion of the Ebola outbreak. The **ESFRI Landmark Euro-BiImaging** is part of the Global BiImaging Project, which will follow-up on the existing collaboration agreements with Australia and India and reach out to new international partners in North and South America, Africa and Asia to develop a sustainable network

20. International Social Survey Program (ISSP)
<http://www.issp.org/menu-top/home/>

21. EUROBAROMETER
<http://ec.europa.eu/commfrontoffice/publicopinion/index.cfm>

22. AFROBAROMETER
<http://afrobarometer.org>

23. Comparative Survey of Electoral Systems (CSES)
<http://www.cses.org>

24. East Asian Social Survey (EASS)
<http://www.eassda.org/modules/doc/index.php?doc=intro>

25. Gallup World Poll
<http://www.gallup.com/home.aspx>

26. EU-SILC
<http://ec.europa.eu/eurostat/web/microdata/european-union-statistics-on-income-and-living-conditions>

27. LATINOBAREMETRO
<http://www.latinobarometro.org/lat.jsp>

28. World Values Survey (WVS)
<http://www.worldvaluessurvey.org/wvs.jsp>

29. Household Budget Surveys (HBS)
<http://ec.europa.eu/eurostat/web/household-budget-surveys>

30. Sustainable Development Goals
<https://sustainabledevelopment.un.org/sdgs>

of collaborating imaging infrastructures. The **ESFRI Landmark ECRIN ERIC** has collaborations with Japan, Brazil and USA. EMPHASIS is part of the International Plant Phenotyping Network. IPPN supports the development of concepts and technologies in plant phenotyping through interactions between major phenotyping centres in 17 countries.

Opening the global dimension in the **ENE** domain is – implicitly or explicitly – integral part of the Energy RI's mission and work plans. **ENE** RIs generally provide R&I services to the international community to address the global challenges of energy supply. Examples of initiatives in this regard are the **ESFRI Landmark ECCSEL ERIC** transnational access programmes or the **ESFRI Project MYRRHA**, which includes four third countries partners within the consortium. The realization of IFMIF as well will have to rely on a broad international collaboration.

PSE is a domain of very high globalization including High Energy Physics, GW interferometer detectors, underground and under-water laboratories and neutrino detectors, as well as large analytical RIs. Among the ESFRI RIs those for astronomy and astroparticle physics are global in their design, construction and operation: the **ESFRI Landmarks SKA, CTA** and **ELT** have observation sites distributed around the globe both in the north and south hemispheres. The ESS-neutron source has been analysed as a Case Study of the GSO regarding the good practices of in-kind contribution management. Accelerator based facilities for nuclear physics and ion physics also involve informal or formal international collaborations e.g. with Russia. Synchrotron radiation sources are ubiquitous in research-intense countries: Europe hosts what is arguably the world leading high-energy synchrotron facility, the **ESFRI Landmark ESRF EBS**, and several national facilities are also leaders in their own specialization, as for example the high-brilliance MAXLab IV. Petra-III was proposed as GRI to the GSO concerning good practices of global-excellence-based access. FELs are a newer kind of source of X-rays with competitive facilities in the USA (LCLS), Japan (SACLA) and the **ESFRI Landmark European XFEL**. At lower energies FERMI@ Elettra is the unique seeded source in the world, and a class of intermediate energy FELs are being completed and coming online in Switzerland, Korea and China.

The global situation for neutron facilities shows an overall growing trend lead by US, Japan, Russia and China, while the European neutron capacity is expected to face an overall decrease despite the **ESFRI Landmark European Spallation Source ERIC** starting operation in coming years. Therefore, the globalization of neutron sources is a serious step to be considered for the benefit of European scientists.

In general, collaborations and exchanges exist between individual facilities within and outside Europe and there is also a healthy flow of scientists between facilities as a natural part of career development as well as the provision of access to European facilities to scientists outside Europe and vice versa, particularly where a facility offers capability not available elsewhere. Some European facilities may also play a role in helping develop facilities and user communities elsewhere, for example supporting the development of the SESAME project in Jordan, or the user community in South Africa. Exchange and collaboration for neutron technologies, knowledge and software are a well established tradition between the European neutron community and the US and Japan, with support recently offered for the development of the Chinese facilities and setting up collaboration projects with Russia.

As to EM RIs, the TEAM project initiated in US in 2004 is a collaborative research project between four US laboratories and two companies. In Japan, National facilities exist at the National Institute of Advanced Industrial Science and Technology and at the Nagoya High Voltage EM Laboratory. Looking further ahead, the Digital Infrastructures in Europe can play an important role in fostering global agreements on the standardisation, sharing and harmonisation of data collection and re-use.





PART 3

ESFRI PROJECTS & ESFRI LANDMARKS

ESFRI Research Infrastructures 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. ESFRI selects proposals of RIs in strategic areas of research and with an adequate level of maturity to become ESFRI Projects, and identifies successfully implemented RIs to become ESFRI Landmarks.

Each ESFRI Project and ESFRI Landmark is described by a dedicated card.

ESFRI PROJECTS

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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, 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.

ESFRI LANDMARKS

PAG 179

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.

A short description of each ESFRI Project and ESFRI Landmark is given as well as updated information on the legal status, the timeline for the construction/operation, and the estimated costs. The information on the **POLITICAL SUPPORT** – expressed by Governments of Member States and Associated Countries – is validated by the ESFRI Delegations.

POLITICAL SUPPORT TO ESFRI PROJECTS

LEAD COUNTRY/ENTITY: MS, AC or EIROforum member leading the Preparation Phase.

PROSPECTIVE MEMBER COUNTRY/ENTITY: MS, AC and third country, which submitted Expressions of political Support (EoS) signed by the national ministries responsible for the RI, or other entity – such as EIROforum member – whose mandated authorities have expressed interest to join the RI through a Council resolution.

POLITICAL SUPPORT TO ESFRI LANDMARKS

LEAD COUNTRY/ENTITY: MS, AC or EIROforum member leading the Implementation/Operation Phases.

MEMBER COUNTRY/ENTITY: MS, AC, third country or other entity – such as EIROforum member – which is Member of the legal entity by any formal agreement, or applied to ERIC Step2 or to other international legal form.

***OBSERVER:** MS, AC, third country and other entity – such as EIROforum member – which is Observer of any legal entity by any formal agreement, or applied to ERIC Step2 or to other international legal form.

PROSPECTIVE MEMBER COUNTRY/ENTITY: MS, AC and third country, which have submitted Expressions of political Support (EoS) signed by the national ministries responsible for the RI, or other entity – such as EIROforum member – whose mandated authorities have expressed interest to join the RI through a Council resolution.

MS, AC and third country, neither being the Lead country, Member Country nor Prospective Member country, but which hosts research institutions and international organisations formally involved in the consortium, are not listed.

A complete list of stakeholder organizations – Research Institutes, Academia, Research Performing Organizations, territorial authorities – is to be found on the own website of the RIs, as institutional participation may not engage the direct responsibility of the Government.



PART 3
**ESFRI
PROJECTS**

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EU-SOLARIS

European Solar Research Infrastructure for Concentrated Solar Power

DESCRIPTION

The European SOLAR Research Infrastructure for Concentrated Solar Power (EU-SOLARIS) is a distributed Research Infrastructures that aims to achieve a real coordination of Research and Technology Development (RTD) capabilities and efforts in Concentrating Solar Power/Solar Thermal Energy (CSP/STE) technologies by the European Research Centres. EU-SOLARIS will become the reference for CSP/STE and maintain Europe at the forefront of these technologies by providing the most complete, high quality scientific portfolio and facilitating the access of researchers to highly specialised facilities via a single access point. EU-SOLARIS will link scientific communities and industry and speed up the development of research and innovation due to a closer collaboration model, knowledge exchange management and a wider dissemination of results. It will increase the efficiency of the economic and human resources required to achieve excellence and provide efficient resources management to complement research and avoid redundancies.

EU-SOLARIS was included in the ESFRI Roadmap 2010 and started the Implementation Phase in 2018 with expected start of operations in 2020.

BACKGROUND

Concentrating Solar Power/Solar Thermal Energy (CSP/STE) technologies are expected to become a considerable supplier of green energy throughout the world. When Concentrating Solar Technologies are deployed with thermal energy storage, they can provide a dispatchable source of renewable energy. EU-SOLARIS is aiming at creating a new legal entity to explore and implement new and improved rules and procedures for European experimental facilities for CSP/STE technologies, in order to optimize their use and Research and Technology Development (RTD) coordination. It is expected to be the first of its kind, where industrial needs will play a significant role and private funding will complement public funding. EU-SOLARIS is envisioned as a distributed large-scale RI with a strong central node in Spain (the CSP/STE RIs of CIEMAT-PSA) and additional facilities in Cyprus (CYI), France (CNRS), Germany (DLR), Greece (CRES, APTL), Italy (ENEA), Portugal (LNEG, U.EVORA),

and Turkey (GÜNAM and SELCUK U). Partnership includes also the industrial sector as a main actor on the decision-making processes leading to the definition, development, siting and implementation of future CSP/STE experimental facilities and as a prominent user of most, if not all, experimental facilities included under the umbrella of EU-SOLARIS.

Due to a number of reasons, including a market failure in access to finance and unfavourable framework conditions, no new plants have been built in Europe since 2013, whereas more than 20 have been built or approved in third countries - in many cases still with participation of EU companies. Without innovation in the EU market, it is difficult for EU companies to offer technology references on their technology advances when competing for contracts abroad. Therefore, reactivating innovation in Europe is crucial for EU companies to keep their global competitive edge thanks to cheaper technologies, progress in the learning curve and economies of scale. And in this framework EU-SOLARIS will have an important role to play.

STEPS FOR IMPLEMENTATION

After the Preparatory and the Interim Phases, EU-SOLARIS is now in the Implementation Phase with operations expected to start in 2020. The Internal Law, Governance model, Access rules and procedures, Business Plan, policy for Technology Transfer and Intellectual Property Rights management, dissemination and outreach plans, list of services to be provided have been prepared during the Preparatory Phase by a consortium composed of 13 research institutions plus the Spanish Ministry of Economy and Competitiveness (MINECO) and the European Solar Thermal Electricity industry Association (ESTELA). The participation of the various non-RTD stakeholders, such as national and regional governments, renewable energy agencies and other funding bodies, was channelled through an Advisory Board for Funding and Administration. The legal form chosen by the consortium for the Operation Phase of EU-SOLARIS during the Preparatory Phase has been the European Research Infrastructure Consortium (ERIC): seven MS/AC already signed a letter of intents to become Members of the EU-SOLARIS ERIC.

A COORDINATION EFFORT
ON CONCENTRATING
SOLAR THERMAL AND
SOLAR CHEMISTRY
TECHNOLOGIES

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: ES
prospective member countries:
CY, DE, EL, FR, PT, TR

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2010

TIMELINE

- **2010-2012**
Design Phase
- **2012-2016**
Preparation Phase
- **2017-2018**
Interim/Transition Phase
- **2018-2020**
Implementation/Construction Phase
- **2020**
Operation Start

ESTIMATED COSTS

capital value: 7 M€
design: 0.5 M€
preparation: 0.5 M€
construction: 6 M€
operation: 0.2 M€/year

HEADQUARTERS

Plataforma Solar de Almeria - CIEMAT
Almeria, Spain

WEBSITE

www.eusolaris.eu



SPAIN

A UNIQUE RESEARCH
INFRASTRUCTURE FOR
TESTING FUSION MATERIALS
IN REALISTIC CONDITIONS

TYPE

single-sited

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: ES

prospective member country:
HR, (EUROfusion)

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2018

TIMELINE

- 2007-2015
Design Phase
- 2015-2019
Preparation Phase
- 2019-2029
Implementation/Construction Phase
- 2029
Operation start

ESTIMATED COSTS

capital value: 710 M€

design: 150 M€

preparation: 40 M€

construction: 420 M€

operation: 50 M€/year

HEADQUARTERS

Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas – CIEMAT
Madrid, Spain

WEBSITE

www.ciemat.es



SPAIN

IFMIF-DONES

**International Fusion Materials Irradiation facility
- DEMO Oriented NEutron Source**

DESCRIPTION

The International Fusion Materials Irradiation Facility - Demo Oriented NEutron Source (IFMIF-DONES) is a single-sited novel Research Infrastructure for testing, validation and qualification of the materials to be used in a fusion reactor. It is based on a unique neutron source with energy spectrum and flux tuned to those expected for the first wall containing future fusion reactors. Materials irradiation data under such conditions are of fundamental interest for the fusion community as those will feed and validate the modelling tools for materials radiation damage phenomena. The IFMIF-DONES will be a major step towards IFMIF as it will develop a unique high-current high-duty cycle accelerator technology, liquid metal target technology and advanced control systems.

IFMIF was first proposed to the ESFRI Roadmap in 2006, but the development of its concept was mostly carried out within the Broader Approach that will deliver the final results in 2020. The IFMIF-DONES will build on the results of the international community by establishing suitable collaboration schemes, whilst bringing back to Europe one important development in the roadmap to fusion energy.

BACKGROUND

The hard mono-energetic spectrum associated with deuterium-tritium fusion neutrons (14.1 MeV compared with <2 MeV on average in fission reactors) exhibit higher cross-sections for nuclear reactions that will generate significant amounts of H and He, as well as atomic displacements, leading to a presently undetermined degradation of structural materials after a few years of operation. Although fission and fusion materials share common issues, the study of radiation-induced damage for fusion materials necessarily has to go far beyond the damage level which is relevant for fission materials due to the the harder neutron spectrum. Therefore, specific sources, like the IFMIF and DONES, must be built to enable the development of fusion technology.

The original IFMIF project started in 1994 as an international scientific research program, carried out by Japan, the European Union, the United States, and Russia, and managed by the International

Energy Agency (IEA). Since 2007, it has been pursued by Japan and the European Union under the Broader Approach Agreement in the field of fusion energy research, through the IFMIF/EVEDA (IFMIF Engineering Validation and Engineering Design Activities) project, which conducts engineering validation and engineering design activities for IFMIF, including IFMIF engineering design, Validation Activities of the Lithium Loop System, Validation Activities of the Irradiation Area System, Validation Activities of the Accelerator System that is still on-going with the design of the LIPAc prototype for the low energy section (9 MeV) of the IFMIF deuteron accelerator.

IFMIF-DONES is based on a 40 MeV, 125 mA in continuous wave mode (CW) deuteron accelerator (5 MW beam average power) hitting with a rectangular beam size (approx. 20 cm x 5 cm) a liquid Li screen target flowing at 15 m/s – to dissipate the beam power – and generating a flux of neutrons of $10^{18} \text{ m}^{-2} \text{ s}^{-1}$ with a broad peak at 14 MeV through stripping nuclear reactions, reproducing the expected conditions of fusion power plants. Materials are irradiated by the neutron beam as close as possible to the Li target to obtain damage rates up to 15 atomic displacements per year (dpa/year) under temperature controlled conditions. After a long irradiation period (up to two years), irradiated modules will be partially dismantled and the irradiated samples will be characterized.

STEPS FOR IMPLEMENTATION

EUROfusion and Fusion for Energy (F4E) started in 2015 a process to develop the engineering design of DONES and to identify possible EU sites to host the facility. In December 2017, F4E positively evaluated the joint Spain-Croatia proposal to site DONES in Granada. As the IFMIF-DONES enters the Roadmap 2018, it will be eligible for the Preparatory Phase grant by the EC and, simultaneously, will begin the Implementation Phase with the initial steps for the construction of the civil engineering infrastructure. Intense international activity is sought in order to benefit from the final results of the Broader Approach Agreement and to establish the broadest international collaboration in the design and construction of the DONES. ESFRI will assist and monitor since the beginning the developments of IFMIF-DONES.

MYRRHA

Multi-purpose hYbrid Research Reactor for High-tech Applications

DESCRIPTION

The Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) is a first-of-a-kind, innovative nuclear research reactor designed as an Accelerator Driven System (ADS), able to operate in subcritical and critical modes. MYRRHA will demonstrate the ADS concept intended for the efficient treatment of the high level nuclear waste through partitioning & transmutation. It will also fulfil the role of Experimental Technology Pilot Plant (ETPP) in the roadmap for the development of the lead fast reactor (LFR) technology, but its design integrates the function of multi-purpose flexible fast neutron spectrum research reactor (50-100 MWth). Its catalogue of applications includes R&D on the partitioning and transmutation of long-lived radioactive waste, the production of radioisotopes for medical applications and fundamental and applied research in support of the development of fast spectrum reactor and fusion safety and technology.

In the ESFRI Roadmap since 2010, MYRRHA will enter the Implementation Phase in 2019 and is expected to become gradually operational as of 2027.

BACKGROUND

In the framework of the European Sustainable Nuclear Industrial Initiative (ESNII), a R&D platform aiming to demonstrate Generation-IV Fast Neutron Reactor technologies, MYRRHA has been identified in 2010 as a major facility contributing to the EU's Strategic Energy Technology Plan (SET plan). Also the Nuclear Physics European Collaboration Committee (NuPECC), whose aim is to promote collaborative ventures between nuclear physicists within Europe, has selected ISOL@MYRRHA to be part of its long-range plan of the top facilities for nuclear physics in Europe.

MYRRHA is designed as a flexible fast spectrum irradiation facility. This means that a fast neutron spectrum is present at every location in the reactor and that every fuel assembly position can be loaded with a driver MOX fuel assembly,

a minor actinides fuel experimental assembly, a dedicated experimental rig for material irradiation or medical and industrial radioisotopes production rig. In this way, the entire reactor volume offers possibilities of loading experimental fuel assemblies in conditions similar to the reactor conditions, being a fast neutron spectrum, and in contact with the flowing liquid lead-bismuth at reactor operating temperatures. MYRRHA will also be able to host at least 8 in-pile sections (IPS) (representing a total volume of $8 \times 3,700 \text{ cm}^3$) with a core-loading pattern optimised to obtain the most appropriate irradiation conditions in the IPS. In this double-walled IPS, a different coolant (Na, NaK, He, H₂O) can be present with temperature and pressure conditions optimised for the experimental fuel/material loaded in the IPS. The R&D programme supporting the design of MYRRHA aims at validating solutions on the main design challenges: lead-bismuth liquid metal in reactor conditions, MOX fuel qualification, materials qualification, resilience of innovative components, reactor physics and modelling of fast and sub-critical cores.

STEPS FOR IMPLEMENTATION

The MYRRHA Preparatory Phase was successfully completed in 2016. The MYRRHA implementation plan involves three phases. The first phase consists in the construction of the 100 MeV accelerator, which is a fully modular infrastructure able to function independently as of 2026-2027, and generating scientific results and revenue. At the end of the first phase, a stage-gate decision is taken whether to proceed with phases 2 and 3 – the development of the accelerator upgrade to 600 MeV and the construction of the reactor – either sequentially, or in parallel.

A legal entity for the construction, the operation and the decommissioning of MYRRHA was identified. The plan is to set up MYRRHA as an AISBL under Belgian law. Important aspects such as the appropriate rules concerning nuclear liability and contractual liability of the MYRRHA consortium and its members were analysed in detail and included in an Intergovernmental Agreement document.

*THE VERY FIRST
PROTOTYPE OF MULTI-
PURPOSE HYBRID NUCLEAR
RESEARCH REACTOR FOR
HIGH-TECH APPLICATIONS*

TYPE

single-sited

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: BE
prospective member countries: CN, JP

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2010

TIMELINE

- **2010-2017**
Design Phase
- **2012-2018**
Preparation Phase
- **2019-2030**
Implementation/Construction Phase
- **2027**
Operation Start

ESTIMATED COSTS

capital value: 1.616 M€
design: 242 M€
preparation: 22 M€
construction: 1.352 M€
operation: 74 M€/year

HEADQUARTERS

Belgian Nuclear Research Centre - SCK-CEN
Mol, Belgium

WEBSITE

www.myrrha.be



BELGIUM

A LARGE SCALE MOBILE EXPERIMENTAL FACILITY TO BETTER MEASURE, MODEL AND EXPLOIT THE WIND AND ITS ENERGY RESOURCE

WindScanner

European WindScanner Facility

TYPE
distributed

LEGAL STATUS
pending

POLITICAL SUPPORT
lead country: DK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY
2010

TIMELINE

- 2012-2015
Preparation Phase
- 2016-2018
Interim/Transition Phase
- 2019-2021
Implementation/Construction Phase
- 2021
Operation Start

ESTIMATED COSTS
capital value: 20.5 M€
design: 8.5 M€
preparation: 5.9 M€
construction: 6.1 M€
operation: 2 M€/year

HEADQUARTERS
DTU Wind Energy
Roskilde, Denmark

WEBSITE
www.windscanner.eu



DENMARK

DESCRIPTION

The European WindScanner Facility (WindScanner) is set out to be a distributed Research Infrastructure for full scale atmospheric boundary-layer experimental research in wind and turbulence fields for wind energy. The WindScanner infrastructure builds upon recent advances in remote sensing-based technology developed on ground-based scanning wind lidars, able to measure and quantify the atmospheric wind fields and turbulence aloft. As well as being deployed onshore, the infrastructure can be operated offshore from stable and floating platforms or by doing measurement of near-coastal wind farms. WindScanner provides unique services for the scientific community and wind industry, a one-point of entry and a joint access programme, joint R&D development activities, joint training and educational programme, stable and effective management and a strategic approach for planning and implementing measurement campaigns in Europe.

In the ESFRI Roadmap since 2010, WindScanner is in the Interim Phase and has indicated the European Research Infrastructures Consortium (ERIC) as the legal form for the future.

BACKGROUND

Wind energy is about to become the leading electricity generating technology across Europe. In 2015, 43% of the electricity produced in Denmark came from wind energy. However, a massive increase in installed wind power capacity throughout Europe is still required to meet the political goals for this sustainable energy system. The energy system of the future must provide secure, affordable and climate-friendly energy, while at the same time creating new jobs and growth. Significant progress in lowering cost of energy (LCoE) has already been achieved, but there is still potential for cost reductions, through market development, research and innovation, for wind energy to reach its full potential. WindScanner is conceived as a new unique European distributed, mobile Research Infrastructure to provide the experimental data needed by the European wind energy's research community for high-quality full-scale atmospheric measurements of the wind fields surroundings today's huge wind turbines, wind farms, bridges, buildings, forests and mountains. The European WindScanner facility uses remote sensed

wind measurements from space and time synchronized scanners to provide detailed wind field maps of the wind and turbulence conditions from the individual turbine scale to entire wind farms extending several kilometres. Via excessive data analysis WindScanner provides detailed inflow and wake measurements for validation and verification of wind turbine design and siting and for future optimisation of design making wind energy become cheaper and more reliable for the benefit of the society.

WindScanners generate very detailed and huge amounts of data, which are challenging for researchers and other users to analyse and interpret. Therefore, in the forthcoming years, the WindScanner data acquisition and post processing needs to become faster accessible to users and the scanned 3D wind velocity data interpretation less complex. The WindScanner infrastructure has its primary use within the fields of measurements around large wind turbines, on and off shore. However, it also serves other purposes such as atmospheric boundary layer research, air safety, wind loads on buildings and bridges, wind circulation in streets and the urban environment in general.

STEPS FOR IMPLEMENTATION

WindScanner was included in the ESFRI Roadmap as a European joint effort to coordinate a network between distributed WindScanner systems and demonstration nodes embedded within leading European organizations for wind energy research. WindScanner ended the Preparatory Phase in 2015 with a Business Plan for the realization of the ERIC as agreed by the research institutions partners. Currently in the Interim Phase, WindScanner is aiming to be operational from 2021.

Once fully established, the WindScanner RI is expected to consist of 6-8 National Nodes throughout Europe, each node having its own portable rapid deployable short and/or long-range WindScanner System. The mobile distributed Research Infrastructure will be led from a WindScanner Central Hub located in Denmark, hosted by DTU. The participants are all partners of the European Energy Research Alliance (EERA) and the WindScanner vision is to develop a European Research Infrastructure underpinning the EERA Joint Programme on Wind Energy.

ACTRIS

Aerosols, Clouds and Trace gases Research Infrastructure

DESCRIPTION

The Aerosols, Clouds and Trace gases Research Infrastructure (ACTRIS) is a distributed infrastructure dedicated to high-quality observation of aerosols, clouds, trace gases and exploration of their interactions. It will deliver precision data, services and procedures regarding the 4D variability of clouds, short-lived atmospheric species and the physical, optical and chemical properties of aerosols to improve the current capacity to analyse, understand and predict past, current and future evolution of the atmospheric environment. ACTRIS serves a vast community of users working on observations, experiments, models, satellite data, analysis and predicting systems. It offers access to advanced technological platforms for exploration of the relevant atmospheric processes in the fields of climate change and air quality.

Included in ESFRI Roadmap in 2016, ACTRIS is striving to apply for the European Research Infrastructure Consortium (ERIC) in 2019.

BACKGROUND

Short-lived atmospheric components – aerosols, clouds, trace gases – have a residence time in the atmosphere from hours to few weeks. The short lifetimes make their concentrations highly variable in time and space and involve fast processes. They are recognised to be among the most significant anthropogenic pollutants affecting Earth's radiation balance and the largest source of uncertainty in terms of radiative forcing impact. In parallel, short-lived atmospheric compounds have recognized adverse health effects at concentrations typically found across Europe and potentially lead to more than 400.000 premature deaths annually in the EU28. Information on concentrations and distributions of aerosols and trace gases is therefore required to reduce air pollution and related adverse effects on health and ecosystems.

ACTRIS addresses these challenges by operating at National Facilities via a combination of measurements of aerosols,

clouds and reactive trace gases both near-surface and with remote-sensing systems, and ancillary measurements of meteorological and radiation quantities. ACTRIS National Facilities consist of both observational and exploratory platforms. ACTRIS relies on appropriate Central Facilities – Topical Centres for instrument calibration and development, Data Centre for data access services, data curation and storage, and Head Office for coordination and management of the RI – to provide harmonized, reliable, and documented observational data and physical access to high quality National Facilities. The Central Facilities are fundamental in providing the physical and remote access to the ACTRIS services, organising training and education, both within and outside the RI, and delivering tailored services for various user groups including scientific community, space agencies, COPERNICUS and the private sector. ACTRIS complements the Environmental RIs domain as it contributes data and services on atmospheric composition changes.

STEPS FOR IMPLEMENTATION

In the ESFRI Roadmap since 2016, ACTRIS is the result of the long-term collaboration within the atmospheric science community sustained by a series of INFRA projects that started in 2000. The aim of the full implementation plan is to set up a Research Infrastructure service system for the complex data-stream that starts at the National Facilities and goes through quality screening and higher level data products made available through the Data Centre, and finally to the repositories that will secure long-term and global access by a large community of users. ACTRIS also offers physical access to Topical Centres, selected observational sites and exploratory facilities for users to conduct their own research.

ACTRIS is now in the Preparation Phase and will gradually move into the Implementation Phase – foreseen in 2019/2024 – to be fully operational in 2025. Interim ACTRIS Council has decided to apply for the ERIC with the aim to submit ERIC Step 1 application in early 2019.

*GROUND-BASED STATIONS
TO UNDERSTAND PAST,
PRESENT AND PREDICT
FUTURE EVOLUTION OF
THE ATMOSPHERE*

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: FI

prospective member countries:
AT, BE, BG, CH, CY, CZ, EL, ES, FR, IT, NL,
NO, PL, RO, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2016

TIMELINE

● **2016-2019**

Preparation Phase

● **2019-2024**

Implementation/Construction
Phase

● **2025**

Operation Start

ESTIMATED COSTS

capital value: 450 M€

design: 3 M€

preparation: 6 M€

construction: 190 M€

operation: 50 M€/year

HEADQUARTERS

University of Helsinki and Finnish -
Meteorological Institute
Helsinki, Finland &
Consiglio Nazionale delle Ricerche - CNR
Rome, Italy

WEBSITE

www.actris.eu



AN INTERDISCIPLINARY
RESEARCH AND
INNOVATION
INFRASTRUCTURE FOR
RIVER-SEA SYSTEMS

DANUBIUS-RI

International Centre for Advanced Studies on River-Sea Systems

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: RO

prospective member countries:

AT, BG, CZ, DE, EL, ES, IT, MD, NL, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2016

TIMELINE

● 2016-2019

Preparation Phase

● 2012-2022

Implementation/Construction Phase

● 2022

Operation Start

ESTIMATED COSTS

capital value: 300 M€

design: Not Available

preparation: 2 M€

construction: 222 M€

operation: 28 M€/year

HEADQUARTERS

DANUBIUS-RI

Murighiol, Romania

WEBSITE

www.danubius-ri.eu



ROMANIA

DESCRIPTION

The International Centre for Advanced Studies on River-Sea Systems (DANUBIUS-RI) is a distributed Research Infrastructure to enable excellent interdisciplinary research and innovation on River-Sea (RS) systems. It spans the environmental, social and economic sciences and brings together research on different environmental sectors. European research on RS systems and their transitional environments is world-leading but fragmented, largely discipline-specific and often geographically isolated. DANUBIUS-RI will draw on existing research expertise across Europe, enhance the impact of European research and maximise the return on investment. It will provide access to a range of European RS systems, facilities and expertise; a *one-stop-shop* for knowledge exchange in managing RS systems; access to harmonised data; and a platform for interdisciplinary research, inspiration, education and training.

In the ESFRI Roadmap since 2016, DANUBIUS-RI is in the Preparatory Phase. Operations are expected to start in 2022.

BACKGROUND

Surface waters are central in global biogeochemical cycles, food and energy production, and societal wellbeing. Biodiversity hotspots at the interface between land and water provide essential ecosystem services and face natural and anthropogenic environmental perturbations at local and global scales. However, the nature of RS systems and their transitional environments and the lack of interdisciplinary Research Infrastructures has contributed to fragmentation of research.

DANUBIUS-RI – named from the world's most international river – covers the RS continuum with a focus on transitional environments, such as estuaries, deltas and the interface with groundwater, and rectifies this fragmentation. The Research Infrastructure will comprise a Hub and a Data Centre in Romania, a Technology Transfer Office in Ireland, and Supersites and Nodes across Europe. The Hub will provide leadership, coordination, and

key scientific, educational and analytical capabilities. Supersites are designated natural sites for observation, research and modelling at locations of high scientific importance across a range of European RS systems. Supersites are: the Danube Delta (RO), Middle Danube (HU), Upper Danube (AT), Nestos (EL), Elbe Estuary (DE), Thames Estuary (UK), Ebro-Llobregat Deltaic System (ES), Po Delta-North Adriatic Lagoons (IT), Guadalquivir Estuary (ES), Tay Catchment (UK), Rhine/Meuse Delta (NL) and Mid Rhine (DE). Nodes are centres of expertise providing facilities and services, data storage and provision, experimental and *in situ* measurements facilities, state-of-the-art analytical capabilities and implementation of standardised procedures and quality control (DANUBIUS Commons). Leading Institutions for the Nodes are in the UK (Observation), Germany (Analysis), Italy (Modelling) and Netherlands (Impact). Additional needs will be met by Accredited Service Providers, under the coordination of the Institutions, thus increasing research capability and capacity across Europe.

STEPS FOR IMPLEMENTATION

DANUBIUS-RI has received political support from fourteen partner countries in Europe, four of which have already made financial commitments, and expressions of support from organisations in 16 other countries in Europe, Africa, Asia, and North America. DANUBIUS-RI has been designated a flagship project of the EU Strategy for the Danube Region.

The initial part of the Hub was inaugurated in September 2015. The Preparatory Phase work is to bring DANUBIUS-RI to the level of legal, financial, and technical maturity for implementation. This includes: further involvement with partners and stakeholders to develop the Nodes, Supersites and other components; seeking political support from additional countries; development of the DANUBIUS Commons; engagement with national funding bodies; application for Structural Funds; and development of ERIC statutes. The aim is to achieve the European Research Infrastructure Consortium (ERIC) status and become operational by 2022.

DiSSCo

Distributed System of Scientific Collections

DATA-INTENSIVE FRONTIER RESEARCH THROUGH UNIFIED ACCESS TO EUROPEAN NATURAL SCIENCE COLLECTIONS

DESCRIPTION

The Distributed System of Scientific Collections (DiSSCo) is a new pan-European Research Infrastructure with the vision to place European natural science collections at the centre of data-intensive scientific excellence and innovation for taxonomic and environmental research, food security, health, and the bioeconomy. DiSSCo mobilises, links and delivers currently fragmented biodiversity and geodiversity information at a scale, form and precision required, tooling scientists to address major challenges of the Anthropocene.

The new RI introduces a step change by massively improving the capacity of scientists to discover, access and analyse complex and previously disjointed information deriving from the study of the vast European natural science collections.

BACKGROUND

Natural science collections are an integral part of the global natural and cultural capital. They include hundreds of millions of animals, plants, fossils, rocks, minerals and meteorites, which account for 55% of the natural sciences collections globally and represent 80% of the world biodiversity and geodiversity. Data derived from these collections underpin countless innovations, including tens of thousands of scholarly publications and official reports – supporting legislative processes relating to health, food security, sustainability and environmental change; inventions and products critical to our bioeconomy, databases, maps and descriptions of scientific observations, instructional material for education, and informational material for the public.

DiSSCo directly addresses the current fragmentation of European collections, by transforming a network of institutions into a coherent RI: a *one-stop-shop* for European collections, collection data and associated expertise. DiSSCo unifies

115 leading natural science collection facilities in 21 countries and has a concrete plan for further expansion. DiSSCo will deploy its service portfolio under four classes and for a broad range of users: i) e-science services – unified discovery, access, interpretation and analysis of complex linked biodiversity and geodiversity data, through a single-entry point; ii) transnational and remote access – universal pan-European physical access and digitisation-on-demand services for all major European collections; iii) support & training – integrated user support desk and open multi-modal training programmes to enhance digital skills across users; iv) Joint Research Programming – prioritisation and support of data-driven innovation-led joint programmes, building on the combined capacity of hundreds of European institutions.

STEPS FOR IMPLEMENTATION

DiSSCo represents the outcome of significant scientific and socio-technical investments, started in 2004, enabling to design a pan-European RI, which unifies European natural collections into a single virtual organisation. Such infrastructure would massively widen the scientific reach of data linked to collections and leverage the impact of distributed facilities.

The European natural science collections develop DiSSCo as an integrated RI to provide unified access and analysis services, building on the super-advanced community – the CETAF network – and on multiple previous access programmes – e.g. SYNTHESIS. Since 2016, DiSSCo has engaged with strong scientific, managerial and technical leaders to prepare for its implementation plan. Each of the DiSSCo national nodes will identify complementary thematic priorities, relevant to the delivery of the DiSSCo service portfolio, ensuring alignment to national Strategies for Smart Specialisation (RIS3), and in support of a knowledge-driven regional growth.

TYPE
distributed

LEGAL STATUS
pending

POLITICAL SUPPORT
lead country: NL
prospective member countries: BE, BG, DK, EE, EL, FR, IT, PT, SK, UK
The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY
2018

TIMELINE

- 2004-2017
Design Phase
- 2018-2022
Preparation Phase
- 2020-2025
Implementation/Construction Phase
- 2025
Operation Start

ESTIMATED COSTS
capital value: 420.3 M€
design: 10.7 M€
preparation: 20.2 M€
construction: 69.4 M€
operation: 12.1 M€/year

HEADQUARTERS
to be defined

WEBSITE
www.dissco.eu



WHOLE-SYSTEM APPROACH
IN INVESTIGATING THE
FUNCTIONING OF EUROPEAN
BENCHMARK ECOSYSTEMS
UNDER GLOBAL CHANGE

TYPE
distributed

LEGAL STATUS
pending

POLITICAL SUPPORT
lead country: DE
prospective member countries:
AT, CH, EL, ES, FI, FR, IL, IT, LV, PL, PT, RO,
RS, SI, SK, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY
2018

TIMELINE

- **2015-2019**
Design Phase
- **2019-2021**
Preparation Phase
- **2021-2026**
Implementation/Construction Phase
- **2026**
Operation Start

ESTIMATED COSTS

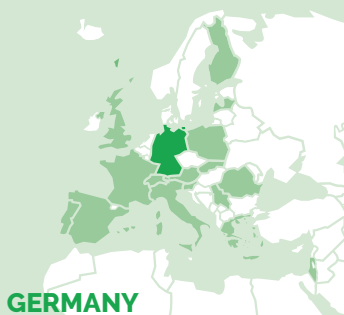
capital value: 119 M€
design: 6,4 M€
preparation: 5 M€
construction: 94 M€
operation: 35 M€/year

HEADQUARTERS

Helmholtz Centre for
Environmental Research - UFZ
Leipzig, Germany

WEBSITE

www.lter-europe.net



eLTER

Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure

DESCRIPTION

The Integrated European Long-Term Ecosystem, critical zone and socio-ecological system Research Infrastructure (eLTER) is a new distributed Research Infrastructure which aims at integrating traditional natural sciences and holistic ecosystem research approaches, including studies of the human component, to better understand ecosystems. Through research and monitoring, eLTER seeks to improve our knowledge of the structure and functions of ecosystems and their long-term response to environmental, societal and economic drivers.

eLTER will provide indispensable integrated data sets – abiotic, biotic, societal, covering all system structures and functions – for system model development and validation, hence supporting predictions and decision-making in an interdisciplinary framework and in collaboration with other *in situ*, domain specific RIs.

eLTER contributes to the knowledge base informing policy and to the development of management options in response to the *Grand Challenges*.

BACKGROUND

In a world of global *Grand Challenges*, multiple stressors act at different temporal and spatial scales with significant losses of biodiversity and ecosystem functions that eventually affect human life. While in the short-term such effects are well studied, little is known about long-term and systemic effects and cross-scale interactions. Closing these knowledge gaps requires a deep understanding of the multifaceted environmental system in order to develop appropriate mitigation measures. eLTER features a unique integrated system approach in a nested design, allowing for interdisciplinary natural science research as well as investigating human/environment/systems at landscape scales. The design of the eLTER is guided by two overarching scientific concepts, applicable from point to continental scales: the Press Pulse Dynamic Model as *horizontal* component, and the spatially-nested hierarchical feedback paradigm of Macrosystems Ecology as a *vertical* component.

eLTER comprises: *in situ*, long-term, cross-disciplinary, multiple-use, large-scale coverage of major European socio-ecological systems. The aim is to secure scientific excellence through the highest quality interoperable services in close interaction with related European and global RIs. This implies both increased research quality through scientific cross-disciplinary synthesis at the system level – including human-environment interactions – and quantity in terms of the number of appropriately designed and equipped research sites. eLTER will contribute to the European environmental RI landscape by building up a pan-European network of long-term ecological research sites.

The design at the European and national level secures full complementarity with the related environmental *in situ* RIs like ICOS ERIC, AnaEE, DANUBIUS-RI and ACTRIS, and e-RIs such as LifeWatch ERIC and DiSSCo.

STEPS FOR IMPLEMENTATION

eLTER has evolved via flagship projects – e.g. ALTER-Net NoE, EnvEurope, ExpeER, and eLTER H2020 – and was cited as *emerging project* in the ESFRI Roadmap 2016. Based on this results, the EU-funded Advance_eLTER project elaborated a design and implementation plan for the submission to the Roadmap 2018.

The first stage of eLTER will be implemented based on an existing very large network of LTER sites – about 400 formally acknowledged ecosystem research sites and 35 LTSER Platforms for socio-ecological research operated by about 150 institutions. The eLTER design defines a hierarchy of sites, with major nodes playing a main role in driving scientific innovation and other sites focussing on data-provisioning and pan-European coverage. This mixed mode of operation will allow eLTER to play an important integrating role for policy-makers. The most important milestones for the planned Preparatory Phase are locations of the Central Services and establishment of the legal entity which is expected in 2026.

AnaEE

Infrastructure for Analysis and Experimentation on Ecosystems

DESCRIPTION

The Infrastructure for Analysis and Experimentation on Ecosystems (AnaEE) is a distributed Research Infrastructure designed to provide the knowledge needed to support a sustainable future. This infrastructure aims, through state-of-the-art experimental facilities, to support scientists in testing the potential impacts of climate change and land use in Europe, and forecasting the risks on European ecosystems, including agricultural systems. AnaEE will thus enable policy-makers, scientists and the industry to develop climate mitigation strategies and provide solutions to the challenges of food security, with the aim of stimulating the growth of a vibrant bio-economy.

In the ESFRI Roadmap since 2010, AnaEE is expected to become a European Research Infrastructure Consortium (ERIC) and start operations in 2019.

BACKGROUND

The sustainability of agricultural, forested, freshwater and other managed and natural ecosystems is critical for the future of mankind. However, the services provided by these ecosystems are under threat due to climate change, loss of biodiversity, and land-use changes. In order to meet the challenges of preserving or improving ecosystems services, securing food supply and building a 21st century bio-economy, we need to understand and forecast how ecosystems will respond to current and future changes including new management approaches and potential environmental tipping points. Without sufficient understanding of the sensitive interdependencies between ecosystems and the environment, Europe will be unable to assess the impacts, control the risks, or potentially utilize the benefits of anticipated large changes in ecosystems structure and function, for the production of nutritious food and goods which are environmentally sustainable and in balance with growing energy demands. Key benefits will include greenhouse gas mitigation and climate adaptation.

AnaEE will adopt an experimental approach built around ecosystems manipulation, measurements, modelling,

mitigation and management. At the core of AnaEE's approach are the distributed experimental facilities needed to expose ecosystems to potential conditions to produce results that will inform predictive models and deliver realistic simulations. AnaEE research has to be process-oriented and address how major biogeochemical cycles, biodiversity and the relationship between biodiversity and ecosystem functions, including agricultural systems' function, will change under the various experimental drivers. The AnaEE experimental facilities will be equipped with state-of-the-art instrumentation and Information Technology Tools and will use common standards of measurements and analysis. AnaEE provides a nexus between the environment and food domains, and aims to cover the greatest number of ecosystem types, soil types, pressures and other factors in terms of experimentation on terrestrial and freshwater ecosystems. The infrastructure will include open-air and enclosed experimental platforms as well as analytical and modelling platforms.

STEPS FOR IMPLEMENTATION

AnaEE is currently in the Implementation Phase with six countries – France, Belgium, Czech Republic, Denmark, Israel and Italy. Additional countries are expected to join in 2018. The infrastructure coordination with its Central Hub has been attributed to France. The Technology Centre has been attributed to Denmark, the Interface and Synthesis Centre to Czech Republic and the Data and Modeling Centre to Italy. The application for the ERIC has been submitted in 2018 and the recruitment of the AnaEE Director General is ongoing.

The coordination and integration of the national platforms, through the Hub and centres will ensure international access, improved measurements and data harmonization, technology development, links between data and models, open access to raw data and syntheses. The Research Infrastructure will be based on distributed advanced experimental platforms that are sustainably funded and responding to a number of key commonly agreed-upon criteria in terms of quality and state-of-the-art equipment.

*INTEGRATED
EXPERIMENTATION TO
FORECAST THE IMPACTS OF
CLIMATE AND LAND-USE
CHANGES ON ECOSYSTEMS*

TYPE

distributed

LEGAL STATUS

ERIC Step1, 2018

POLITICAL SUPPORT

lead country: FR
prospective member countries: BE, CZ, DK, IL, IT

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2010

TIMELINE

- 2007-2010**
Design Phase
- 2012-2016**
Preparation Phase
- 2016-2018**
Implementation/Construction Phase
- 2019**
Operation Start

ESTIMATED COSTS

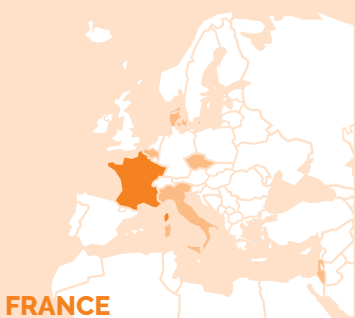
capital value: 337 M€
design: 1.2 M€
preparation: 4.7 M€
construction: 1.1 M€
operation: 0.8 M€/year

HEADQUARTERS

Institut National de la Recherche
Agronomique - INRA
Paris, France

WEBSITE

www.anaee.com



FRANCE

A MULTI-SCALE
PHENOTYPING PLATFORM
FOR FOOD SECURITY IN
DIFFERENT AGRO-CLIMATIC
SCENARIOS

TYPE
distributed

LEGAL STATUS
pending

POLITICAL SUPPORT
lead country: DE
prospective member countries:
BE, CY, CZ, FR, IE, IT, NL, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY
2016

TIMELINE

- **2017-2020**
Preparation Phase
- **2020-2021**
Implementation/Construction Phase
- **2021**
Operation Start

ESTIMATED COSTS
capital value: 160 M€
design: Not Available
preparation: 4 M€
construction: 73 M€
operation: 3.6 M€/year

HEADQUARTERS
Forschungszentrum Jülich
Jülich, Germany &
Institut National de
la Recherche Agronomique-INRA
Montpellier, France

WEBSITE
<https://emphasis.plant-phenotyping.eu/>



EMPHASIS

European Infrastructure for Multi-scale Plant Phenomics and Simulation

DESCRIPTION

The European Infrastructure for Multi-scale Plant Phenomics and Simulation (EMPHASIS) is a distributed Research Infrastructure to develop and provide access to facilities and services addressing multi-scale phenotyping in different agro-climatic scenarios. EMPHASIS will establish an integrated European phenotyping infrastructure to analyse genotype performance under diverse environmental conditions and quantify the diversity of traits contributing to performance in diverse environmental scenario – plant architecture, major physiological functions and output, yield components and quality. EMPHASIS aims to address the technological and organizational limits of European Phenotyping, for a full exploitation of genetic and genomic resources available for crop improvement in changing climate.

Inserted in the ESFRI Roadmap in 2016, EMPHASIS is expected to enter the Implementation Phase in 2020 and become operational in 2021.

BACKGROUND

Sustainable intensification of crop production is a major challenge to ensure amount and quality of biomass for nutrition and industry. Designing high yielding crop varieties adapted to contrasting environmental conditions, climate change and management, is a priority. Technological advancements have boosted the characterisation of genomes, without sufficient development in phenotypic characterisation. The mission of EMPHASIS addresses an important bottleneck in sustainable and improved crop production in different, current and future, agro-climatic scenarios: how to translate from high-throughput genotypic analysis of crop variants to high-throughput and high-resolution phenotyping in order to identify high-yield crop varieties for defined environmental conditions. To achieve this, EMPHASIS proposes a major upgrade/reorientation of existing European Research Infrastructure by linking and developing national initiatives, amongst which are national platforms with (semi)-controlled conditions

for high-resolution phenotyping and high-throughput phenomics, experimental fields with control of rainfall and CO2 highly-equipped with phenotyping devices, a coordinated network of field experiments in distributed sites with lighter but efficient phenotyping close to practical breeding set-ups and modelling platforms to test existing and virtual combinations of alleles in different climates and management practices. Some methods used will include sensors and imaging in plant architecture and dynamics, consistent distributed information system, and statistics and dynamic modelling.

EMPHASIS can test genotypes in current and future agro-climatic scenarios and provide community access to controlled and field conditions; link data acquisition to a European data management and to crop models simulating performance in current and future climates; develop, evaluate and disseminate novel technologies and provide new opportunities to European companies and make infrastructures and concepts accessible to academia and industry in Europe.

STEPS FOR IMPLEMENTATION

The Preparatory Phase of EMPHASIS started in 2017 to bring the project to the level of legal, financial, and technical maturity required for implementation. EMPHASIS PP provide the basis for the establishment of the legal framework, the business plan and the preparation of an information system for a sustainable and innovative pan-European infrastructure for plant phenotyping. Actually, political support and commitment to EMPHASIS has been expressed by nine European countries in the form of previous investments and an additional investment from Germany. EMPHASIS has already committed 49 M€ (67%) of the total cost until full establishment in the next five years. EMPHASIS is already placing Europe in a leading position via the International Plant Phenotyping Network, and has already engaged further Member States in their current plans. It is timely that this is secured in a long-term, sustainable pan-European Research Infrastructure filling an important gap in the Health & Food landscape.

EU-IBISBA

European Industrial Biotechnology Innovation and Synthetic Biology Accelerator

DESCRIPTION

The Industrial Biotechnology Innovation and Synthetic Biology Accelerator (EU-IBISBA) is a distributed Research Infrastructure aiming at supporting research in industrial biotechnology (IB) by providing access to first class facilities for all industrial biotechnology professionals, including academic researchers, SMEs and large companies. EU-IBISBA will operate in a multidisciplinary environment developing translational research in industrial biotechnology and developing the synthetic biology discipline. These areas derive from underpinning knowledge from biochemistry, microbiology, genetics, mathematics, computational science, and engineering disciplines such as chemical and process engineering, which will be in large part drawn from European infrastructures dedicated to more basic research.

EU-IBISBA will provide a research nexus for biology researchers and chemical engineers, favouring the connection of different knowledge domains, and providing a hub for public-private collaboration. EU-IBISBA will form a perfect environment for education and training of biotechnologists and entrepreneurs.

BACKGROUND

Industrial biotechnology is the convergence of numerous scientific and engineering disciplines to provide biocatalysts and bioprocesses for the production of a wide variety of goods. Currently, synthetic biology promises to revolutionise industrial biotechnology using advanced techniques, including genome engineering for the construction of biocatalysts, especially microbial cell factories. However, to realize this promise and accelerate the development of advanced bioprocesses for a wide range of manufacturing sectors it is necessary to address numerous challenges linked to the application of process design specifications and engineering principles to complex biological systems.

EU-IBISBA will support this learning process, providing academics and the private sector with the infrastructure for the development and testing of innovation pipelines, beginning at TRL2 and moving

upwards to TRL6, a range that corresponds to the so-called innovation valley of death. It will provide the infrastructure framework for translational research services and innovation in the area of IB. Its mission is to support the maturation of synthetic biology within the focused framework of end-to-end bioprocess development, using engineering principles to achieve industrial process fitness by design.

EU-IBISBA will provide innovation in areas such as computer-assisted design of biocomponents, biocatalysts and bioprocesses, from their early stage construction and proof-of-concept to pilot phase testing of integrated bioprocesses. EU-IBISBA will cover a range of technology areas, including downstream processing and multi-performance analyses. It is expected that EU-IBISBA will accelerate innovation for subsequent translation into goods and services for a wide range of sectors including energy (e.g. liquid biofuels), chemicals (e.g. organic acids), materials (e.g. bioplastics) and ingredients for the food, feed, cosmetics and pharma sectors (e.g. enzymes, antioxidant and antibiotics).

STEPS FOR IMPLEMENTATION

EU-IBISBA is built on a long-term collaboration between the consortium partners in international, mostly EU-funded projects – BIOCORE, NANO3BIO e RENESING – and as the result of the successful deployment of facilities in several European countries, in particular the case of INRA's Toulouse White Biotechnology facility. In July 2017, the consortium MoU has been signed by partner institutions from 9 European countries. EU-IBISBA was the object of ESFRI assessment in 2016, which has provided the basis for the maturation of a new proposal built through stakeholder meetings, one-to-one discussions with industrial partners and the IBISBA 1.0 project, a H2020 Integrating Activities for Starting Communities project.

Currently in its Design Phase, EU-IBISBA reflects the necessity to provide Europe with a Research Infrastructures that will be competitive in the international arena facing US and China in industrial biotechnology.

AN ACCELERATOR
FOR RESEARCH AND
INNOVATION IN INDUSTRIAL
BIOTECHNOLOGY AND
SYNTHETIC BIOLOGY

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: FR

prospective member countries:
EL, ES, FI, IT, NL

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2018

TIMELINE

- **2018-2019**
Design Phase
- **2019-2022**
Preparation Phase
- **2022-2025**
Implementation/Construction Phase
- **2025**
Operation Start

ESTIMATED COSTS

capital value: 52.6 M€
design: 3 M€
preparation: 4 M€
construction: 1.1 M€
operation: 65.1 M€/year

HEADQUARTERS

Institut National Des Sciences
Appliquées - INSA
Toulouse, France

WEBSITE

www.ibisba.eu



FRANCE

A COORDINATION EFFORT
TO INTERCONNECT THE
BEST EXPERIMENTAL AND
MODELLING FACILITIES FOR
SYSTEMS BIOLOGY

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT**lead country:** pending**prospective member countries:**
IT, SI

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2010

TIMELINE

- **2012-2015**
Preparation Phase
- **2016-2019**
Implementation/Construction Phase
- **2019**
Operation Start

ESTIMATED COSTS**capital value:** Not Available**design:** Not Available**preparation:** 4.7 M€**construction:** 10 M€**operation:** 5.2 M€/year**HEADQUARTERS**University of Naples Federico II
Naples, Italy**WEBSITE**<http://project.isbe.eu/>

ISBE

Infrastructure for System Biology Europe

DDESCRIPTION

The Infrastructure for Systems Biology Europe (ISBE) is a distributed Research Infrastructure that enables efficient access to the best expertise, resources and services, such as model building, fit-for-modelling data, tools and training in systems biology. ISBE is built on national strengths, through a matrix of interconnected national systems biology centres, and makes them easily accessible for all European researchers. ISBE will set, improve and promote standardisation of biological data, tools and models as well as operating procedures, ensuring that resources from different laboratories, countries and sectors can be integrated and become re-usable. ISBE play a key role in enhancing the European bio-economy by providing resources and services to academia, industry and the public sector to deliver solutions that address *Grand Challenges* in healthcare, food production, quality of life, and sustainable bio-energy.

Included in the ESFRI Roadmap 2010, ISBE is planning to apply for the European Research Infrastructure Consortium (ERIC) legal framework.

BBACKGROUND

Biological processes are the result of complex dynamic interactions within and between molecules, cells, organs and entire organisms. Systems biology integrates multiple and diverse data sets in predictive computational models, which allow multi-scale exploration of biological systems. This requires combining biological and biomedical data and expertise with knowledge and technologies from the fields of mathematics, computer science, physics and engineering. National governments and the European Commission have recognised the importance of systems biology and have invested in it over the past ten years.

ISBE adds value to national and European investments by offering open access to expertise, resources and training through its matrix of national systems

biology centres. The core of ISBE is a pan-European network of interconnected national Systems Biology Centres (nSBCs). Together they will span the wide spectrum of systems biology expertise in health, agriculture, biotech and other branches of the life sciences in academia, hospitals and industry. Each nSBC will be embedded within its national research community and linked to a central coordinating hub (CIO).

The expertise, resources and services that are offered by nSBCs cover the three tightly related expertise domains of ISBE: i) modelling, ii) stewardship and standardisation and iii) model-compliant data generation. In ISBE, the Data Integration Centres are particularly reliant on being able to identify data from suitable physiological conditions that can be incorporated into models. The Data Generation and Stewardship Centres can streamline this process by providing standard formats and interfaces for access, storage and exchange.

STEPS FOR IMPLEMENTATION

ISBE ended its Preparatory Phase in July 2015. The project was coordinated by the Imperial College London and executed by a Steering Committee with representatives from 23 research institutions and funding bodies from 11 countries. During the Preparatory Phase, ISBE played a key role to link various expertise and technologies into an integrated project and establishing connections with various other ESFRI RIs in a meaningful way – for example allowing the creation of computer models which integrate both *omics* data from existing Research Infrastructures in the area of life sciences and health.

During the Construction Phase, ISBE has started to deliver web-based services for: i) development of experimental and computational facilities for systems metabolomics; ii) modelling, stewardship of research assets – through FAIRDOM; and iii) training – continuing activities of ERASyAPP. Building phase activities are based on *in-kind* and *in-cash* contributions from members of the Consortium.

**PENDING**

METROFOOD-RI

Infrastructure for Promoting Metrology in Food and Nutrition

DESCRIPTION

The Infrastructure for promoting Metrology in Food and Nutrition (METROFOOD-RI) is a new distributed Research Infrastructure aimed to promote scientific excellence in the field of food quality and safety. It provides high-quality metrology services in food and nutrition, comprising an important cross-section of highly interdisciplinary and interconnected fields throughout the food value chain, including agrifood, sustainable development, food safety, quality, traceability and authenticity, environmental safety, and human health.

METROFOOD-RI consists of a physical infrastructure (P-RI) and an electronic infrastructure (e-RI) to coordinate and integrate existing networks of plants, laboratories, experimental fields/farms for crop production/animal breeding, small-scale plants for food processing and storage, kitchen-labs for food preparation. The e-RI will make available an access platform to share and integrate knowledge and data on metrological tools for food analysis, focusing on food composition, nutritional contents, levels of contaminants and markers.

BACKGROUND

The agri-food sector is a strategic asset of all the European Countries and one of the largest and most important economic activities, with particular social relevance: it is vital to ensure employment, preserve rural public goods, supply healthy and quality food, and facilitate the integration of SMEs into the international food chain. Food quality and authenticity have now become a focus of consumer's requirements all over the world. Food traceability and safety are key factors to ensure food quality and to protect consumers' interests. In particular, food safety represents one of the most important elements of public health policies at a global level. High-quality data on the food chain are of fundamental importance to populate the expanding data technologies with useful contents and, according to the FAIR principles, enable advanced

research on food and food metrology.

METROFOOD-RI mission is to enhance quality and reliability of measurement results and make available and share data, information and metrological tools, in order to enhance scientific excellence in the field of food quality and safety and strengthen scientific knowledge, also promoting scientific cooperation and to integration. The general objective is to enhance scientific cooperation and encourage interaction between the various stakeholders, as well as the creation of a common and shared base of data, information and knowledge. The scientific offer is addressed to a broad set of users and stakeholders, such as: public and private labs and groups engaged in research activities for food data collection and measurement reliability and basic frontier research in food and nutrition; Food Business Operators and producer associations; policy makers, food inspection and control agencies; consumers/ consumer associations and citizens.

STEPS FOR IMPLEMENTATION

METROFOOD-RI was cited as *emerging project* in the ESFRI Roadmap 2016 and in 2017 completed its Early Phase upon the EU-funded PROMETROFOOD project. During this phase, METROFOOD-RI has performed a detailed Design and Feasibility Study, including an inventory of the available facilities, an analysis of the physical-RI and e-RI services, the development of two pilot services, Quality Systems and Data Management Plans, an analysis of users and stakeholders, a users' strategy and access policy, and plans for training.

The main objectives for the planned Preparatory Phase are to attain firm additional MS/AC commitments, to better align governance and financial management models, and to set up all the legally binding agreements necessary to establish the ERIC status. The Implementation Phase is planned to start in 2021, with full operation foreseen for 2024.

HIGH-LEVEL METROLOGY SERVICES IN FOOD AND NUTRITION FOR THE ENHANCEMENT OF FOOD QUALITY AND SAFETY

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: IT
prospective member countries: CH, CZ, EL, MD, MK, PT, RO, SI, TR
The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2018

TIMELINE

- **2015-2017**
Design Phase
- **2018-2021**
Preparation Phase
- **2021-2024**
Implementation/Construction Phase
- **2019**
Operation Start

ESTIMATED COSTS

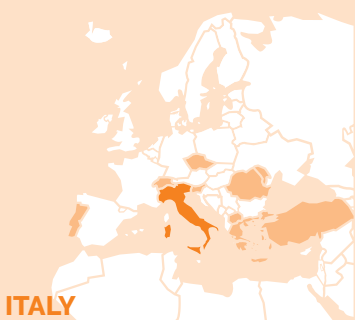
capital value: 102.4 M€
design: 4.6 M€
preparation: 48.3 M€
construction: 78.8 M€
operation: 31 M€/year

HEADQUARTERS

Agenzia Nazionale per le nuove tecnologie, l'Energia e lo sviluppo economico sostenibile - ENEA
Rome, Italy

WEBSITE

www.metrofood.eu



ITALY

A COORDINATED
PLATFORM TO MANAGE
MICROBIAL RESOURCES
TO SUPPORT RESEARCH IN
BIOTECHNOLOGY

TYPE
distributed

LEGAL STATUS
pending

POLITICAL SUPPORT
lead countries: ES, PT
prospective member countries:
BE, EL, FR, LV, NL, PL
The full list of research institutions
involved must be found in the website
of the RI

ROADMAP ENTRY
2010

TIMELINE

- **2012-2016**
Preparation Phase
- **2017-2019**
Implementation/Construction
Phase
- **2021**
Operation Start

ESTIMATED COSTS
capital value: Not Available
design: Not Available
preparation: 3.1 M€
construction: 0.8 M€
operation: 0.7 M€/year

HEADQUARTERS
University of Minho
Braga, Portugal

WEBSITE
www.mirri.org



MIRRI

Microbial Resource Research Infrastructure

DESCRIPTION

The Microbial Resource Research Infrastructure (MIRRI) is the pan-European distributed Research Infrastructure for microbial resources. MIRRI serves public and private bioscience users by facilitating access to a broad range of high quality bioresources and data in a legal compliant way. The MIRRI partners strive to alleviate the fragmentation of bioresource holdings and expertise, to deliver fit-for-purpose microbial material, to add value to microbial diversity, and to discover and preserve the yet unknown or uncultivated microorganisms. MIRRI cooperates with its users and other RIs to exploit the microbial diversity to the benefit of the bioeconomy. The materials and services will be provided by partners in MIRRI member countries, coordinated by their national nodes. Users will be able to easily search MIRRI services and make requests on the MIRRI access portal.

In the ESFRI Roadmap since 2010, MIRRI is striving to establish the European Research Infrastructure Consortium (ERIC) by 2019.

BACKGROUND

Microbial resources have been recognised as essential raw materials for the advancement of health and for biotechnology, agriculture, food technology and research in the life sciences. To date, less than 1% of the estimated number of species are described and available to be harnessed by man and less than 0.1% of prokaryote strains published in the scientific literature were deposited in public service collections or mBRCs or simply retained for future study and use. About 0.5 million strains are supplied each year by collections registered with the World Data Centre for Microorganisms (WDCM). It is estimated that 70% of strains used in published research are not coming from collections, thus tens of thousands resource strains are sourced for research often without proper authentication and provenance.

MIRRI will provide a wealth of additional information and linking to datasets such as literature, environmental data, sequences and chemistry that will facilitate

scientists to select organisms suitable for their research and enable innovative solutions to be developed. MIRRI will support researchers from academia and bio-industry offering a facilitated access to genetic resources via the envisioned MIRRI portal – a *one-stop-shop* for material, data and expertise; broader coverage of genetic resources – coordinated approach towards isolation and deposit of microorganisms; improved tailored service offer from mBRCs also coordinating smaller collections, interoperability of data – facilitated mining of trusted data, increase knowledge transfer to users and implementation of best practices for transition to a mBRC.

By offering long-term deposition of raw material of high scientific and economic value for basic research and innovation in biotechnology, MIRRI will contribute to the H2020 societal challenge to improve health, food security, agriculture, forestry, marine and maritime and inland water research and to address aspects of clean and efficient energy.

STEPS FOR IMPLEMENTATION

MIRRI was included in the ESFRI Roadmap 2010 and the Preparatory Phase was conducted in 2012-2016. Recently it was decided that the statutory seat of MIRRI ERIC will be located in Portugal (University of Minho, Braga) while the Collaborative Working Environment Hub will be operated from Spain (University of Valencia, Paterna) in cooperation with LifeWatch-Spain, a closely related e-Infrastructure. It is envisaged to submit the Step 1 application for the establishment of MIRRI ERIC in Autumn 2018 in order to have the official inauguration of MIRRI ERIC in 2019.

The Assembly of Members shall be the decision-making body of MIRRI ERIC. Those decisions shall be implemented by the Executive Director, assisted by the staff of the Central Coordinating Unit. The National Coordinators Forum will support the Executive Director with the development of annual work programmes and budgets and will ensure efficient interaction between MIRRI ERIC and the national mBRCs.

EST

European Solar Telescope

AN ADVANCED TELESCOPE
FOR OBSERVING THE
SUN AND ITS MAGNETIC
ACTIVITY

DESCRIPTION

The European Solar Telescope (EST) is a 4-metre class telescope dedicated to study the fundamental processes in the Sun that control the solar atmosphere and its activity and the physical conditions in the heliosphere. EST will be optimized for high-resolution multi-wavelength simultaneous multi-instrument observations of the photosphere and chromosphere, as well as magnetic structures therein. One aim is to address the still unresolved and difficult question concerning the emergence of magnetic fields at the solar surface and transfer of magnetic and kinetic energy from subsurface layers to the solar atmosphere. This is the key question for understanding how the magnetic field is controlling the solar atmosphere and its activity. As the Sun is the only star at which photospheric and chromospheric features can be resolved, these observations will be of astrophysical wide relevance. Understanding the interaction of plasmas with magnetic fields has many technological application, e.g. in fusion nuclear reactors. Space missions are also tributary of data from ground solar telescopes.

In the ESFRI Roadmap since 2016, EST will enter the Implementation Phase in 2021. First light is planned for 2027.

BACKGROUND

The solar physics community was involved in the development of the project from the beginning: i) creation of the EAST consortium, ii) elaboration of the conceptual design study, iii) I3 Trans-National Access network SOLARNET and iv) GREY project. The solar astronomy community is organized through SOLARNET and ASTRONET and operates with success, since the last decades, a set of national observing facilities and infrastructures on the Canary Islands including the Swedish Solar Telescope, the DOT, the VTT, GREGOR and THEMIS, most of which are approaching the end-of life stage. These national observatories shall be decommissioned or reoriented to become test facilities for detector development or to educational programmes, and the research programme shall concentrate on

the EST. Key elements of the landscape are the space missions, in particular the ESA Solar Orbiter programme to be launched in 2018, and the US Daniel K. Inouye Solar Telescope (DKIST, formally the Advanced Technology Solar Telescope ATST), currently being built in Hawaii. DKIST is an asymmetric telescope with an observation programme concentrated on the Sun's corona and linked with space missions.

EST has the same diameter (4m) but it is symmetric and optimized to detect light polarization as it is mandatory for the study of the emergence of magnetic fields at the solar surface and transfer of magnetic and kinetic energy from subsurface layers to the solar atmosphere. A significant advance can be achieved by obtaining observations, of the lower/cooler part of the solar atmosphere, with greatly improved spatial and temporal resolutions. The behaviour of the solar atmosphere in response to the input of magnetic energy is then observable with space instrumentation. The combination of space and ground-based instrumentation will allow a throughout comprehension of the solar magnetic dynamics.

STEPS FOR IMPLEMENTATION

EST will be built in the Canary Islands, where the current aging telescopes are already situated. This will give continuity and increase the importance of the scientific parks existing at present in the islands. Operation of the telescope will progressively implement *queue mode* observing, which is standard for night-time telescopes, allows optimisation of the observations, and does not require on-site presence of the beneficiary. 30% of the observing time will be through open calls for proposals, and the open access data policy – after a one-year proprietary period – allows access to the whole interested scientific community.

Siting will be decided between the Tenerife or Roque de los Muchachos both at 2.400 m of altitude in the Canary Islands along with sea-level and mainland facilities including the Telescope Operation and Science Center (TOSC) to steer the operation of the EST and the Science Data Center in Germany, to provide data storage and access to the solar physics community.

TYPE

single-sited

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: ES
prospective member countries: SE, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2016

TIMELINE

- 2008-2011
Design Phase
- 2016-2021
Preparation Phase
- 2021-2027
Implementation/Construction Phase
- 2029
Operation Start

ESTIMATED COSTS

capital value: Not Available

design: 6 M€

preparation: 15 M€

construction: 200 M€

operation: 12 M€/year

HEADQUARTERS

Instituto de Astrofísica de Canarias
Canary Islands, Spain

WEBSITE

www.est-east.eu



A NETWORK OF NEUTRINO
TELESCOPES IN THE
MEDITERRANEAN SEA
FOR ASTROPARTICLE AND
OSCILLATIONS RESEARCH

KM3NeT 2.0

KM3 Neutrino Telescope 2.0

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: NL

prospective member countries:
EL, FR, IT

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2016

TIMELINE



ESTIMATED COSTS

capital value: 196 M€

design: Not Available

preparation: 45 M€

construction: 151 M€

operation: 3 M€/year

HEADQUARTERS

KM3NeT-HQ Amsterdam Science Park
Amsterdam, The Netherlands

WEBSITE

www.km3net.org



THE NETHERLANDS

DESCRIPTION

The KM3 Neutrino Telescope 2.0 (KM3NeT 2.0) is a three-sites Research Infrastructure housing the next generation neutrino telescopes. Once completed, the telescopes will have detector volumes between megaton and several cubic kilometres of clear sea water. Located in the deepest seas of the Mediterranean, KM3NeT 2.0 will open a new window on our Universe, but also contribute to the research of the properties of the elusive neutrino particles. With the ARCA telescope, KM3NeT 2.0 scientists will search for neutrinos from distant astrophysical sources such as supernovae, gamma-ray bursters or colliding stars. The ORCA telescope is the instrument for KM3NeT 2.0 scientists studying neutrino properties exploiting neutrinos generated in the Earth's atmosphere. Arrays of thousands of optical sensors will detect the faint light in the deep sea from charged particles originating from collisions of the neutrinos and the Earth. The facility will also house instrumentation for Earth and Sea sciences for long-term and on-line monitoring of the deep sea environment and the sea bottom at depth of several kilometers.

In the ESFRI Roadmap since 2016, KM3NeT 2.0 is in the Implementation Phase and will start delivering science in 2020.

BACKGROUND

The discovery of a flux of very energetic cosmic neutrinos reported by IceCube represents *de facto* the birth of the neutrino astronomy. Many questions arose about the origin of the observed cosmic neutrinos – do they come from sources in our galaxy or do they have an extragalactic origin, can these sources be localised and are they point-like or not? Other questions concern the energy spectrum and the flavour composition of the flux. As a consequence of this discovery, the importance of building a cubic kilometre (KM3) scale high-energy neutrino telescope in the northern hemisphere became even more strong and led to the definition of the next phase in construction of the KM3NeT 2.0 infrastructure with the ARCA telescope dedicated to the search for very high-energy cosmic neutrinos. Thanks to its location in the Mediterranean Sea, the ARCA telescope provides a coverage of 87% of the neutrino sky and

allows a survey of almost the whole galaxy including the Galactic Center.

Another goal of the KM3NeT 2.0 scientists is to study the properties of the neutrino particles themselves. The sizable contribution of electron neutrino to the third neutrino mass eigenstate as reported by Daya Bay, Reno and other experiments paved the way for the determination of the neutrino mass hierarchy that is one of the last neutrino properties to be measured. The design of the ORCA detector of KM3NeT 2.0 is optimised for the study of neutrinos created by cosmic rays in the Earth's atmosphere. Together, the ARCA neutrino telescope and the ORCA neutrino detector of the KM3NeT 2.0 Research Infrastructure offer the scientists the unique possibility of performing both all flavour neutrino astroparticle physics and also to advance fundamental neutrino particle physics.

KM3NeT 2.0 addresses neighbouring disciplines like astrophysics (sources of cosmic rays, high-energy neutrino astronomy), particle physics (neutrino oscillations, search for exotic particles) and cosmology (dark matter), but has also strong connections to Earth and Sea Sciences. To measure deep-water parameters with cabled sensors will add a novel option to the toolbox of oceanographers and marine biologists.

STEPS FOR IMPLEMENTATION

Three suitable deep-sea sites are identified, namely going from west to east, KM3NeT-Fr, off-shore Toulon (France), KM3NeT-It, off-shore Portopalo di Capo Passero (Italy) and KM3NeT-Gr, off-shore Pylos (Greece). The first phase of construction of the KM3NeT 2.0 Research Infrastructure has begun in 2015 at the KM3NeT-It and KM3NeT-Fr site and is expected to be finished in 2017. For this, a Memorandum of Understanding for KM3NeT-phase1 has been sign by all participating funding agencies. For the next phase of construction, a Letter of Intent for KM3NeT 2.0 has been published. This Letter of Intent will serve as a reference document for requests for funding by the various stakeholders in Europe and abroad. Pending funding, KM3NeT 2.0 could become reality as early as in 2020. The third and final phase of construction of the KM3NeT Research Infrastructure will also include the KM3NeT-Gr site and is foreseen to start after 2020.

E-RIHS

European Research Infrastructure for Heritage Science

DESCRIPTION

The European Research Infrastructure for Heritage Science (E-RIHS) is a distributed Research Infrastructures to support research on heritage interpretation, preservation, documentation and management. It will comprise: E-RIHS Headquarters and National Hubs, fixed and mobile instruments in national infrastructures of recognized excellence, physically accessible collections/archives and virtually accessible heritage data. Both cultural and natural heritage are addressed: collections, buildings, archaeological sites, digital heritage. E-RIHS will provide state-of-the-art tools and services to cross-disciplinary research communities advancing understanding and preservation of global heritage. It will provide access to a wide range of cutting-edge scientific infrastructures, methodologies, data and tools, training, public engagement, access to repositories for standardized data storage, analysis and interpretation. E-RIHS will enable the community to advance heritage science and global access to the distributed infrastructures in a coordinated and streamlined way.

In the ESFRI Roadmap since 2016, E-RIHS is in the Preparatory Phase towards the Implementation Phase that is foreseen to start in 2021.

BACKGROUND

Heritage Science has brought about the need of structuring the net of infrastructures operating throughout Europe. Fragmentation, duplication of efforts, isolation of small research groups put at risks the competitive advantage of European heritage science research, promoted so well by the unique cultural heritage. The long-term tradition of this field of research, the ability to combine with innovation, and the integration promoted by EU-funded projects such as EU-ARTECH, CHARISMA and IPERION CH in conservation science, and ARIADNE in archaeology represent the background of E-RIHS.

E-RIHS exploits the synergy of the cooperation among the academy, research centres and cultural institutions. The global lead that the EU holds in this research

field, so precariously supported by a combination of national and EU measures, requires a joint and resolved effort. This has been fully recognized by the European Union with the continuous and reiterated support of initiatives aimed at integrating existing Heritage Science infrastructures, as well as, with a focus on Member States' national research programs, the JPI on Cultural Heritage, coordinating efforts of 17 EU national funding bodies supporting heritage science. The enthusiastic reviews of these initiatives testify the success of their action to advance knowledge and to establish a research community, acknowledged as *advanced* in official EU documents concerning conservation, or quickly growing in the field of archaeology.

This demonstrates beyond any doubt both the scientific and the socio-economic importance connected with Heritage Science: it is a sector and a research community that has achieved the maturity necessary to make the leap towards a permanent European Research Infrastructure that will impact broadly on society and economy.

STEPS FOR IMPLEMENTATION

E-RIHS is currently leading a Preparatory Phase with the aim to establish the European Research Infrastructures Consortium (ERIC). The establishment of a legal structure and governance and the refinement of the business plan for long-term sustainability will be the three most important deliverables, together with the implementation of users' access strategy taking advantage of the existing projects of the consortium. E-RIHS partnership joins 15 countries – 14 EU Member States plus Israel, 2 ERICs RIs and 3 institutions representing scientific communities. E-RIHS also involves over 100 heritage science institutions worldwide. Participation to E-RIHS ERIC is open to more potential founding Members – or Observers – throughout the next years of the Preparatory Phase. E-RIHS will be launched as a stand-alone RI in 2021. Further developments are planned for connecting and including partners and facilities outside Europe, and gradually reaching the status of a Global Research Infrastructure.

AN INFRASTRUCTURE FOR
HERITAGE INTERPRETATION,
PRESERVATION,
DOCUMENTATION AND
MANAGEMENT

TYPE

distributed

LEGAL STATUS

pending

POLITICAL SUPPORT

lead country: IT

prospective member countries:
BE, CY, CZ, DE, EL, ES, FR, HU, IL, NL, PL,
PT, SI, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY

2016

TIMELINE

● **2017-2020**

Preparation Phase

● **2019-2021**

Interim/Transition Phase

● **2021-2025**

Implementation/Construction Phase

● **2025**

Operation Start

ESTIMATED COSTS

capital value: Not Available

design: 25 M€

preparation: 4 M€

construction: 20 M€

operation: 5 M€/year

HEADQUARTERS

to be hosted in Italy, Florence

WEBSITE

www.e-rihs.eu



ITALY

A RESEARCH
INFRASTRUCTURE FOR
HOLOCAUST RESEARCH
AND REMEMBRANCE

EHRI

European Holocaust Research Infrastructure

TYPE
distributed

LEGAL STATUS
pending

POLITICAL SUPPORT
lead country: NL
prospective member countries:
AT, CZ, DE, IL, RO, SK, UK
The full list of research institutions involved
must be found in the website of the RI

ROADMAP ENTRY
2018

TIMELINE

- **2010-2019**
Design Phase
- **2019-2021**
Preparation Phase
- **2021-2022**
Implementation/Construction
Phase
- **2022**
Operation Start

ESTIMATED COSTS
capital value: 15 M€
design: 15 M€
preparation: 3 M€
construction: 0,8 M€
operation: 2 M€/year

HEADQUARTERS
to be defined

WEBSITE
www.ehri-project.eu



DDESCRIPTION

The European Holocaust Research Infrastructure (EHRI) is a new pan-European distributed RI that supports the Holocaust research community. It provides access to information about dispersed sources, and develops tools and methods that enable researchers and archivists to collaboratively work with such sources. It thereby seeks to overcome one of the hallmark challenges of Holocaust research – the wide dispersal of sources across Europe and beyond, and the concomitant fragmentation of Holocaust historiography. By integrating sources and research, EHRI enables the study of the Holocaust as a European phenomenon.

Providing access – both online via the EHRI Portal and physical via fellowships and training – is vital for the innovation of Holocaust research and for the training of the next generation of Holocaust researchers and archivists. Through its outreach and public history activities, EHRI further ensures the meaningful remembrance of the Holocaust as a formative European experience.

BBACKGROUND

Holocaust archives are an important part of European cultural heritage. The availability and accessibility of properly contextualised and researched documentation are vital to enable transnational research on the Holocaust as a local, European and universal phenomenon. Until 1989, Israel, the United States and Western Europe were the main centres for Holocaust research. Locating and researching Holocaust documentation in other parts of Europe is still difficult due to the wide dispersal of the archival source material in national, regional and local research infrastructures. As a result studying the Holocaust from a truly European perspective remains challenging.

By facilitating an extensive network of researchers and archivists, EHRI initiates new transnational and collaborative approaches to the study of the Holocaust. From the beginning, EHRI has invested in the integration of multiple disciplines – history, archival science and digital humanities. The development of innovative approaches to deal with digital content facilitates the processing of large amounts

of data, which is conducive for new and enhanced research. By establishing working relationships with archivists and researchers active in related fields – Nazi crimes against non-Jewish victims' groups, Genocide Studies – EHRI will maximise its reach and impact, and ensure that it benefits from insights gained in related fields.

EHRI particularly focuses on increasing visibility of local, peripheral and hidden archives, thereby facilitating local research into Jewish life during the Holocaust. This focus enables the study of the Holocaust from below, contributes to the strengthening of local community consciousness, and offers educational opportunities at a local level. All these aspects are important given the increasing challenges to the memory of the Holocaust in Europe.

Online availability of Holocaust sources and research has relevance well beyond the walls of academia. The Holocaust continues to have enormous social, cultural and political resonance, and EHRI supports the democratisation of knowledge about the Holocaust, thereby contributing to the fight against Holocaust denial and ensuring that its lessons will never be forgotten.

STEPS FOR IMPLEMENTATION

EHRI has been working on integrating Holocaust-related sources and research documentation since 2010. The first phase was funded under FP7 and the current project is supported under Horizon 2020. More than twenty organisations – research institutions, libraries, archives, museums and memorial sites – form a core working group, but EHRI equally relies on the support of many other individuals and organisations in the broad fields of Holocaust studies and digital humanities.

By bringing together experts from different fields, and by building an innovative digital infrastructure supported by a large community, EHRI is a flagship project that showcases the opportunities for historical research in the digital age. EHRI aims at a relatively short Preparation Phase to prepare the financial, legal and the remaining technical aspects of the permanent RI. The Implementation Phase is foreseen in 2021 with the Operation Phase starting in 2022.



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**ESFRI
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ECCSEL ERIC

European Carbon Dioxide Capture and Storage Laboratory Infrastructure

CARBON DIOXIDE CAPTURE AND STORAGE TECHNOLOGIES TO ENABLE LOW TO ZERO CO₂ EMISSIONS

TYPE distributed

LEGAL STATUS ERIC, 2017

POLITICAL SUPPORT

lead country: NO

member countries: FR, IT, NL, UK

prospective member countries: CH, EL, ES

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2008-2010

Design Phase

2014-2015

Interim/Transition Phase

2016

Operation Start

2011-2014

Preparation Phase

2015-2030

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 1.000 M€

design: Not Available

preparation: 10 M€

construction: 100 M€

operation: 0.85 M€/year

HEADQUARTERS

ECCSEL ERIC
Trondheim, Norway

WEBSITE

www.eccsel.org



on the analysis of current research and facility gaps. This guides and coordinates member countries' and facilities' upgrades and new investments.

ECCSEL facilitates fundamental and applied research leading to commercial applications. It enables its users to act commercially in the knowledge market in various ways: i) engineering and technology companies may promote their newest ideas and solutions based on research and innovation in the forefront of the technological development; ii) plant owners and industries may increase knowhow to invest in state-of-the-art technologies.

IMPACT

ECCSEL ERIC operates a world-class distributed CCS Research Infrastructure that offers access to conduct research, enabling researchers to generate substantial knowledge which can lead to new innovative solutions – more efficient products, processes and services related to CCS – and thereby help to address societal challenges like climate change and secure energy supply. ECCSEL raises the technological level of European industry and SMEs, improving their competitiveness through their involvement in instrument and technology development and service provision.

It helps to maintain Europe at the forefront of the international CCS scientific community making the European Research Area more attractive for European and international scientists, and reinforces cooperation between research institutions. ECCSEL also helps provide insight into the social and economic impact of European science.

DESCRIPTION

The European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL) aims at opening access to a European Research Infrastructure with high-quality research facilities devoted to next generation Carbon Dioxide Capture and Storage (CCS) technologies in an efficient and structured way to help enable low to zero CO₂ emissions from industry and power generation to combat global climate change. ECCSEL has implemented, operates and develops a distributed, integrated RI based on a selection of the best research facilities in Europe for Carbon capture, transport and storage. ECCSEL opens access to researchers from universities, research institutes, industry and SMEs from Europe and beyond.

Conceived and included in the ESFRI Roadmap 2008, ECCSEL was established as a European Research Infrastructure Consortium (ERIC) in June 2017. ECCSEL ERIC started operation with five initial European founding Member countries – France, Italy, Netherlands, United Kingdom and Norway, hosting the Operations Centre.

ACTIVITY

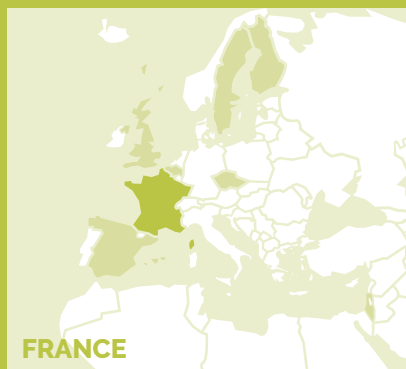
Fourteen facility owners in currently five

ECCSEL ERIC Member countries offer open access to more than 55 world-class research facilities across Europe. More facilities and member countries are planned to be included in the future. ECCSEL covers a large range of research areas relevant for capture, transport, storage and use (selected technologies) of CO₂. This includes fabrication and testing of polymer-based membranes, absorption kinetics studies, solvent degradation, thermodynamics studies, solvent production, chemical looping combustion facility, high pressure absorption, ultra-low permeability media, rock engineering, geo-mechanical testing, hydrothermal studies, gas monitoring, CO₂ injection, meteo-oceanographic physical and geochemical studies, marine biology, double loop circulating fluidized bed reactor system, high-pressure oxy-fuel combustion facility, coal to hydrogen generation pilot plant, gas-phase densities and gas-phase composition, thermogravimetric measurements under high pressure, and studies of microbiological and geochemical processes. A number of current facilities are being upgraded and some new facilities are currently being constructed. Further future extensions and new facilities are being planned too. ECCSEL ERIC has created a research strategy and a facility roadmap based

A HIGH-FLUX FACILITY FOR NUCLEAR FUEL AND MATERIAL PERFORMANCE, AND FOR RADIOISOTOPES PRODUCTION

JHR

Jules Horowitz Reactor



FRANCE

DESCRIPTION

The Jules Horowitz Reactor (JHR) is a reference international user facility to observe and understand material and fuel behaviour in extreme nuclear environment with irradiation loops reproducing the operational condition of the different power reactor technologies. Its primary uses will be research into the performance of nuclear fuel at existing reactors, testing of materials used in reactors, testing designs for fuel for future reactors and the production of radioisotopes used in medicine.

The site preparation for the project began at the Cadarache Research Centre in 2007. The first concrete step for the reactor's foundations was poured in 2009, and the central containment structure was completed with the addition of a 105-tonne dome in late 2013. JHR will be built and managed in the framework of an international cooperation between several organizations bound by a Consortium Agreement signed on March 2007 by partners from 9 countries. JHR is expected to be in operation in 2022.

ACTIVITY

The JHR is an experimental reactor facility. It is not intended to generate electrical power, but to provide scientific data concerning nuclear fuel and material behaviour under exposure to very high stresses – high neutron fluxes. The nuclear unit is composed of only one civil engineering structure supporting two zones with different containments: the Reactor Building (RB) and the Nuclear Auxiliary Building (NAB). The objective of this single structure is to

TYPE single-sited

LEGAL STATUS

POLITICAL SUPPORT

lead country: FR

prospective member countries: BE, CZ, ES, FI, IL, IN, SE, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2007-2009

Preparation Phase

2022

Operation Start

2009-2020

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 1.800 M€

design: 200 M€

preparation: 100 M€

construction: 1.500 M€

operation: Not Available

HEADQUARTERS

Cadarache Research Centre - CEA
Cadarache, France

WEBSITE

www-rjh.cea.fr

contain all the radioactive materials in one place. The reactor is a pool type reactor with a maximum power output of approximately 100 megawatts. This power is dissipated via the primary and the secondary circuit to the external cold source during irradiation; the core, the primary circuit and experimental rigs, are completely enclosed in the RB. The Fission Product Laboratory will be settled in this area to be connected to several fuel loops either for low activity gas measurements (HTR) or high activity gas measurements (LWR rod plenum) or water measurements (LWR coolant) with gaseous chromatography and mass spectrometry.

The reactor pool is connected to several storage pool and hot cells located in the NAB through a water block. The experimental process will make use of two hot cells to manage experimental devices before and after the irradiation. Safety experiments are an important objective for JHR and require an *alpha cell* to manage devices with failed experimental fuel. A fourth hot cell will be dedicated to the transit of radioisotope for medical application and to the dry evacuation of used fuel. Three storage pools are dedicated respectively to spent fuel, experimental devices and mechanical components management. The reactor's

versatile modular design allows it to accommodate up to 20 simultaneous experiments. Its instrumentation allows previously unavailable real-time analysis to be performed.

IMPACT

JHR has a planned lifespan of around 50 years, and is designed to be adaptable for a variety of research uses by nuclear utilities, nuclear steam system suppliers, nuclear fuel manufacturers, research organisations and safety authorities. JHR will represent in Europe a unique experimental facility accessible to industry, research institutes, nuclear regulatory authorities and their technical supports.

JHR will be a key RI for the nuclear international community extending performances and assessing safety for nuclear power plants in doing so also strengthening technology credibility and public acceptance. In addition, it will be effective in training new generations of scientist and engineers in the strategic field of nuclear energy also guaranteeing the high level of expertise needed in the staff of power plants in all steps of their lifecycle, including operation and decommission. JHR will also ensure the production of radioelements for nuclear medicine and for non-nuclear industry.

EISCAT_3D

Next generation European Incoherent Scatter radar system

AN UPGRADE OF THE EISCAT SYSTEMS TO INVESTIGATE THE ATMOSPHERE AND NEAR-EARTH SPACE ENVIRONMENT

TYPE single-sited

LEGAL STATUS EISCAT Scientific Association, 1975

POLITICAL SUPPORT

lead country: SE

member countries: CN, FI, JP, NO, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2005-2009

Design Phase

2015-2017

Interim/Transition Phase

2022

Operation Start

2010-2014

Preparation Phase

2017-2021

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 123 M€

design: 2.6 M€

preparation: 8.5 M€

construction: 72.2 M€

operation: 5.1 M€/year

HEADQUARTERS

EISCAT Scientific Association
Kiruna, Sweden

WEBSITE

www.eiscat3d.se



in the ionosphere. The measured spectra reveal high-resolution information on the ionospheric plasma parameters, but can also be used for obtaining atmospheric data and observations of meteors and space debris orbits. In both active and passive mode, the receivers will provide high-quality scientific and monitoring data from the ionosphere as well as from space within its designed frequency spectrum. The research will both be organized through common observation modes and through requests from individual groups.

DESCRIPTION

The next generation European Incoherent Scatter radar system upgrade (EISCAT_3D) will be a three-dimensional imaging radar to study the atmosphere and the near-Earth space environment above the Fenno - Scandinavian Arctic as well as to support the solar system and radio astronomy sciences. The EISCAT_3D system will consist of a phased-array radar system located in Northern Fenno Scandinavia near space research centres in Kiruna (Sweden), Sodankylä (Finland) and Tromsø (Norway), two rocket launch facilities at Andøya (Norway) and Esrange (Sweden), and several other distributed instrument networks for geospace observation such as magnetometers and auroral cameras. The radar system is designed to investigate how the Earth's atmosphere is coupled to space but it will also be suitable for a wide range of other scientific targets including climate change, space weather, plasma physics, space debris and near-Earth object studies.

In the ESFRI Roadmap since 2008, EISCAT_3D is in the Implementation Phase since June 2017 and operations are expected to start at the end of 2021.

ACTIVITY

EISCAT_3D will be an integral part of EISCAT Scientific Association which has

successfully managed incoherent scatter radars on the mainland and on Svalbard for more than thirty-five years. The present EISCAT systems are fully integrated in the global network of incoherent scatter radars. The EISCAT_3D system will consist of five phased-array antenna fields located in the northernmost areas of Finland, Norway and Sweden. Each field will consist of around 10,000 crossed dipole antenna elements arranged in 109 hexagons in a honeycomb-structure. One of these sites – the core site – will transmit radio-waves at 233 MHz, and all five sites will have sensitive receivers to measure the returned radio signals. The central array of each site will be of a size of about 70 m from side to side, and the sites will be located from 90 km to 250 km from the core site in order to be able to maximise the coverage by the system.

EISCAT_3D is designed to use several different measurement techniques which, although they have individually been used elsewhere, have never been combined together in a single radar system. The design of EISCAT_3D allows large numbers of antennas to be combined together to make either a single radar beam, or a number of simultaneous beams, via beam-forming. EISCAT_3D will measure the spectra of radio-waves that are back-scattered from free electrons, whose motions are controlled by inherent ion-acoustic and electron plasma waves

IMPACT

The original scientific vision for EISCAT_3D was that it would become a RI almost fully dedicated to the research area of solar-terrestrial physics. This is an area of physics where the interaction between the Sun and the Earth is studied, which is significant for most aspects of human life. Understanding, and being able to predict, the effects of solar-terrestrial processes has profound consequences for a range of practical applications including long-term global climate change, human space-flight, satellite operations, communications, position finding, terrestrial monitoring, long-distance energy transport and human health.

EISCAT_3D, while functioning mainly as a radar for scientific research, was also envisioned to have a substantial user community from the applied sciences sector, requiring data products relevant to the above mentioned applications. Additionally, it was also designed to be used as a vehicle to advance all aspects of the incoherent scatter technique, including the development of new methods of radar coding, signal processing and data analysis.

INTERACTIVE, REAL-TIME
OCEAN OBSERVATION
SYSTEMS TO ADDRESS
SOCIETAL AND SCIENTIFIC
CHALLENGES



EMSO ERIC

European Multidisciplinary Seafloor and water-column Observatory

TYPE distributed

LEGAL STATUS ERIC, 2016

POLITICAL SUPPORT

lead country: IT

member countries: EL, ES, FR, IE, PT, RO, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2012
Preparation Phase

2016
Operation Start

2012-2016
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 100 M€

design: Not Available

preparation: 5.4 M€

construction: 137.8 M€

operation: 20 M€/year

HEADQUARTERS

EMSO ERIC
Rome, Italy

WEBSITE

www.emso.eu

DESCRIPTION

The European Multidisciplinary Seafloor and water-column Observatory (EMSO) is a European Research Infrastructure that includes open-ocean, seafloor observatories down to 4,850 metres depth, and shallow-water test sites from the Northeast Atlantic, across the Mediterranean to the Black Sea. EMSO acquires high-quality environmental data and represents a major asset for researchers who have access to multidisciplinary data to respond to pressing scientific and societal challenges. These data cover a multi- and inter-disciplinary range of research areas including biology, geology, chemistry, physics, engineering and computer science, from polar to tropical environments, down to the abyss. The data generated in EMSO allow facing multivariate questions over different space and time scales, overcoming the traditional approach of focusing on single data streams.

EMSO is a European Research Infrastructure Consortium (ERIC) since 2016, with the goal of ensuring long-term, sustained, continuous data streams from the ocean, the majority of the biosphere of our planet.

ACTIVITY

EMSO is an array of seafloor and water-column observatories distributed across Europe seas. EMSO provides crucial data for the understanding of fundamental processes in the marine domain that is significant for a number of short, medium and long-term events such as global

change or catastrophic episodes with slow patterns that are difficult to discern with short sampling due to long-term processes variability. The high resolution, long-time-series collection of multiple variables across a breadth of environments represents the only approach capable of shedding light on the complexity of these systems and is required to document and predict episodic events, such as earthquakes, submarine slides, tsunamis, benthic storms, biodiversity changes, pollution, and gas hydrate (methane) release. Climate change, ocean ecosystem disturbance, and marine hazards represent urgent scientific and societal challenges and EMSO is designed to provide relevant data at an unprecedented level of accuracy, consistency, comparability, and continuity at the regional scale. In real-time it also generates long-term measurements of ocean parameters.

The interactive monitoring capacity of EMSO allows tracking these critical changes and delivering knowledge and tools to enable Europe to evaluate strategies to prepare and adapt to these changes. EMSO allows the pooling of resources and expertise, and coordination to assemble harmonised data into a comprehensive regional

ocean image, which will then be made available to researchers and stakeholders worldwide via an open and interoperable data access system.

IMPACT

EMSO offers opportunities for hosting new hi-tech jobs and spurring development of innovative applications and services in strategic industry sectors such as fishing and tourism, renewable energy, deep-sea mining, offshore industry. EMSO has already started to generate significant socio-economic benefits; advanced training and support services (incubator, testing) for industry, particularly for SMEs; high quality educational and services for academic and mass media; a lobby group for marine research policy, innovation and ethics for government; and education and citizen science interactivity for the general public.

The accurate and timely environmental information gained with EMSO will nourish mitigation and protection strategies of challenges and threats including geo-hazards, habitat loss, human and animal migration, and food security, including anthropogenic damage to marine-related industry activities, tourism, recreation and aesthetics.

EPOS

European Plate Observing System

*A LONG-TERM PLAN
FOR THE INTEGRATION
OF NATIONAL AND
TRANSNATIONAL RESEARCH
INFRASTRUCTURES FOR
SOLID EARTH SCIENCE*



TYPE distributed

LEGAL STATUS ERIC Step2, 2018

POLITICAL SUPPORT

lead country: IT

member countries: DK, FR, NO, PT, SI, UK

***observers:** CH, EL

prospective member countries: AT, BE, ES, FI, IE, IS, NL, PL, RO

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2000-2010

Design Phase

2015-2022

Implementation/Construction Phase

2010-2014

Preparation Phase

2020

Operation Start

ESTIMATED COSTS

capital value: 500 M€

design: 30 M€

preparation: 4.5 M€

construction: 32 M€

operation: 18 M€/year

HEADQUARTERS

Istituto Nazionale di Geofisica
e Vulcanologia - INGV
Rome, Italy

WEBSITE

www.epos-eu.org

DESCRIPTION

The European Plate Observing System (EPOS) aims to create a pan-European infrastructure to monitor and unravel the dynamic and complex solid Earth system by integrating the diverse and advanced Research Infrastructures for solid Earth science relying on new e-science opportunities. EPOS will enable innovative multidisciplinary research for a better understanding of the Earth's physical and chemical processes that control earthquakes, volcanic eruptions, ground instability and tsunamis as well as the processes driving tectonics and Earth's surface dynamics. Through integration of data, models and facilities, EPOS will allow the Earth science community to make a step change in developing new concepts and tools for key answers to scientific and socio-economic questions concerning geo-hazards and geo-resources for a safe and sustainable society.

EPOS is currently in the Implementation Phase. The establishment of the European Research Infrastructure Consortium (ERIC) is foreseen in 2018.

ACTIVITY

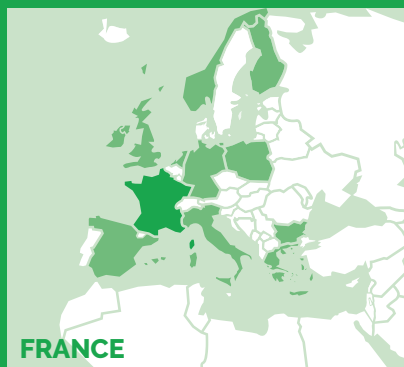
Solid Earth science is concerned with the internal structure and dynamics of planet Earth, from the inner core to the surface; it deals with physical and chemical processes covering wide temporal and spatial scales, from microseconds to billions of years and from nanometres to thousands of kilometres. Geology, natural hazards, natural resources and, in general, environmental processes do not respect national boundaries, therefore seamless, transnational integration of measurements and data is often vital for optimal research and related activities. Integration of data and services from different disciplines in Earth science is an essential step to unravel and monitor these processes with the final goal of forecasting their impact on the environment. Indeed, the solid Earth science community has chosen to establish an all-encompassing framework including all the different solid Earth disciplines: seismology, near-fault observatories, geodetic data and products, volcanic observations, satellite data and products, geomagnetic observations, anthropogenic hazards, geological information and modelling, multi-scale laboratories and geo-energy test-beds for low-carbon energy.

EPOS is developing such a holistic, sustainable, multidisciplinary research platform to provide coordinated access to harmonized and quality controlled data from diverse Earth science disciplines, together with tools for their use in analysis and modelling. EPOS brings together 25 European nations and combines national Earth science facilities, the associated data and models, together with the scientific expertise into one integrated delivery system for the solid Earth. This infrastructure will allow the Earth sciences to achieve a step change in our understanding of the planet; it will enable us to prepare for geo-hazards and to responsibly manage the subsurface for infrastructure development, waste storage and the use of Earth's resources.

IMPACT

The data and services made available by EPOS are of interest to academy, industry and society. Understanding how the Earth works as a system is critically important to modern society. Society requires resources to support home life, industry and business and it needs security in the face of natural hazards. Volcanic eruptions, earthquakes, floods, landslides and tsunamis are all Earth phenomena impacting on society. Solid Earth science by bringing together many diverse disciplines such as geology, seismology, geodesy, volcanology, geomagnetism as well as chemistry and physics, is the place where to find answers on how to maintain the Earth a safe, prosperous, and habitable planet. Combining a sound physical understanding of natural hazards with the means to monitor and forecast their occurrence will mitigate their effects increasing public awareness of natural risks.

THE EUROPEAN CONTRIBUTION TO THE GLOBAL SEA AND OCEAN IN DEPTH PROFILING BY FLOATS



FRANCE

DESCRIPTION

The European contribution to the International Argo Programme (EURO-ARGO) is a distributed Research Infrastructure that organizes and federates the European contribution to the international Argo programme for *in situ* ocean observations. EURO-ARGO aims at sustaining the European contribution to the global Argo array of profiling floats which measure temperature and salinity every 10 days throughout the deep global oceans to deliver data both in real-time and delayed mode for climate change research and monitoring as well as operational services such as Copernicus. It also aims at developing the new phase of Argo extending the network to abyssal oceans, biogeochemical parameters, marginal seas and high latitudes.

The EURO-ARGO ERIC was established in 2014 after a successful Preparatory Phase project with 7 Members and 2 Observers. In 2018, the EURO-ARGO ERIC federates 10 Members and 2 Observers.

ACTIVITY

The overall objective of the EURO-ARGO Research Infrastructure is to deploy about 350 new floats per year as necessary to maintain an array of about 1.000 floats in operation at any given time – 25% of the global array – with enhanced coverage in the European regional seas that requires increased sampling in the Nordic, Baltic, Mediterranean and Black seas.

EURO-ARGO contributes to the establishment of the Argo global array – almost 4.000 drifting profiling floats

EURO-ARGO ERIC

European contribution to the international Argo Programme

TYPE distributed

LEGAL STATUS ERIC, 2014

POLITICAL SUPPORT

lead country: FR

member countries: BG, DE, EL, ES, FI, IE, IT, NL, UK

***observers:** NO, PL

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2011
Preparation phase

2014
Operation start

2011-2014
Implementation/Construction phase

ESTIMATED COSTS

capital value: 10 M€

design: Not Available

preparation: Not Available

construction: Not Available

operation: 8 M€/year

HEADQUARTERS

EURO-ARGO ERIC
Plouzané, France

WEBSITE

www.euro-argo.eu

worldwide – for *in situ* measurements integrated with other elements of the climate observing system, in particular satellite observations, to detect climate variability from seasonal to decadal scales and provide long-term observations of climate change in the oceans. This includes regional and global changes in temperature and ocean heat content, salinity and freshwater content, sea level and large-scale ocean circulation. In addition, EURO-ARGO provides data to constrain global and regional ocean analysis and forecasting models, delivers information to initialize seasonal and decadal forecasting ocean/atmosphere-coupled models and produce the evidences necessary for calibration and validation of satellite data.

Contributions to the global array are progressing and European partners continue to be major actors in the Argo data management system to target research – climate and oceanography – and operational oceanography communities and to implement the new phase of Argo. The EURO-ARGO Research Infrastructure is indeed at the forefront of the development of the new phase of ARGO with an

extension to biogeochemical variables, the deep ocean and the polar seas.

IMPACT

Given the prominent role of the EURO-ARGO Research Infrastructure for climate change research and its contribution to seasonal and decadal climate forecasting, the socio-economic impacts are expected to be largely on the medium and the long-term runs. EURO-ARGO has developed strong links with the European ocean and climate change research communities that are heavily relying on Argo observations. The EURO-ARGO is also a major *in situ* infrastructure for the Copernicus Marine Environment Monitoring Service (CMEMS) and the European Marine Observation and Data Network (EMODnet). Long-term ocean observations will lead to a better understanding and prediction of climate change – e.g sea-level rise – and improved mitigation strategies. Through the purchase of 1/4 of the deployed floats per year, EURO-ARGO will contribute to the consolidation and to the strengthening of the global competitiveness of European manufacturers in the highly aggressive field of innovation related to marine equipment.

IAGOS

In-service Aircraft for a Global Observing System

GLOBAL-SCALE AND
LONG-TERM ATMOSPHERIC
MONITORING SYSTEM FROM
COMMERCIAL AIRCRAFT

TYPE distributed

LEGAL STATUS AISBL, 2014

POLITICAL SUPPORT

lead countries: FR, DE

member country: UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2013
Preparation Phase

2014
Operation Start

ESTIMATED COSTS

capital value: 9.2 M€

design: 4.4 M€

preparation: 3.5 M€

construction: 45 M€

operation: 7 M€/year

HEADQUARTERS

IAGOS AISBL
Brussels, Belgium

WEBSITE

www.iagos.org



emission and Kyoto monitoring. Regional air quality models will assimilate IAGOS near real-time data to improve forecasts. IAGOS data are also utilised for the calibration and validation of satellite sensors. Cooperation with aviation industry and instrumentation developers aims at designing strategies to deal with the observation of ice particles and dust, including volcanic ash and their operational consequences.

DESCRIPTION

The In-service Aircraft for a Global Observing System (IAGOS) is a distributed Research Infrastructure that operates a global-scale monitoring system for atmospheric trace gases, aerosols and clouds by using the existing provisions of the global air transport system to provide essential data on climate change and air quality. It complements the global observing system in addition to ground-based networks, dedicated research campaigns and observations from satellites, balloons, and ships. IAGOS builds on the scientific and technological experience gained within the research projects MOZAIC – Measurement of Ozone and Water Vapour on Airbus in-service Aircraft – and CARIBIC – Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container. The technical, organisational and legal concept for IAGOS has been developed during its Preparatory Phase.

IAGOS was formally implemented in January 2014 as an International not-for-profit Association under Belgian Law (AISBL) with its seat in Brussels.

ACTIVITY

The dual setup of IAGOS aims at providing global-scale coverage of key observables on a day-to-day basis with a more complex set of observations with reduced coverage.

The IAGOS-CORE component comprises the implementation and operation of autonomous instruments installed on long-range aircraft of several internationally operating airlines for continuous, global-scale and daily measurements of reactive gases, greenhouse gases (e.g. CO₂, CH₄), aerosol and cloud particles. The IAGOS-CARIBIC component consists of a heavily modified cargo container equipped with instruments for a large suite of trace gases and aerosol parameters, which is deployed once per month for four intercontinental flights. At present 8 aircraft are equipped with IAGOS-CORE instrumentation and one aircraft carries the IAGOS-CARIBIC container. At the end of its Construction Phase,

IAGOS aims for an operational fleet of up to 20 equipped passenger aircraft. IAGOS contributes to improved understanding of climate change and global air quality by providing regular *in situ* observations on a scale and in numbers that would be impossible to achieve using research aircraft and for which other measurement methods (e.g. satellites) have technical limitations. This input is essential for climate research, emissions monitoring, weather prediction and air quality forecasting. Data is provided for climate models, including those used by the Copernicus Atmosphere Monitoring Service, and for the carbon cycle models employed for the verification of CO₂

IMPACT

The direct impact is mainly on SMEs who are manufacturing instruments or are involved in the development and aeronautic maintenance of the instrumentation in order to assure continued airworthiness in accordance with international regulations for aviation. Engagement of airline companies as suppliers of transportation capacity and technical support was achieved on the basis of individual negotiations and by direct involvement as full project partners. Currently 3 European airlines – Deutsche Lufthansa, Air France and Iberia – and 3 airlines from outside Europe – China Airlines, Cathay Pacific, and Hawaiian Airlines – are involved. Negotiations with other airlines from Europe and other countries are on-going in order to extend coverage. IAGOS contributes observational data directly to the aviation industry and airlines for improving operational procedures and thus reducing costs and enhancing aviation safety.

A long-term impact comes through the improved accuracy of numerical model predictions for air quality and climate change on the global and regional scale.

*HIGH PRECISION
SCIENTIFIC DATA ON
CARBON CYCLE AND
GREENHOUSE GAS
BUDGETS TO SUPPORT
CLIMATE ACTION*



FINLAND

DESCRIPTION

The Integrated Carbon Observation System (ICOS) is a distributed Research Infrastructure to generate high-precision data and integrate knowledge on the carbon cycle and greenhouse gas (GHG) budgets and of their perturbations. ICOS conducts long-term observations in three networks – atmosphere, ecosystems, and oceans – as required to understand the present state and extrapolate to the future behaviour of the global carbon cycle and GHG fluxes. ICOS has an increasing role in scientific support of climate policy. The most important technological impact is standardisation. Further technology developments and implementations, related to GHGs, will be promoted by a close integration of research, education and innovation.

The structure of ICOS consists of ICOS National Networks, ICOS Central Facilities, and the ICOS European Research Infrastructure Consortium (ERIC) which was established in October 2015. ICOS ERIC manages and oversees the activities and strategic goals, and distributes data and elaborated data products.

ACTIVITY

The first objective of ICOS is to build a single and coherent data set and to open it for effective access to facilitate research on GHG concentration, related emissions and natural sinks. Data are assimilated in biogeochemical and ecological process models. ICOS aims at establishing a reference standard for the future development of similar integrated and operative GHG observation networks also beyond Europe. The second objective is to provide information for understanding

ICOS ERIC

Integrated Carbon Observation System

TYPE distributed

LEGAL STATUS ERIC, 2015

POLITICAL SUPPORT

lead country: FI

member countries: BE, CZ, DE, DK, FR, IT, NL, NO, SE, UK

***observer:** CH

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2005-2006

Design Phase

2013-2016

Implementation/Construction Phase

2008-2013

Preparation Phase

2016

Operation Start

ESTIMATED COSTS

capital value: 116 M€

design: Not Available

preparation: 4.3 M€

construction: 80 M€

operation: 24.2 M€/year

HEADQUARTERS

ICOS ERIC
Helsinki, Finland

WEBSITE

www.icos-ri.eu

of regional budgets of greenhouse gas sources and sinks, their human and natural drivers, and the controlling mechanisms. ICOS ERIC allows detecting changes in regional greenhouse gas fluxes, early warning of negative developments and the response of natural fluxes to extreme climate events. In order to provide this information ICOS builds National Networks of atmospheric, ecosystem and ocean stations. European level ICOS Central Facilities, are dedicated to collecting and processing the data received from the National Networks and to provide calibration gases or specific analyses. The ICOS ERIC data policy endorses full and open exchange of data, metadata and products that will be made available to the researchers with minimum time delay. It follows general data sharing principles as outlined by GEOSS.

The data and knowledge provided by ICOS ERIC will reduce the uncertainties in Earth System models and in predictions on future GHG concentrations as exploited in the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC).

IMPACT

Environmental Research Infrastructures in general, and ICOS in particular, generate important knowledge on

our ecological life support systems that provide priceless services. This is particularly evident in the field of GHG: not reaching our safe climate change target level by inadequate mitigation will lead to extremely large societal costs for adaptation and predictable high damages. The investments and running costs needed for a global GHG monitoring and analysis network are marginal compared to these costs and could be easily compensated due to improved effectiveness of the mitigation strategies. Additional benefit will come from detecting and pointing to surprise changes in the earth system and from detecting non-compliance of regions, sectors or countries with the agreed objectives. Furthermore, ICOS GHG observations and outreach activities, have already increased the public awareness and stimulated changes towards green economy and decarbonisation of agricultural, industrial and transport processes.

A substantial impact comes also from the harmonization and standardization of measurements and data formats including improved QA/QC standards and data protocols. These efforts support primarily the research community, but industry and policy makers also benefit from reliable and standardized openly accessible data sets.

LifeWatch ERIC

e-Infrastructure for Biodiversity and Ecosystem Research

*A DISTRIBUTED
e-INFRASTRUCTURE TO
SUPPORT RESEARCH
AND SUSTAINABILITY
OF BIODIVERSITY AND
ECOSYSTEMS*



TYPE distributed

LEGAL STATUS ERIC, 2017

POLITICAL SUPPORT

lead country: ES

member countries: BE, EL, IT, NL, PT, SI

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2011

Preparation Phase

2017

Operation Start

2011-2016

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 150 M€

design: 3 M€

preparation: 5 M€

construction: 142 M€

operation: 12 M€/year

HEADQUARTERS

LifeWatch ERIC
Seville, Spain

WEBSITE

www.lifewatch.eu

DESCRIPTION

The e-Infrastructure for Biodiversity and Ecosystem Research (LifeWatch) is a distributed Research Infrastructure to advance biodiversity research, to address the big environmental challenges and support knowledge-based strategic solutions to environmental preservation. This mission is achieved by providing access to a multitude of data sets, services and tools enabling the construction and operation of Virtual Research Environments (VREs).

LifeWatch has been established as a European Research Infrastructure Consortium (ERIC) since March 2017, with the Statutory Seat and the ICT e-Infrastructure Technical Offices – located in Spain – that jointly assist the coordination and management of the day-to-day institutional relationships and administrative, legal, financial issues. It also coordinates the implementation of e-Services demanded by the Service Centre in Italy, the Virtual Laboratories and Innovations Centre in The Netherlands, as well as other distributed facilities located in other Member Countries of the LifeWatch ERIC which are encouraged to establish Thematic Centres in accordance with its overall architectural scheme.

ACTIVITY

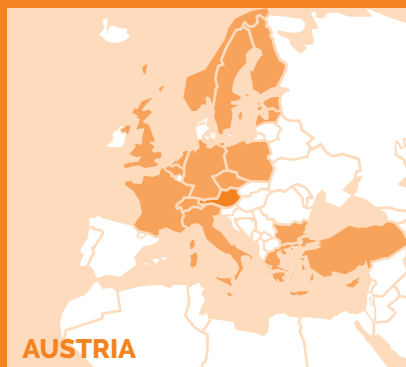
The Statutory Seat and the ICT e-Infrastructure Technical Offices also coordinate and manage the ICT e-Infrastructure distributed construction, maintenance, deployment and operations. The Service Centre provides the interface with the Biodiversity and Ecosystem Research Scientific Community, identifies the needs of the multiple users' groups from different domains and areas of interest and coordinates the development and operation of the related Services. It also assists in deploying the Services provided by LifeWatch ERIC, including those enabling discovery, visualization, and download of data and applications for analysis, synthesis and modelling of scientific topics. Thus the Service Centre identifies new data resources, incorporates vocabularies, semantics and services to aggregate larger typologies of data. It also provides the optimisation of the access and use of Service Centre facilities as a whole, and offers web-based tools to facilitate Social Networking and Social Learning (including e-Learning). Finally, it promotes the awareness of LifeWatch ERIC for users and general public, and enhances the visibility of LifeWatch ERIC scientific outcomes, by publicising and disseminating them.

The Virtual Laboratories and Innovations Centre coordinates and manages the requirements and needs analysis, design and implementation of the scientific case studies and productions of the LifeWatch ERIC Virtual Laboratories. These e-Labs are implemented and deployed through the LifeWatch ERIC ICT distributed e-Infrastructure facilities, and made accessible through the Service Centre to the Biodiversity and Ecosystem Research Scientific Community. This procedure guarantees the overall coherence of the Research Infrastructure by promoting synergies in regards to the semantic interoperability among data, services and their final users.

IMPACT

LifeWatch ERIC provides the instruments to empower its users, as its Virtual Research Environments enable ideas and people to move in an open way within a digital context. It builds capacity to foster opportunities for large-scale scientific development; to enable accelerated data capture; to support knowledge based decision making for the management of biodiversity and ecosystems. It benefits the ERA through the design of infrastructure capabilities driven by scientific and societal needs; enabling new ways of interoperability among science, policy and society; providing the adequate VRE for the interaction of user-driven research, training and innovation activities; cooperating with the private sector in developing the best ICT technologies needed for its construction and operation, providing innovative applications derived from the research carried out; delivering excellence, as a key principle by building capacity and by the priority of the most promising talent.

A GATEWAY FOR
ACCESS TO BIOBANKS
AND BIOMOLECULAR
RESOURCES FOR HEALTH
RESEARCH



AUSTRIA

BBMRI ERIC

Biobanking and BioMolecular Resources Research Infrastructure

TYPE distributed

LEGAL STATUS ERIC, 2013

POLITICAL SUPPORT

lead country: AT

member countries: BE, BG, CZ, DE, EE, EL, FI, FR, IT, LV, MT, NL, NO, PL, SE, UK

***observers:** CH, CY, TR, (WHO/IARC)

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2011
Preparation Phase

2014
Operation Start

2011-2013
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 195 M€

design: Not Available

preparation: Not Available

construction: Not Available

operation: 3.5 M€/year

HEADQUARTERS

BBMRI ERIC
Graz, Austria

WEBSITE

www.bbMRI-eric.eu

DESCRIPTION

The Biobanking and BioMolecular Resources Research Infrastructure (BBMRI) is one of the largest Research Infrastructures for health research in Europe by providing a gateway for access to biobanks and biomolecular resources coordinated by the National Nodes. BBMRI aims at improving the accessibility and interoperability of the existing comprehensive collections, either population-based or clinical-oriented, of biological samples from different (sub-) populations of Europe or rare diseases. These collections include the associated data on factors such as health status, nutrition, lifestyle, and environmental exposure of the study subjects.

BBMRI became a European Research Infrastructure Consortium (ERIC) in December 2013. The agreement of ultimately 19 countries – 17 Members and 3 Observers, and one International Organisation (WHO/IARC) – enabled to set up a pan-European distributed Research Infrastructure that shall develop into one of the most important tools in biomedical and clinical discovery.

ACTIVITY

BBMRI ERIC facilitates the access to quality-defined human disease relevant biological resources in an efficient as well as ethically and legally compliant manner. It aims at reducing the fragmentation of the biomedical research landscape through harmonisation of procedures and by implementing common standards and fostering high-level collaboration.

BBMRI ERIC provides tools and expertise, as well as knowledge and experience sharing on ethical, legal and societal

issues (ELSI), Information Technologies (IT) as well as Quality Management (QM) for biobanks and research on biomolecular resources. Key ELSI services include: providing an Ethics Check for projects; providing a custom-based Helpdesk and Knowledge Base; sharing of knowledge, experiences and best practices; monitoring of relevant ethical and legal frameworks in development and coordinating joint replies to relevant public consultations. Key IT services include: Directory 4.0 provides aggregate information about biobanks and their sample/data collections to ensure their findability; Negotiator 1.0 facilitates access to biobanks allowing communication between researchers requesting samples/data from biobanks, allowing refinement of their queries; BIBBoX is an integrated toolbox for biobanks based on open-source software to support biobanks in implementing missing IT components; MIABIS 2.0 represents the minimum information required to initiate collaborations between biobanks and to enable the exchange of biological samples and data with the aim to facilitate the reuse of bio-resources and associated data. Key QM services include: recommended standards and best practices; sharing QM expertise on a European scale; Quality Expert Working Groups; and Self-Assessment Surveys.

All services are intended for researchers searching for high-quality samples and data, for biobankers promoting their biobanks and looking for fellow biobanks, for funding organisations to provide overview of infrastructure, as well as other users for the benefit of European citizens.

IMPACT

BBMRI ERIC will provide a one-stop access to the collections of the European biobanking community, expertise and services to foster access to other parties, including the private sector for the benefit of mankind. New medical applications, new therapies, new preventives, new diagnostics, personalised or stratified medicine and new biomedical industries shall evolve to improve socio-economic competitiveness and increasing possibilities for equitable healthcare in Europe. Expectantly, BBMRI ERIC will impact on partnerships with patients/donors, who will be informed that their own tissues, samples and personal data can yield discoveries and advances in medicine, diagnostics, and therapies. In return, BBMRI ERIC is taking up the responsibility to use the samples and data made available to the research in the best way for the advancement of knowledge, ultimately contributing to improve EU's healthcare systems.

EATRIS ERIC

European Advanced Translational Research Infrastructure in Medicine

A NEW DEVELOPMENT
PATHWAY FOR TRANSLATING
NOVEL BIOLOGICAL INSIGHTS
INTO EFFECTIVE SOLUTIONS

TYPE distributed

LEGAL STATUS ERIC, 2013

POLITICAL SUPPORT

lead country: NL

member countries: CZ, EE, ES, FI, FR, IT, LU, NO, PT, SE, SI

***observer:** LV

prospective member country: RO

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2010

Preparation Phase

2011-2013

Implementation/Construction Phase

2010-2011

Interim/Transition Phase

2013

Operation Start

ESTIMATED COSTS

capital value: 500 M€

design: Not Available

preparation: 5 M€

construction: 4.5 M€

operation: 2.5 M€/year

HEADQUARTERS

EATRIS ERIC

Amsterdam, The Netherlands

WEBSITE

www.eatris.eu



THE NETHERLANDS

and Tracing, to provide a single point of entry to high-end expertise and cutting-edge translational imaging facilities, defragmenting the technical know-how and making optimal use of resources to improve R&D output; Biomarkers for precision medicine, to facilitate the validation and development of biomarkers for the prevention, diagnosis and prognostic assessment of disease as well as for the prediction of therapy response.

In order to ensure that each project has a comprehensive team and best chance of success, EATRIS also offers regulatory support, as well as education and training opportunities in translational research.

IMPACT

Improving the output of scientific discoveries into innovative and high impact medicines, diagnostics and medical devices will have a considerable socio-economic impact in Europe and globally, especially in the long-term. The wide range of interest of EATRIS, that extends also to rare and neglected diseases and includes personalised medicine, is expected to give a general improvement in the drug discovery process leading to the development of innovative solutions, also aimed at patient groups. EATRIS acts as a forum for open debate between the three sectors – academic community, industry and the public – in order to improve communication, legal and regulatory alignment and competitiveness, and reduce uncertainty for the practitioners of translational science. Also, by encouraging training in translational science, EATRIS supports the long-term sustainability of the discipline, and will facilitate further innovation by providing the next generations of top international talent.

DESCRIPTION

The European Advanced Translational Research Infrastructure in Medicine (EATRIS) is a distributed RI that provides a unique *one-stop shop* access to the combined expertise and high-end technologies, required to develop new products for translational medicine, from target validation to early clinical trials. By selecting several key resources in Europe, users can access to research tools and guidance required for drug development, ranging from state-of-the-art scientific equipment, knowledge-based resources from sample collections to GMP manufacturing and regulatory guidance. Services and access to patient cohorts are provided in the fields of advanced therapy medicinal products, biomarkers, imaging and tracing, small molecules and vaccines.

EATRIS received the status of European Research Infrastructure Consortium (ERIC) in November 2013. It comprises 90 leading institutes in 13 countries – 12 Members and 1 Observer – that represent the wide diversity of stakeholders who seek solutions to the many issues arising in the development of new therapies.

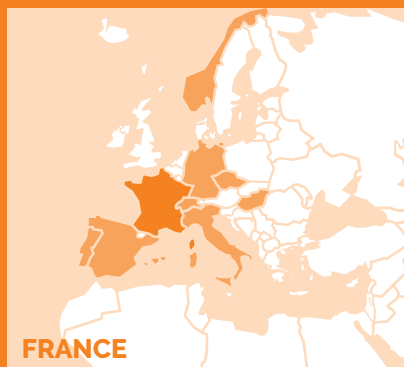
ACTIVITY

By bringing together Europe's best institutions in academic translational

medicine, EATRIS has created a portfolio of research services focused on predicting the performance of novel products, selecting the right patient, and entering clinical development as safely and effectively as possible. On the basis of a detailed database and knowledge of its growing member institutions, EATRIS quickly matches the users' needs with the right expertise and facilities to build project teams along technology pipelines and supporting services, running from target/biomarker validation up to clinical proof of concept, covering the following areas: Advanced Therapy Medicinal Products (ATMP) and biologics – including Gene Therapy Medicinal Products (GTMP), Cell Therapy Medicinal Products (CTMP), and Tissue Engineered Products (TEP) – represent a new category of medicines with a wide therapeutic potential for treating different types of diseases such as cancer, neurodegenerative and cardiovascular diseases; Small Molecules, to support the pre-clinical and clinical development of drug candidates, utilising academic expertise around novel targets; Vaccines, to cover the entire vaccine development and production pipeline ranging from late-phase pre-clinical development to clinical trials.

These pipelines are supported by cutting edge enabling technologies: Imaging

A NETWORK FOR
MULTINATIONAL, HIGH-
QUALITY, CLINICAL TRIALS
FOR TOP-LEVEL MEDICAL
RESEARCH



FRANCE

ECRIN ERIC

European Clinical Research Infrastructure Network

TYPE distributed

LEGAL STATUS ERIC, 2013

POLITICAL SUPPORT

lead country: FR

member countries: CZ, DE, ES, HU, IT, NO, PT

***observer:** CH

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2011
Preparation Phase

2014
Operation Start

2011-2014
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 5 M€

design: 1 M€

preparation: 6 M€

construction: 20 M€

operation: 5 M€/year

HEADQUARTERS

ECRIN ERIC
Paris, France

WEBSITE

www.ecrin.org

DESCRIPTION

The European Clinical Research Infrastructure Network (ECRIN) is a distributed RI that supports the conduct of multinational, high-quality, transparent clinical trials by overcoming the obstacles caused by fragmentation and poor interoperability of the national, clinical research environment in Europe. ECRIN creates added value through access to expertise and patients, increasing the reach, diversity, and result quality of clinical trials. As such, it fulfils the vision of a society where all decisions in medical practice are based on sound scientific evidence from high-quality clinical research.

ECRIN started in 2004 by connecting research facilities at multiple sites in countries across Europe and providing services for top-level clinical research. ECRIN was officially awarded the status of European Research Infrastructure Consortium (ERIC) in December 2013. With 8 Members and 1 Observer, ECRIN ERIC became fully operational in 2014.

ACTIVITY

Difficulties in locating clinical trials units, fulfilling local legal, regulatory and ethical requirements, and coordinating multinational trial management deter many researchers from attempting multinational trials. This means that most independent trials are conducted in single centres, or multiple centres within one country.

ECRIN provides a pathway through Europe's fragmented health and legal systems with its pan-European infrastructure that is designed to support multinational clinical research and unlock

access to patients and medical expertise. ECRIN's support is primarily provided during implementation, but also for preparation and protocol evaluation of the trial study. While advice and information are freely provided during preparation, access to ECRIN trial management services is subject to scientific and logistical evaluation of the full study protocol.

ECRIN's work comprises multiple strands of activity. ECRIN provides guidance, consulting and operations management for multinational clinical trials on a not-for-profit basis. This work is facilitated by European Correspondents, based in Member and Observer countries, who maintain connections with national clinical trial unit networks. ECRIN maintains openly accessible tools for key trial features including regulations, ethical requirements, outcome measures, and trial unit locations for medicines, medical devices and nutrition, and risk-adapted monitoring strategies. Communication of ideas, news and principles behind clinical research to people working in the field, patients, policymakers and the public is a key ECRIN activity. Interaction with disease-related investigation networks and other distributed research infrastructures ensures extensive

collaboration with various research fields, synergistic use of resources and expansion of the user community and reach of ECRIN activities. ECRIN works with colleagues worldwide to promote implementation of recommendations for integrated clinical trial governance.

IMPACT

ECRIN is a major tool to address the health *Grand Challenge* and has major impact on citizens and economy. Clinical trials assessing the safety and efficacy of new products result in health innovation, with a strong positive impact on the health industry – medicines, vaccines, medical devices, diagnostics – and nutrition sectors.

In addition to enlarging the health industry market, clinical trials exploring new indications for already authorized products – repurposing trials – have an impact on citizens' health. Clinical trials comparing authorized treatments – comparative effectiveness trials – result in an improvement in healthcare strategies, with a measurable economic impact on wellbeing and productivity, and in healthcare cost containment. Independent, multinational trials are key instruments for optimisation of healthcare solutions and promotion of evidence-based medical practice in Europe and globally.

ELIXIR

A distributed infrastructure for
life-science information

A SUSTAINABLE
INFRASTRUCTURE FOR
INTEROPERABILITY OF PUBLIC
BIOLOGICAL AND BIOMEDICAL
DATA RESOURCES

TYPE distributed

LEGAL STATUS ELIXIR Consortium Agreement, 2013

POLITICAL SUPPORT

lead country: UK, (EMBL)

member countries: BE, CH, CZ, DE, DK, EE, ES, FI, HU, IE, IL, IT, LU, NL, NO, PT, SE, SI

***observers:** CY, EL

prospective member country: FR

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2007-2011

Preparation Phase

2013-2020

Implementation/Construction Phase

2011-2013

Interim/Transition Phase

2014

Operation Start

ESTIMATED COSTS

capital value: 125 M€

design: Not Available

preparation: Not Available

construction: Not Available

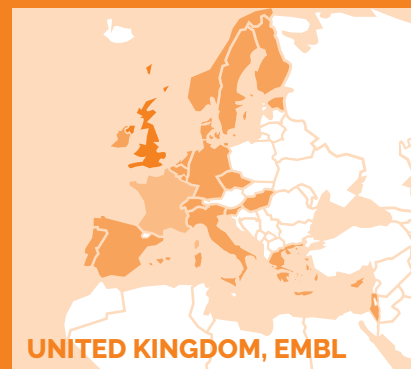
operation: 95 M€/year

HEADQUARTERS

Wellcome Genome Campus
Hinnton, United Kingdom

WEBSITE

www.elixir-europe.org



of that country. Resources include: safe and secure data repositories; added-value databases providing researchers with access to well curated data; bio-compute centres for cloud computing and analysis; services for the integration of data, software, tools and resources; education and training; standards, ontology and data management expertise.

ELIXIR ensures that users – individual scientists, large consortia or indeed other Research Infrastructures – can easily access data resources that are sustainable, built on strong community standards, and safeguarded in the long-term.

IMPACT

Industry's interest in, and usage of, European bioinformatics resources is high as demonstrated by the millions of hits from commercial users to the websites of ELIXIR Nodes and the number of patents awarded that reference life science databases. ELIXIR's Innovation and SME programme ensures that high-tech companies across Europe can access the services run by ELIXIR partners; over one hundred such companies have so far benefitted from bespoke events targeting the pharma and agri-tech sectors.

Open life science data drives major societal value and truly facilitates researchers to solve the *Grand Challenges*. For example, the identification of novel risk factors for Alzheimer's disease based on a large-scale meta-analysis are founded on prior estimates on human genetic variation calculated from public datasets. The development and validation of drug-design tools, many of which have been successfully commercialised, has relied on carefully curated datasets extracted from publicly archived data resources such as the Protein Data Bank.

DESCRIPTION

The distributed infrastructure for life-science information (ELIXIR) is a unique initiative that consolidates national centres, services, and core bioinformatics resources into a single, coordinated infrastructure. ELIXIR coordinates and develops life science resources across Europe so that researchers can more easily find, analyse and share data, exchange expertise, and implement best practices, and gain greater insights into how living organisms work. By coordinating these resources, ELIXIR helps address the *Grand Challenges* across life sciences, from marine research – via plants and agriculture – to health research and medical sciences.

In 2013, ELIXIR became a permanent legal entity following the ratification of the ELIXIR Consortium Agreement (ECA) by EMBL and the first funding five countries. At present, ELIXIR includes 20 countries and an inter-governmental organisation (EMBL) that have signed the ECA and are full members of the ELIXIR Board. In addition, one country is an Observer.

ACTIVITY

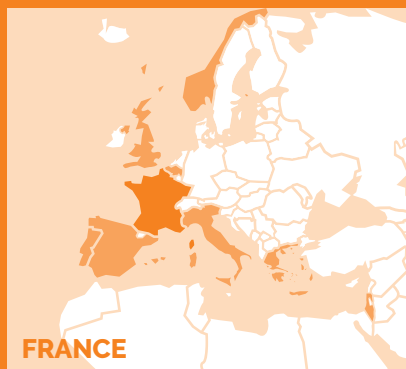
ELIXIR is a distributed Research Infrastructures, which builds on existing data resources and services across Europe. It follows a Hub and Nodes model, with a single Hub located alongside

EMBL-EBI at the Wellcome Genome Campus in Hinnton (Cambridge, UK) and a growing number of Nodes located at centres of excellence throughout Europe, which coordinate nationally the bioinformatics services within that country.

The ELIXIR Hub accommodates the ELIXIR Executive Management and the administrative staff, coordinates and supports integration of services run from the ELIXIR Nodes, has overall responsibility for developing and delivering the ELIXIR Programme and managing ELIXIR-funded activities carried out by Nodes. The Hub coordinates and supports ELIXIR's governance bodies and technical committees works with other biomedical science infrastructures to help address the challenges of Big Data together. It leads ELIXIR's communications and external relations activities, including support to industry supports the institutions within the Node, and collaborates with national and European funders and policy-makers.

ELIXIR Nodes, sited throughout ELIXIR Members' countries, run the resources and services that are part of ELIXIR infrastructure. An ELIXIR Node is a collection of research institutes within a member country and each Node has a lead institute that oversees the work of that Node. The Nodes build on the strengths of the scientific communities

A WORLD-CLASS PLATFORM FOR FUNDAMENTAL AND APPLIED RESEARCH ON MARINE BIORESOURCES AND MARINE ECOSYSTEMS



FRANCE

EMBRC ERIC

European Marine Biological Resource Centre

TYPE distributed

LEGAL STATUS ERIC, 2018

POLITICAL SUPPORT

lead country: FR

member countries: BE, EL, ES, IL, IT, NO, PT, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2011-2014

Preparation Phase

2017

Operation Start

2014-2016

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 164.4 M€

design: 15.7 M€

preparation: 4.9 M€

construction: 92 M€

operation: 11.2 M€/year

HEADQUARTERS

EMBRC ERIC
Paris, France

WEBSITE

www.embrc.eu

DESCRIPTION

The European Marine Biological Resource Centre (EMBRC) is a distributed Research Infrastructures providing a strategic delivery mechanism for excellent and large-scale marine science in Europe. EMBRC offers services to users from academia, industry, technology and education in all sectors in the fields of marine biology and ecology, particularly supporting the development of blue biotechnologies. Users will be able to easily search EMBRC services and prices and make requests on the EMBRC access portal on the EMBRC website. The EMBRC investigation capacity and capability covers the whole range of marine biodiversity, using approaches ranging from molecular biology to ecology, chemistry, bioinformatics and mathematics, and to integrative biology. EMBRC key thematic areas include marine biodiversity and ecosystem function, developmental biology and evolution, marine products and resources – biotechnology, aquaculture, fisheries – and biomedical science.

In the ESFRI Roadmap since 2008, EMBRC established the European Research Infrastructure Consortium (ERIC) in 2018.

ACTIVITY

Marine biodiversity is becoming a major target for fundamental science as well as an increasingly important resource for food, energy and industrial applications. EMBRC will provide key facilities, equipment and services to access and study marine ecosystems and biodiversity, to develop key enabling technologies and to deliver training for staff and users as well as joint development activities to improve access to marine biological

resources and marine models. EMBRC will develop system administration and data integration and connect to important e-Infrastructures in life and environmental sciences. The RI is at a pivotal position between biological sciences, biomedical sciences and agronomical, ecological and environmental science, with a unique potential to attract new actors in marine biology. It will deliver new resources and new services, leading to new processes and products for Blue Growth. EMBRC addresses Europe's *Grand Challenges*, including Biodiversity, Food Security and Competitive Industry. In particular, the RI complies with the following demands: respond to growing demand for bioresources, develop sustainable new materials, strengthen knowledge for health research and train future scientists.

EMBRC will act as a centre for knowledge transfer and as a core technology infrastructure for the utilisation of marine bioresources. It will provide the framework to significantly enhance interactions between science and industry, notably in the key domains of resource management and conservation, aquaculture and blue biotechnology. It will offer access to the infrastructure sites, on-site or remote access to biological resources and analytical services as well as virtual access to data. It will help to coordinate the negotiation of Material Transfer Agreements and host and collaborative

agreements, in order to avoid restrictions in accessing the Research Infrastructure.

IMPACT

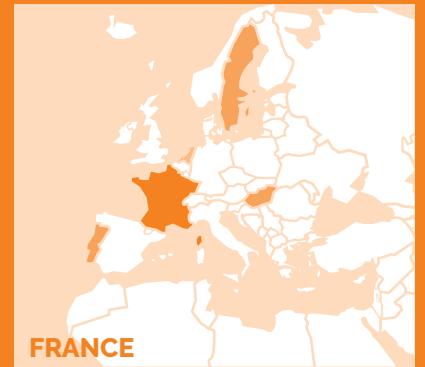
EMBRC members operate their centres, facilities, laboratories mostly in Marine Research Stations that are located in maritime peripheral European regions. Thus, EMBRC Research Infrastructures are often geographically separated from major areas of industry concentrations; they are located in areas with lower economies and unemployment rates sometimes above the European or their respective national averages. EMBRC nodes help to overcome isolation of the regions and to build trans-regional/national complementarities and synergies. EMBRC not only evidences the territorial socio-economical impact but it has also the potential to provide this impact via its outcome of research and innovation strategies using its biological resources and technological platforms. This kind of socio-economic impact would have wider and maybe also more important impact as it could be showed across all EU countries.

EMBRC has in recent years developed closer collaboration with relevant industries. It can be expected that EMBRC will play a central role in addressing the development of bioresources and contribute to establish a prominent European Blue Bioeconomy.

ERINHA

European Research Infrastructure on Highly Pathogenic Agents

THE EUROPEAN
COORDINATION
FOR THE STUDY OF
HIGHLY PATHOGENIC
MICRO-ORGANISMS
CLASSIFIED AS RG4



FRANCE

TYPE distributed

LEGAL STATUS AISBL, 2017

POLITICAL SUPPORT

lead country: FR

member countries: HU, PT, SE

prospective member country: NL

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2010-2017
Preparation Phase

2018
Operation Start

2017-2018
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 5.8 M€

design: Not Available

preparation: 5.1 M€

construction: 0.7 M€

operation: 0.7 M€/year

HEADQUARTERS

ERINHA AISBL
Brussels, Belgium &
ERINHA CCU
Paris, France

WEBSITE

www.erinha.eu

a coordinated pan-European distributed RI providing access to high containment facilities and complementary functions.

ERINHA is the sole European Research Infrastructure specifically dedicated to Highly infectious pathogens of RG4 study. It is a unique and innovative infrastructure that intends to bring Europe to the forefront of research on highly virulent agents and offer European expertise to overcome and prevent the spread of epidemics. ERINHA contributes to the H2020 societal challenge *Secure societies – protecting freedom and security of Europe and its citizens and Health, Demographic Change and Wellbeing*.

IMPACT

The benefit to society by coordinating capacities to prevent and respond to the spread of epidemics is high, directly affecting human health, avoiding negative impact on national health care systems, and on the economy. Disease outbreaks cost millions to countries' economies, therefore optimising Europe's preparedness to detect and tackle these diseases is crucial.

ERINHA has potential to contribute to boost European competitiveness and Research & Innovation. It aims to facilitate complex and comprehensive research programmes able to compete with those conducted outside the EU. It has capacity to respond to the needs of academia and industry better and faster than the field would in general. Industry is an important user sector, interested in paying the facilities to run their own experiments rather than access the facilities themselves. This could contribute to ERINHA's long term sustainability and ERINHA will need to balance the needs of its different users.

DESCRIPTION

The European Research Infrastructure on Highly Pathogenic Agents (ERINHA) aims to develop an adequate and coordinated effort to address the challenges posed by the emergence or re-emergence of highly dangerous human and animal micro-organisms infecting humans, with high risks for public health, society and the economy. ERINHA seeks to reinforce the European capacities for the study of Risk Group 4 pathogens, enhance the coordination of Biosafety Level 4 (BSL-4) activities and give access to BSL-4 and complementary facilities to all interested European scientists by establishing a pan-European distributed RI.

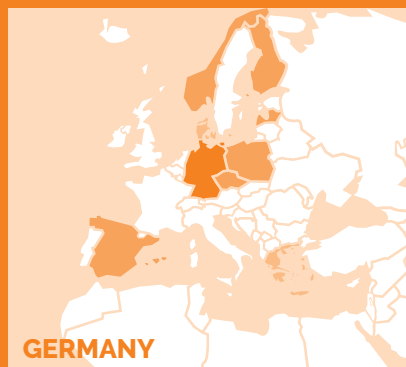
ERINHA encompasses basic research into pathogen isolation/characterisation, the pathogenesis of human diseases caused by dangerous micro-organisms. It enables translational research to develop new counter measures including diagnostic tools, therapeutics and prophylactics and applied research to improve knowledge, skills and the evidence-base around high containment working practices.

ERINHA is on the ESFRI Roadmap since 2008 and in the Implementation Phase since July 2017.

ACTIVITY

One of the great challenges of the 21st century is the capability to react on human and animal highly pathogenic micro-organisms which are characterized by a high mortality rate induction, unavailability of prophylactic or therapeutic means and easy human-to-human transmission. All infectious micro-organisms are classified by risk group according to the pathogenicity, modes of transmission and host range of the organism. The most highly infectious pathogens are classified as Risk Group 4. To protect environment from spread and to protect scientists from infection, these micro-organisms must be handled and stored in Biosafety Level 4 facilities. The recent epidemic context – outbreak of Ebola, recent cases of Lassa and CCHF in Europe – have demonstrated the reality of dangerous infectious threats and the worldwide vulnerability towards emerging and re-emerging infectious diseases and has highlighted the need for such an infrastructure to prevent and respond to the spread of epidemics more effectively and efficiently. A European coordinated strategy is needed to ensure preventing each European citizen from pandemics or bioterrorist attack involving suspected group 4 pathogens. It implies

THE HIGH-THROUGHPUT
SCREENING PLATFORMS AND
CHEMISTRY RESOURCES FOR
LIFE SCIENCES



GERMANY

DESCRIPTION

The European Infrastructure of Open Screening Platforms for Chemical Biology (EU-OPENSREEN) is a distributed Research Infrastructure that develops novel small chemical compounds which elicit specific biological responses on organisms, cells or cellular components. EU-OPENSREEN enables scientists to use compound screening methods to validate novel therapeutic targets and support basic mechanistic studies addressing fundamental questions in cellular physiology – across human, animal and plant systems – using the methods of chemical biology. As a large-scale RI with an “open” pre-competitive character, EU-OPENSREEN is a cost-effective solution to the need of the broad scientific community providing access to Europe’s leading screening platforms and chemistry groups, constructing a jointly used compound collection and operating an open-access database accessible on a global basis.

In the ESFRI Roadmap since 2008, EU-OPENSREEN has established the European Research Infrastructure Consortium (ERIC) in 2018.

ACTIVITY

Understanding how biological processes operate and how the underlying mechanisms function at the organismic, cellular, and molecular level is fundamental to a knowledge-based management of the needs and risks of the world’s growing population. This understanding touches all aspects of life such as human health and well-being, nutrition and environment. Ground-breaking insights into cellular and organismic metabolic or signalling pathways, which are involved – e.g in the progression of diseases – are gained by studying the effect of chemical compounds on biological

EU-OPENSREEN ERIC

European Infrastructure of Open Screening Platforms for Chemical Biology

TYPE distributed

LEGAL STATUS ERIC, 2018

POLITICAL SUPPORT

lead country: DE

member countries: CZ, ES, FI, LV, NO, PL

prospective member countries: DK, EL

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2010-2013
Preparation Phase

2018-2019
Implementation/Construction Phase

2013-2017
Interim/Transition Phase

2019
Operation Start

ESTIMATED COSTS

capital value: 82.3 M€

design: Not Available

preparation: 4.3 M€

construction: 6.2 M€

operation: 1.2 M€/year

HEADQUARTERS

EU-OPENSREEN ERIC
Berlin, Germany

WEBSITE

www.eu-openscreen.eu

systems – i.e. pharmacology. Post-genome biology with its powerful technologies of genome sequencing, transcriptomics, proteomics and metabolomics has provided a deluge of information on new cellular targets for basic research and early drug discovery. Unfortunately, the availability of suitable tools for systematic biochemical investigation of cellular target and pathway function is substantially lagging behind this deluge of omics data. This forms the basis for the development of novel diagnostic and therapeutic approaches in health research and opens novel opportunities in many other areas of the Life Sciences.

EU-OPENSREEN integrates high-capacity screening platforms throughout Europe, which jointly use a rationally selected compound collection, comprising commercial and proprietary compounds collected from international chemists. By testing systematically and repeatedly this chemical collection in hundreds of assays originating from very different biological themes, the screening process generates enormous amounts of information about the biological activities of the substances and thereby steadily enriches our understanding of how and where they act. EU-OPENSREEN supports all stages of a tool development project, including assay adaptation, high-throughput screening, and chemical optimisation of the hit compounds.

All tool compounds and data are made available to the scientific community.

IMPACT

EU-OPENSREEN may have several impacts, not only from the perspective of the RI in sharing technologies and data but also from the societal point of view. This is exemplified by mentioning the demand to generate improved efficacy and safety of health treatments in the day-to-day lives of European citizens. In addition to pharmacology applications in early drug discovery and toxicology, EU-OPENSREEN also covers the production of crop-protective compounds, which are of paramount importance to society via the understanding of the response of wild or crop plants to environmental and agricultural substances. The broad biology approach of EU-OPENSREEN will promote the availability of safe, efficacious and sustainable chemical products for unmet needs in medicine, nutrition, agriculture and the environment.

Academic stakeholders, providing the physical screening infrastructure, are joined by industrial stakeholder companies – large, medium and small – of the Pharmaceutical, Agri-Science and Biotechnology sectors. By doing so, EU-OPENSREEN will advance the development of solutions for the *Grand Challenges* and guarantee the European competitiveness.

Euro-BioImaging

European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences

THE LARGE-SCALE OPEN PHYSICAL USER ACCESS TO STATE-OF-THE-ART BIOLOGICAL AND BIOMEDICAL IMAGING TECHNOLOGIES

TYPE distributed

LEGAL STATUS ERIC Step2, 2018

POLITICAL SUPPORT

lead country: FI

member countries: BG, CZ, HU, IT, NO, PT, (EMBL)

***observer:** BE

prospective member countries: AT, EL, ES, IL, NL, PL, SK, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2010-2014

Preparation Phase

2016-2018

Implementation/Construction Phase

2014-2015

Interim/Transition Phase

2016

Operation Start

ESTIMATED COSTS

capital value: 90 M€

design: Not Available

preparation: 5.2 M€

construction: 21 M€

operation: 1.6 M€/year

HEADQUARTERS

to be hosted in Finland

WEBSITE

www.eurobioimaging.eu



compute services. The significantly improved research conditions for life scientists will increase European competitiveness, exchange the brain drain for a brain gain and open new research fields to European researchers. In a next step, this will fundamentally advance the molecular understanding of health and disease. For example, new and faster drug development processes will be enabled, leading to better diagnosis, therapy and disease prevention.

DESCRIPTION

The European Research Infrastructure for Imaging Technologies in Biological and Biomedical Sciences (Euro-BioImaging, EuBI) provides a large-scale open physical user access to state-of-the-art imaging technologies for life scientists. It will offer image data support and training for infrastructure users and providers and continuously evaluate and include new imaging technologies to ensure sustainable cutting-edge services. EuBI consists of a set of complementary, strongly interlinked and geographically distributed Nodes – specialised imaging facilities – to reach European scientists in all Member States. The infrastructure is empowered by a strong supporting and coordinating entity, the EuBI Hub. The Hub provides the virtual entry point from which users are directed to their desired technology as served by the respective EuBI Nodes. Since May 2016, EuBI has opened Interim Operation and provides open access to 28 of 29 Node Candidates in 11 countries and at EMBL, offering 36 imaging technologies.

In the ESFRI Roadmap since 2008, EuBI is striving to establish the European Research Infrastructure Consortium (ERIC) by 2018.

ACTIVITY

Advanced and innovative imaging technologies are becoming increasingly

important for analysis of molecular dynamics in cells and organisms, delivering crucial information more easily than standard biochemical methods. Nevertheless, European life scientists often lack access to pioneering imaging technologies. EuBI reduces this gap by coordinating a distributed imaging infrastructure offering open access to external users from other European research institutions. Such open access model brings numerous benefits to the scientific community: it mitigates the scarcity of expert staff and the high costs for individual institutions to install innovative imaging technologies; it increases international cooperation and boosts transfer of knowledge among European researchers. EuBI will allow life scientists working in academia, health care and industry to gain access to a broader range of much-needed advanced imaging technologies and knowledge, building bridges from basic biological to medical and clinical research.

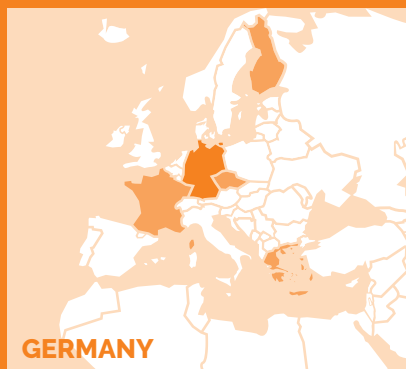
In practice, the EuBI ERIC provides: i) physical access to cutting-edge imaging technologies at the Nodes, including advanced probes, expertise and training, methods, software and analysis tools, and ii) virtual access to common image data services provided by the Hub such as software tools for image processing, common repositories for reference image data sets for sharing and re-use, academically owned cloud storage and

IMPACT

The massively improved research conditions for life scientists will not only allow Europe to secure its global leadership position in imaging technologies and open new research fields to European research but also to fundamentally advance the molecular understanding of health and disease. New and faster drug development will be enabled, leading to better diagnosis, therapy and disease prevention and therewith increasing the quality of life for patients. In addition, EuBI will provide the essential imaging infrastructure for European scientists to develop the innovative solutions for other *Grand Challenges* including food security, bio-economy, inclusive and innovative societies.

By opening access to the complete range of cutting-edge technologies while at the same time coordinating and sharing the costs of deployment, EuBI allows its Member States a much better return on investment for biological and medical imaging platforms. The harmonization of access to imaging technologies across Europe Infrastructures overcomes the current duplication of infrastructure investments and the fragmentation of the European research landscape in this area.

A COLLECTION OF SERVICES ON MOUSE MODELS TO UNRAVEL THE ROLE OF GENE FUNCTION IN HUMAN HEALTH AND DISEASE



GERMANY

INFRAFRONTIER

European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models

TYPE distributed

LEGAL STATUS GmbH, 2013

POLITICAL SUPPORT

lead country: DE

member countries: CZ, EL, FI, FR, (EMBL)

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2012

Preparation Phase

2013

Operation Pstart

2010-2013

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 180 M€

design: Not Available

preparation: Not Available

construction: Not Available

operation: 80 M€/year

HEADQUARTERS

INFRAFRONTIER GmbH
Munich, Germany

WEBSITE

www.infrafrontier.eu

DESCRIPTION

The European Research Infrastructure for the generation, phenotyping, archiving and distribution of mouse disease models (INFRAFRONTIER) is providing the biomedical research community with the tools needed to study the systemic effects of genetic alterations to unravel the role of gene function in human health and disease. By offering access to a unique collection of mouse models and research tools and associated data, and to state-of-the-art technologies for mouse model development and phenotype analyses, INFRAFRONTIER enhances medical research by promoting studies that lead to breakthrough discoveries in cancer, metabolic and cardiovascular diseases, lung diseases, infectious diseases and the group of rare diseases, global threats to our socio-economic wellbeing.

The INFRAFRONTIER GmbH was established in April 2013. The application for the INFRAFRONTIER ERIC is currently under preparation in an Inter-Ministry Working Group.

ACTIVITY

In basic biomedical research the identification of the genetic bases for human disease is a fundamental goal and the investigation of gene function through mouse mutants and phenotyping is a central element in achieving this goal. The disease models available from INFRAFRONTIER can be used to address basic and fundamental scientific questions about in vivo gene function and may further our understanding of disease genetics. The number of human genetic studies has increased over the last years and a great opportunity now exists to validate possible disease candidates and

pathways in human using mouse models. Overall, the mouse is widely regarded as the best model system for developing an understanding for human biology.

The INFRAFRONTIER RI is providing open access to international resources for mouse models, data, scientific platforms and services to study the functional role of the genome in human health and disease and supports the global user community in biomedical research. INFRAFRONTIER provides access to: i) mouse disease model generation using different genetic resources and technologies; ii) archiving and distributing of scientifically valuable mouse strains through the European Mouse Mutant Archive (EMMA), the third largest mouse repository worldwide and integral component of INFRAFRONTIER; iii) whole-organism, systemic analysis of genotype-phenotype interactions using cutting-edge analytical and diagnostic methodology in the INFRAFRONTIER mouse clinics. INFRAFRONTIER supports a bottom-up approach for individual scientists and research groups and provides top-down capacities for large-scale international initiatives such as the International Mouse Phenotyping Consortium (IMPC).

In addition, INFRAFRONTIER offers a wide range of state-of-the-art training opportunities and consulting services. Training courses cover hands on

cryopreservation courses that are offered by EMMA partners for many years. Mouse clinics of INFRAFRONTIER offer outstanding training opportunities in first-line mouse phenotyping as well as specialised phenotyping courses.

IMPACT

In addition to the wide use to focus on basic and fundamental scientific questions in human health and disease, mouse models are exploited for addressing more applied questions ranging from the identification and validation of novel drug targets to the analysis of drug action and side effects and safety and efficacy testing of potential drugs. Drug companies exploit phenotype results from mouse models at multiple key decision points during pre-clinical research, including target and compound selection but also for avoiding unwanted target liabilities that could lead to failures later on in the clinic.

Furthermore, genetically engineered mouse models are successfully used for testing treatment regimes in co-clinical trials in mouse and humans contributing to the rational design of clinical trials. By offering open access to centralised and sustainable gold-standard resources, INFRAFRONTIER reduces duplication of efforts thereby contributes to cost efficiency, reduction of animal use, and data reproducibility.

INSTRUCT ERIC

Integrated Structural Biology Infrastructure

A PEER-REVIEWED
ACCESS TO A BROAD
RANGE OF TECHNOLOGY,
EXPERTISE AND TRAINING
IN STRUCTURAL BIOLOGY

TYPE distributed

LEGAL STATUS ERIC, 2017

POLITICAL SUPPORT

lead country: UK

member countries: BE, CZ, DK, FR, IL, IT, NL, PT, SK

***observers:** EL, ES, SE, (EMBL)

prospective country: FI

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2012

Preparation Phase

2012-2017

Implementation/Construction Phase

2011-2012

Interim/Transition Phase

2017

Operation Start

ESTIMATED COSTS

capital value: 400 M€

design: Not Available

preparation: 8 M€

construction: 175 M€

operation: 30 M€/year

HEADQUARTERS

Instruct ERIC
Oxford, United Kingdom

WEBSITE

www.instruct-eric.eu



UNITED KINGDOM

constantly increasing. INSTRUCT is working to reinforce the ERA by establishing commonalities with other RI procedures and service provision. A key contribution is the access management system (ARIA) which was developed by INSTRUCT and is made available to other ESFRI and national infrastructures, helping to create a common web platform that supports cross-disciplinary RI use. INSTRUCT has and continues to establish an extensive network of international partners. MoUs and formal partnerships have been defined or are at final stages of definition with China, India, Brazil, Argentina, Uruguay and Mexico, and with the Middle East synchrotron SESAME in Jordan.

IMPACT

The impact of structural biology is considerable, including both academic, commercial and more indirect economic gains. INSTRUCT ERIC has a direct impact on academic science: it serves a community of more than 35,000 structural biologists. Dissemination and training activities targeting non-structural biological scientists potentially expand the user community to more than 100,000 with a potential to exceed 400,000 globally.

INSTRUCT is embedded in the drug discovery process through collaborations with several European companies and the EU-funded vaccine network. There is considerable potential to contribute to the design of innovative, effective and safe medicines using structural approaches. Any reduction in the burden of disease through improved prevention and/or treatment produces considerable potential economic gains, as well as contributing to healthier ageing and improved public health.

DESCRIPTION

The Integrated Structural Biology Infrastructure (INSTRUCT) is a distributed Research Infrastructure that provides peer-reviewed access to a broad palette of state-of-the-art technology and expertise as well as training and technique development in the area of integrated structural and cell biology, with the major goal of underpinning fundamental research and promoting innovation in the biological and medical sciences. Biological and medical research requires an integrated approach combining multiple technologies: INSTRUCT is a major player in delivering this strategy, promoting innovation and discovery in biomedical science, defining a plan for structural biology in Europe that will help to develop the European Research Area, supporting the biotechnology and pharmaceutical industries, and helping to meet the *Grand Challenges* as defined by Horizon 2020.

Entered in the ESFRI Roadmap 2006, INSTRUCT established the European Research Infrastructure Consortium (ERIC) in July 2017.

ACTIVITY

INSTRUCT ERIC offers access to structural biology facilities at its Centres upon

application by the users. All proposals are peer-reviewed using an efficient and transparent process. Applications for access can be submitted at any time or via special calls with specific criteria. All applications are evaluated on scientific merit with specific attention for those that require innovative integrative approaches. INSTRUCT ERIC provides advanced technologies and unique expertise across the range of technologies and methods for sample preparation, structural and cellular characterisation, and data analysis. Access to the advanced technologies are underpinned by foundation methods at each Centre to ensure high sample quality and preparative work.

In addition to access to state-of-the-art technologies, INSTRUCT also generates scientific output through grants for small pilot projects, internships, and an extensive training programme. In five years of operations, 49 Training Courses have been commissioned and funded, 26 internships have been awarded, 35 R&D pilot awards have been made. The training courses have included a total number of 695 participants who have had opportunities to improve their skills in structural biology methods. A total of 455 publications have acknowledged INSTRUCT support and the number is

CHERENKOV TELESCOPE
ARRAY FOR HIGH-ENERGY
GAMMA-RAY ASTRONOMY
TO PROBE A NON-THERMAL
UNIVERSE



CTA
Cherenkov Telescope Array

TYPE single-sited

LEGAL STATUS gGmbH, 2014

POLITICAL SUPPORT

lead country: IT

member countries: AT, AU, CH, CZ, DE, ES, FR, JP, SI, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2011-2016

Preparation Phase

2019-2024

Implementation/Construction Phase

2017-2018

Interim/Transition Phase

2024

Operation Start

ESTIMATED COSTS

capital value: 400 M€

design: Not Available

preparation: 8 M€

construction: 297 M€

operation: 20 M€/year

HEADQUARTERS

CTAO gGmbH

Heidelberg, Germany

WEBSITE

www.cta-observatory.org

DESCRIPTION

The Cherenkov Telescope Array (CTA) is a Research Infrastructure for ground-based very high-energy gamma-ray astronomy. With two host sites in the southern and northern hemispheres – on the European Southern Observatory (ESO) at Paranal grounds in Chile and at the Instituto de Astrofísica de Canarias (IAC) in Roque de los Muchachos Observatory in Spain – it will extend the study of astrophysical origin of gamma-rays at energies of a few tens of GeV and above, and investigate cosmic non-thermal processes. CTA will provide the first complete and detailed view of the universe in this part of the radiation spectrum and will contribute towards a better understanding of astrophysical and cosmological processes, such as the origin of cosmic rays and their role in the Universe, the nature and variety of particle acceleration around black holes and the ultimate composition of matter and physics beyond the Standard Model.

In the ESFRI Roadmap since 2008, CTA became a gGmbH in 2014 and is actually striving to establish the European Research Infrastructure Consortium (ERIC) with operations expected to start in 2024.

ACTIVITY

High-energy gamma-rays probe a non-thermal Universe because, apart from the Big Bang, there is nothing hot enough in the known Universe to emit such gamma-rays. These gamma-rays can be generated when highly relativistic particles collide with ambient gas, or interact with photons and magnetic fields (bottom-up process). By studying their energy and flux spectrum, it is possible to trace these cosmic rays and electrons in distant regions of our own Galaxy or even in other galaxies. High-energy gamma-rays can also be produced in a top-

down fashion by decays of heavy particles such as the hypothetical dark matter particles. Therefore, gamma-rays provide a window to the discovery of the nature and constituents of dark matter, relics which might be left over from the Big Bang. The present generation of imaging atmospheric Cherenkov telescopes (H.E.S.S., MAGIC and VERITAS) has in recent years opened the realm of ground-based gamma-ray astronomy in the energy range above a few tens of GeV. The Cherenkov Telescope Array will explore our Universe in depth in Very High Energy (VHE, E>10 GeV) gamma-rays and investigate cosmic non-thermal processes, in close cooperation with observatories operating at other wavelength ranges of the electromagnetic spectrum, and those using other messengers such as cosmic rays and neutrinos.

CTA will consist of arrays of Cherenkov telescopes that will be built at two separate sites, one in the southern hemisphere with wide gamma-ray energy range and high resolution to cover the plane of the Milky Way, and the second in the northern hemisphere specialised for lower energies, which will focus on extragalactic and cosmological objects. The array will allow the detection of gamma-ray induced cascades over a large area on the ground, increasing the number of detected gamma rays dramatically, while at the same time providing a much larger number of views of each cascade. The design foresees an improvement in sensitivity of a factor of 5-10 in the current very high-energy

gamma ray domain from ~ 100 GeV to some 10 TeV – and an extension of more than three orders of magnitude in the accessible energy range, up to above 100 TeV.

IMPACT

CTA has broad social and economic impact. In social dimension, being a world-wide RI, CTA fosters international collaboration and mobility across not only Europe but also Americas, Asia, Africa and Australia requiring people from different cultures work together. It also creates a unique network of researchers in academia and in industry giving a new dimension to the publicly funded basic science.

CTA telescopes demand forefront research and their large number implies that technologies involved cannot remain at laboratory scale but need to scale up to large deployment of products useful for commercialisation and application in other areas – e.g. photosensors with vastly improved characteristics may find application in medical imaging. SMEs in different countries are already involved in production of CTA components, and various aspects of operation and maintenance of CTA will be outsourced to local industry. The array sites, headquarters and data management centre will attract skilled individuals who will directly contribute to the local economy and training of local technicians and engineers in an intellectually challenging environment.

ELI

Extreme Light Infrastructure

THE WORLD'S FASTEST AND MOST INTENSE ADVANCED LASERS TO UNRAVEL THE FUNDAMENTAL SECRETS OF THE UNIVERSE AND MATERIALS



CZECH REPUBLIC, HUNGARY, ROMANIA

TYPE distributed

LEGAL STATUS AISBL, 2013

POLITICAL SUPPORT

lead countries: CZ, HU, RO

member countries: DE, FR, IT, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2007-2010

Preparation Phase

2018

Operation Start

2011-2017

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 850 M€

design: Not Available

preparation: 6 M€

construction: 850 M€

operation: 80 M€/year

HEADQUARTERS

ELI-DC AISBL
Brussels, Belgium

WEBSITE

www.eli-laser.eu

two machines, a very high intensity laser, where beams from two 10 PW lasers are coherently added to get intensities of the order of 10^{23} - 10^{24} W/cm², and a very intense, brilliant gamma beam, which is obtained by incoherent Compton back scattering of a laser light off a brilliant electron beam from a conventional linear accelerator. Applications include nuclear physics experiments to characterize laser - target interaction, photonuclear reactions, and exotic nuclear physics and astrophysics (<http://www.eli-np.ro>).

DESCRIPTION

The Extreme Light Infrastructure (ELI) is a Research Infrastructure of global interest using extreme light-matter interactions at the highest intensities, shortest time scales and broadest spectral range. ELI will provide unprecedented energy and attosecond resolution of coherent radiation and laser-accelerated particles for fundamental studies in atomic, molecular, plasma and nuclear physics to serve a large variety of scientific applications, ranging from biology, chemistry and medicine to astrophysics in the laboratory.

ELI has facilities in the Czech Republic, Hungary and Romania with complementary scientific profiles. Construction has been implemented by national authorities in the host countries and coordinated by the ELI Delivery Consortium International Association (ELI-DC), International not-for-profit Association under Belgian Law (AISBL). The three facilities will jointly operate as a European Research Infrastructure Consortium (ERIC) starting in 2018.

ACTIVITY

In Dolni Brezany, near Prague, Czech Republic, the ELI-Beamlines facility

mainly will focus on the development of short-pulse secondary sources of radiation and particles, and on their multidisciplinary applications in molecular, biomedical and material sciences, physics of dense plasmas, warm dense matter, laboratory astrophysics. In addition, the pillar will utilise its high-power, high-repetition-rate lasers for high-field physics experiments with focused intensities of about 10^{23} W/cm², investigating exotic plasma physics, and non-linear QED effects (www.eli-beams.eu).

The ELI Attosecond Light Pulse Source (ELI-ALPS) in Szeged, Hungary is establishing a unique facility, which provides light sources between THz (10^{12} Hz) and x-ray (10^{18} - 10^{19} Hz) frequency range in the form of ultrashort pulses with high repetition rate. ELI-ALPS will be dedicated to extremely fast dynamics by taking snap-shots in the attosecond scale (a billionth of a billionth of second) of the electron dynamics in atoms, molecules, plasmas and solids. It will also pursue research with ultrahigh intensity lasers (<http://www.eli-alps.hu>).

In Magurele, Romania, the ELI Nuclear Physics (ELI-NP) facility focuses on laser-based nuclear physics. It will host

IMPACT

The Extreme Light Infrastructure will lead to new regimes in fundamental physics, enable the advent of new technologies, and deliver particles and photon sources with extreme high energies, beyond the physical limits of conventional technologies. As the first international laser user facility, ELI is open to an international community of scientific and industrial users, attracting the world's best scientists to unique research opportunities including physics, chemistry, biology, medicine, materials sciences, and combinations thereof.

Contributions to *Grand Societal Challenges* will cover a broad range of areas: analytical studies in environmental research, climate research, medical diagnostics and treatment, pharmacology, bio-medicine, or from materials research for renewable and nuclear energies, nuclear waste management, and space applications.

THE WORLD'S BIGGEST
EYE ON THE SKY TO
REVOLUTIONISE OUR
PERCEPTION OF THE
UNIVERSE



ELT

Extremely Large Telescope

TYPE single-sited

LEGAL STATUS ESO, EIROforum member

POLITICAL SUPPORT

lead entity: ESO

The following countries are members of ESO

member countries: AT, BE, CH, CZ, DE, DK, ES, FI, FR, IT, NL, PL, PT, SE, UK

prospective member country: IE

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2006-2012
Preparation Phase

2024
Operation Start

2014-2024
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 1120 M€

design: Not Available

preparation: Not Available

construction: Not Available

operation: 45 M€/year

HEADQUARTERS

ESO
Garching bei München, Germany

WEBSITE

www.eso.org/public/teles-instr/elt

DESCRIPTION

Extremely Large Telescope (ELT) is a revolutionary new ground-based telescope for the advancement of astrophysical knowledge, allowing detailed studies of objects including planets around other stars, the first objects in the Universe, super-massive black holes, and the nature and distribution of the dark matter and dark energy which dominate the Universe. Equipped with a 39-metre primary mirror, the ELT will be the largest optical/near-infrared telescope in the world: the world's biggest eye on the sky.

The ELT is an integral part of ESO, the EIROforum organisation operating facilities at a number of sites in Chile. The ELT programme was approved in 2012 and green light for the first phase of construction was given at the end of 2014. It will be located at Cerro Armazones, a 3060-metres high mountain in the central part of Chile's Atacama Desert, about 20 kilometres from Cerro Paranal, home of ESO's Very Large Telescope (VLT). The ELT construction is expected to be completed by 2024.

ACTIVITY

The telescope's primary mirror will be almost half the length of a soccer pitch in diameter and will gather 15 times more light than today's largest optical telescopes. The optical design comprises a three-mirror anastigmat with two flat folding mirrors providing the adaptive optics to correct for the turbulent atmosphere, giving unprecedented image quality. One is supported by more than 5,000 actuators operating at a frequency of 1,000 Hz. The primary mirror consists of 798 hexagonal segments, each 1,4 metres wide. The secondary mirror will have a diameter

of 4 metres. The telescope will have several science instruments, with switching from one instrument to another within minutes. The ability to observe over a wide range of wavelengths from the optical to mid-infrared will allow scientists to exploit the telescope's size to the fullest extent.

Science with the ELT covers many areas of astronomy – from the Solar System to extra-solar planets, from nearby galaxies to the furthest observable objects at the edge of the visible Universe, from fundamental physics to cosmology. They include discovering and characterising planets and proto-planetary systems around other stars, resolving stellar populations in a representative sample of the Universe, the study of the physical processes that form and transform galaxies across cosmic time, the discovery and identification of distant type Ia supernovae and constraining dark energy by directly observing the global dynamics of the Universe, as well as searching for possible variations over cosmic time of fundamental physical constants.

IMPACT

The ELT is a major technological challenge and triggers industrial interest and preparedness to deliver extraordinary performance, as it occurred in previous ESO projects (notably the VLT and ALMA).

ESO has since many years devolved its instrumentation programme so that science instruments are largely designed and built by national institutes, often in collaboration with industry. In this model, national facilities cover the human resources cost against compensation in guaranteed observing time. The ELT will employ advanced technologies and engineering solutions in a number of areas, from gigantic, lightweight high-precision structures, opto-mechanical systems, optical design and control systems. Many of these technologies will be applicable to other areas of technology development. As regards short-term benefits, these are found in spin-off technologies and the inspirational and educational aspects, strengthening the scientific and engineering recruitment base and public awareness of science.

Concerning the contribution to societal challenges, astronomy is basic science in its most fundamental form and its main purpose is to enhance our understanding of the Universe, its evolution and the role of planet Earth as our cosmic home. Astronomy findings have a profound impact on society in the long run, both in technological and cultural terms. Astronomy is a major theme in education and training, inspiring new generations in STEM topics. It also triggers innovative technology solutions, and international cooperation.

EMFL

European Magnetic Field Laboratory

A UNIQUE EFFORT TO
GENERATE THE HIGHEST
POSSIBLE MAGNETIC FIELDS
FOR EXCELLENT RESEARCH

TYPE distributed

LEGAL STATUS AISBL, 2015

POLITICAL SUPPORT

lead countries: FR, DE, NL

member country: UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2008

TIMELINE

2009-2012
Preparation Phase

2014
Operation Start

2009-2014
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 170 M€

design: Not Available

preparation: Not Available

construction: Not Available

operation: 20 M€/year

HEADQUARTERS

EMFL AISBL
Brussels, Belgium

WEBSITE

www.emfleu



IMPACT

The EMFL has developed transportable pulsed magnets and generators allowing fields of up to 40 Tesla to be combined with large neutron, X-ray, or laser sources impacting fundamental science programmes across disciplines. Neutron and synchrotron experiments in pulsed fields allow researchers to reveal the microscopic properties of matter; they are conducted jointly between the EMFL and a number of large facilities that are leaders in their field. Both in Dresden and Nijmegen the adjacent THz radiation facilities ELBE and FELIX Laboratory are connected to the high field magnets and offer combined experiments.

Magnetic fields can help defeat cancer as they are used to trace tumours or to do nanodrug delivery, in combination with Magnetic Resonance Imaging (MRI). EMFL researchers also develop a compact and inexpensive beam delivery alternative for proton beam therapy. EMFL supports applied research for forming, joining, and welding metals by using the large compressive forces produced by very short and intense energy-efficient magnetic-field pulse technology with many extra benefits for economy and environment. Magnetic fields can help scientists reveal the hidden physical properties of neodymium-like or other brand new magnetic materials that can be used to create smaller, more efficient electric motors. EMFL supports the application of high-temperature superconductivity to energy storage and transport, and into developing magnetic levitation and was involved in preliminary measurements demonstrating the enormous technological potential of graphene.

DESCRIPTION

The European Magnetic Field Laboratory (EMFL) develops and operates the highest possible magnetic fields that can be used for scientific research, and making them available to the scientific community. The EMFL unites, coordinates and reinforces all existing European large-scale high magnetic field Research Infrastructures in a single body. These facilities are the Laboratoire National de Champs Magnétiques Intenses (LNCMI), with its sites for pulsed fields in Toulouse and continuous fields in Grenoble, the Dresden High Magnetic Field Laboratory (HLD) and the High Field Magnet Laboratory (HFML) in Nijmegen. The EMFL formally represents and operates tasks, in particular the access program, of the parent laboratories. The UK community, represented by the University of Nottingham, joined EMFL at the end of 2015.

The parent organizations of the three facilities have created a legal structure in the form of an International not-for-profit Association under Belgian Law (AISBL) sited in Belgium. The AISBL statutes were signed in January 2015.

ACTIVITY

The LNCMI is a French large-scale facility operated by CNRS and associated to INSA, UPS and UGA, enabling researchers from all over the world to perform experiments

in the highest possible magnetic fields. Continuous fields up to 37 Tesla are available at the Grenoble site. Pulsed fields up to 99 Tesla and 208 Tesla semi-destructively are available at the Toulouse site. The HLD in the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) focuses on modern materials research at high magnetic fields. It serves as a research facility for both in-house and user projects and provides research opportunities for pulsed magnetic fields up to 90 Tesla for routine operation. The HLD aims at reaching magnetic fields up to the feasibility limit of about 100 Tesla. The HFML in Nijmegen is committed to generate the highest available continuous magnetic fields. HFML is a Dutch large European research facility open for external researchers and operated by the Radboud University (RU) and Netherlands Organisation for Scientific Research (NWO). In the HFML resistive magnets with fields up to 37.5 Tesla are available and a 45 Tesla hybrid magnet is under development.

The main research activities supported by the EMFL are: magnetic and superconducting materials, strongly correlated electron systems, low-dimensional magnetic materials, nanostructured materials, magnet design and technology, semiconductors and nano-systems, mesoscopic physics, strongly correlated electron systems, molecular magnetism, soft condensed matter.

REVOLUTIONARY
STORAGE RING AND
BEAMLINES FOR X-RAY
SYNCHROTRON SCIENCE
AND INNOVATION



ESRF EBS

European Synchrotron Radiation Facility Extremely Brilliant Source

TYPE single-sited

LEGAL STATUS ESRF, EIROforum member

POLITICAL SUPPORT

lead entity: ESRF

The following countries are members of ESRF

member countries: BE, CH, DE, DK, ES, FI, FR, IT, NL, NO, RU, SE, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2016

TIMELINE

2012-2015
Preparation Phase

2023
Operation Start

2015-2022
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 128 M€

design: 1 M€

preparation: 1 M€

construction: 150 M€

operation: 82 M€/year

HEADQUARTERS

ESRF
Grenoble, France

WEBSITE

www.esrf.eu

DESCRIPTION

The European Synchrotron Radiation Facility (ESRF) is the world-leading source of synchrotron X-rays. Operating more than 40 beamlines with state-of-the-art instrumentation, the ESRF serves ~10.000 scientists each year who study materials and living matter at the atomic and nanometric scale. It is a truly European facility and a key component of the ERA. The ESRF initiated an Upgrade Programme in 2009, and completed the initial phase in 2015 with 19 new and rebuilt beamlines, enabling 3 orders of magnitude gains in performance for X-ray microscopy and imaging experiments.

The ongoing new phase – the ESRF Extremely Brilliant Source (EBS) – consists of the construction of a new storage ring, based on a revolutionary ESRF lattice design, and of new beamlines that will exploit the new source. EBS, bringing two orders of magnitude increase in source brilliance, will open a new era in X-ray science.

ACTIVITY

The ESRF – the first and highly successful third-generation synchrotron source – started operations in 1994, and since then has promoted and inspired synchrotron science and innovation worldwide.

Every year, ~10.000 scientific users across all disciplines of natural sciences use the ESRF and their work generates ~2.000 peer-reviewed publications. ESRF has delivered up to now ~2.400.000 instrument-hours (i.e. ~140.000 hours/year). Approximately 98% of the beam time at the ESRF is granted through peer-reviewed scientific excellence based

access and 2% is acquired for proprietary research. Approximately 30% of all projects submitted to the ESRF involve innovation/ industrial technology developments. A transparent scheme monitors beam time distribution among the scientists' countries and aims for a *juste retour* with respect to the shareholders' contributions.

The ESRF provides scientific support to users and carries out the necessary research and development work in synchrotron techniques enabling, among others, Nobel Prizes in Chemistry in 2003, 2009 and 2012. The ESRF has created, together with the ILL and EMBL, a hub of excellence that has stimulated the co-location of specialist laboratories such as the Institute for Structural Biology, the Partnership for Structural Biology, the Partnership for Soft Condensed Matter, industrial research collaborations and a world class cryo-EM platform.

Centred on rebuilding the ESRF storage ring – based upon the all-new hybrid multi-bend achromat lattice designed at the ESRF – the ESRF EBS will deliver unprecedented source brilliance and coherence (~100x). The EBS project includes also the construction of four new state-of-the-art beamlines, a scientific instrumentation programme with ambitious detector projects and a data management

and analysis strategy. Most beamlines, including the Collaborating Research Groups beamlines, will also be upgraded. The ESRF EBS represents an investment of 150 M€ over the period 2015-2022.

IMPACT

The new ESRF EBS enhances the ESRF's impact on science and on partner countries. The ESRF EBS source will start operations in 2020 but is already a global reference: more than 13 projects worldwide aim at reproducing the ESRF EBS model, which will be the reference for at least another decade. The construction of EBS is currently securing industrial innovation with contracts and partnerships with companies based in ESRF Member and Associate countries.

The engineering challenges of the ESRF EBS are boosting industrial capacity in areas such as magnet and detector technology, nano-manipulation, control systems, vacuum technology, precision mechanics and high-power radiofrequency technology for accelerators. Developments in data management, analysis tools and open access repositories will further impact science and technology at European and global levels with an impact in the broader field of analytical science and facilities.

European Spallation Source ERIC

European Spallation Source

THE WORLD'S MOST
POWERFUL NEUTRON
SOURCE FOR
INTERDISCIPLINARY
RESEARCH IN PHYSICAL AND
LIFE SCIENCES



DENMARK, SWEDEN

TYPE single-sited

LEGAL STATUS ERIC, 2015

POLITICAL SUPPORT

lead countries: DK, SE

member countries: CH, CZ, DE, EE, ES, FR, HU, IT, NO, PL, UK

***observer:** BE, NL

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2010
Preparation phase

2025
Operation Start

2010-2025
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 1.843 M€

design: Not Available

preparation: 80 M€

construction: 654 M€

operation: 140 M€/year

HEADQUARTERS

European Spallation Source ERIC
Lund, Sweden

WEBSITE

www.europeanspallationsource.se

DESCRIPTION

The European Spallation Source (ESS) is a Research Infrastructure with the vision to build and operate the world's most powerful neutron source, enabling scientific breakthroughs in research related to materials, energy, health and the environment, and addressing some of the most important societal challenges of our time. The ESS will deliver a neutron peak brightness of at least 30 times greater than the current state-of-the-art, thus providing the much-desired transformative capabilities for interdisciplinary research in the physical and life sciences.

ESS officially became a European Research Infrastructure Consortium (ERIC) in October 2015. The facility is under construction in Lund (Sweden), while the ESS Data Management and Software Centre (DMSC) is based in Copenhagen (Denmark). When the ESS user programme begins in 2023, an estimated two to three thousand visiting scientists will come to ESS annually to perform experiments. Most users will be based at European universities and institutes, and others within industry.

ACTIVITY

Neutrons are excellent for probing materials on the molecular level. For everything from motors and medicine,

to plastics and proteins, detailed studies are dependent on how many neutrons can be produced by a neutron source. This is a significant limitation for existing sources based on nuclear reactors. As a result, scientists and engineers have developed a new generation of neutron sources based on particle accelerators and spallation technology, a much more efficient approach.

ESS will provide up to 100 times brighter neutron beams than existing facilities today. A total of 15 instruments will be built during the construction phase to serve the neutron user community – Europe today has nearly 6.000 researchers using neutrons – with more instruments during operations. The suite of ESS instruments will gain 10-100 times over current performance enabling neutron methods to study real-world samples under real-world conditions. The 15 instrument concepts were selected through an inclusive process, involving applications from the community and peer-review by scientific and technical committees. The final recommendation was made by the ESS Scientific Advisory Committee and approved by ESS Council. In the long term, expansion of the suite up to 22 instruments is anticipated. Commissioning of the accelerator will begin in 2019,

with the user programme for the earliest instruments set to open in 2023.

To succeed in its mission ESS relies on the expertise of its partners from across Europe, and also from other areas of the globe. The European Spallation Source has a large network of laboratories to exchange knowledge, personnel and experience with, and that in many cases will contribute directly to the project through In-Kind Contributions (IKCs). These IKCs are expected to finance more than 35% of the total 1.843 million € estimated for the construction costs.

IMPACT

ESS will be an attractive and environmentally sustainable large compound that will make an impact on the world's stage. Before the expected world-scale scientific impact can be realised with the operation phase, the construction of the ESS does have a direct economic impact by generating growth and jobs, advance development and fuel innovation potential in the Öresund region and across the EU. The realisation of ESS enables access to frontier technology, experienced technical and scientific staff as well as unique production facilities and technologies, which would otherwise be unattainable.

In addition, the ESS will be a key instrument for addressing the *Grand Challenges* through novel insights on matter at the molecular and atomic level and applications to energy, carbon sequestration methods, health issues at biology level as well as drug development and delivery strategies, plant water-uptake processes of relevance for agriculture, novel data storage materials, and more.

THE FIRST
SUPERCONDUCTING
HARD X-RAY FREE-
ELECTRON LASER FOR
LIFE AND MATERIALS
SCIENCES



European XFEL

DESCRIPTION

The European X-Ray Free-Electron Laser (European XFEL) will be the world leading facility for the production of high repetition rate ultra-short X-ray flashes with a brilliance that is a billion times higher than that of the best conventional synchrotron X-ray radiation sources. The European XFEL is opening up areas of research that were previously inaccessible. Using the X-ray flashes of the European XFEL, scientists will be able to map the atomic details of viruses, decipher the molecular composition of cells, take three-dimensional images of the nanoworld, film chemical reactions, and study processes such as those occurring deep inside planets.

The European XFEL is organized as a non-profit company with limited liability under German law (GmbH) that has international shareholders. The international European XFEL project – with 12 participating countries – is being operated in Hamburg and Schleswig-Holstein since October 2017.

ACTIVITY

X-ray free-electron lasers (FELs) are accelerator based light sources that generate extremely brilliant and ultra-short, from few to 100 femtoseconds (fs) pulses of transversely coherent X-rays with very short wavelengths (down to ~ 0.05 nm). The goal is to exploit these X-rays for revolutionary scientific experiments in a variety of disciplines, including physics, chemistry, materials science, and biology. In the US and Japan, FELs are based on room-temperature linear accelerators (warm-LINACS). In Europe,

European XFEL

European X-Ray Free-Electron Laser Facility

TYPE single-sited

LEGAL STATUS European XFEL, EIROforum

POLITICAL SUPPORT

lead entity: European XFEL

The following countries are members of European XFEL

member countries: CH, DE, DK, ES, FR, HU, IT, PL, RU, SE, SK, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2006-2009
Preparation Phase

2017
Operation Start

2009-2017
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 1.490 M€

design: Not Available

preparation: Not Available

construction: 1.490 M€

operation: 118 M€/year

HEADQUARTERS

European XFEL GmbH
Schenefeld, Germany

WEBSITE

www.xfel.eu

the European XFEL Facility exploits the superconducting linear accelerator technology (cold-LINAC). This technology allows for a very large number of pulses per second, in the case of the European XFEL up to 27.000 pulses per second. Electron bunches are accelerated to high energies (up to 17.5 GeV) in a ~2 km LINAC and then passed through (up to 200 m long) undulators, where they will generate bursts of coherent X-rays through the self-amplified spontaneous emission (SASE) process. Initially, 3 photon beamlines and 6 instruments are being built. Eventually, 5 photon beamlines and 10 experimental stations will enable experiments ranging from coherent diffraction imaging to spectroscopy and exploit the high intensity, coherence, and time structure of the new source.

Some expected scientific benefits will consist in studying molecular configuration rearrangements during chemical reactions down to the sub-picosecond (ps) scale, observing the dynamics of fluctuations on unprecedented time and length scales, providing experimental access to regions of the phase diagram of materials currently found only in astrophysical environments. A fascinating perspective benefit is the investigation of the

structure of individual macromolecules down to atomic resolution, without the need for crystallization.

IMPACT

The European XFEL facility expands the leading position of Europe in accelerator based X-ray sources, that are pushing the frontiers of condensed matter physics, materials science, chemistry, structural biology and pharmacology. The specific developments in detector and accelerator technology generate innovation and know-how transfer to industry. The expected fundamental research breakthroughs in materials sciences, chemistry and catalysis, and macromolecular structure, will also generate innovation.

The European XFEL provides an opportunity to educate a new generation of scientists to address the frontiers of research on nano-scale materials, and this in a multi-national, open environment, promoting the European dimension of knowledge and its international mobility. Consortia are created among European universities and research centres to develop instrumentation for the facility, impacting the coordination of efforts in the fields of research related with health issues, energy and environment.

FAIR

Facility for Antiproton and Ion Research

*AN ANTIPROTON AND ION
BEAMS ACCELERATOR
FACILITY TO EXPLORE THE
NATURE OF MATTER AND
THE EVOLUTION OF THE
UNIVERSE*



GERMANY

TYPE single-sited

LEGAL STATUS GmbH, 2010

POLITICAL SUPPORT

lead country: DE

member countries: FI, FR, IN, PL, RO, RU, SE, SI, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006**TIMELINE**

2005-2010

Preparation Phase

2025

Operation Start

2012-2025

Implementation/Construction Phase

ESTIMATED COSTS

capital value: Not Available

design: Not Available

preparation: Not Available

construction: 1.262 M€

operation: 234 M€/year

HEADQUARTERS

FAIR GmbH
Darmstadt, Germany

WEBSITE

www.fair-center.de

DESCRIPTION

The Facility for Antiproton and Ion Research (FAIR) is a new accelerator complex providing high-energy, high-intensity primary and secondary beams of antiprotons and ions to enable forefront research into the structure and dynamics of matter under extreme conditions, thereby also providing new insights into the evolution of the Universe and the nucleosynthesis in stars and star explosions.

On October 2010, ten countries signed an international agreement on the construction of the FAIR accelerator facility in Darmstadt. These countries are the shareholders of the FAIR GmbH, the established legal entity for the realization of FAIR. In total over 50 countries are involved in the FAIR science program by contributing to the construction and to the exploitation of the FAIR detectors. The FAIR experiments are organized in four large collaborations: APPA, CBM, NUSTAR and PANDA encompassing more than 2.500 scientists in total. FAIR is expected to deliver beams for science experiments in 2025. Partial operation – FAIR Phase 0 science programme – will start in 2018.

ACTIVITY

FAIR will be constructed in Darmstadt, adjacent to the GSI facility, and will use the upgraded GSI accelerators as injector chain. Within a broad scientific-technological approach, FAIR develops and exploits novel accelerator, detector and computing technologies for unprecedented research into nuclear structure and nuclear astrophysics, physics of hadrons and fundamental physics with antiproton beams, physics of compressed nuclear matter, plasma physics, atomic physics, materials research and biomedical applications.

The heart of the new facility is the superconducting synchrotron SIS100 with a circumference of about 1.100 metres. A complex system of storage-cooler rings and ca 3.2 kilometres of beam transport lines deliver the beams to various experiment stations which house a suite of highly sophisticated detectors. Altogether, the buildings and tunnel sections provide about 135.000 square metres of usable space for the complex scientific-technical infrastructure. The superconducting synchrotron SIS100 is capable of delivering for the science programs high intensity primary beams with energies of up to 11.5 GeV for uranium and of 29 GeV for

protons. Moreover, a broad range of exotic radioactive ion beams and antiproton beams can be provided at the facility. FAIR will enable parallel operation of up to four research programs, thereby allowing a very cost-efficient exploitation of the facility.

The scientific scope and instrumentation of FAIR is complementary to that at other existing or planned large accelerator Research Infrastructures, but none of the other facilities combines the full set of features in one and the same project: large variety of the ion species – from antiprotons to uranium, high beams intensities, high beam energies, cooled antiproton and exotic ion beams, parallel operation.

IMPACT

In addition to the fundamental science research, FAIR is focusing on applications like radiobiological risk assessments for manned space missions, material sciences, plasma physics studies, and radiotherapy research and development. FAIR has also a potential of broader impact at international level as collaborations in detector and magnet development – e.g. with JINR-Dubna – are already active. This is also reflected by strong and active cooperation between FAIR and many laboratories worldwide optimizing synergies in research and development, and use of existing infrastructures. FAIR is intended to provide research opportunities well beyond the European scope from the beginning, thus catering for scientific communities of countries that cannot afford such large Research Infrastructure by themselves and would greatly benefit from it.

AN UPGRADE OF THE
HIGHEST-ENERGY
PARTICLE COLLIDER IN
THE WORLD TO EXPLORE
NEW PHYSICS



HL-LHC

High-Luminosity Large Hadron Collider

TYPE single-sited

LEGAL STATUS CERN, EIROforum member

POLITICAL SUPPORT

lead entity: CERN

The following countries are members of CERN

member countries: AT, BE, BG, CH, CY, CZ, DE, DK, EL, ES, FI, FR, HU, IL, IN, IT, LT, NL, NO, PK, PL, PT, RO, RS, SE, SI, SK, TR, UA, UK

prospective member countries: HR

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2016

TIMELINE

2014-2017
Preparation Phase

2026
Operation Start

2017-2025
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 1.408 M€

design: 205 M€

preparation: 34 M€

construction: 1.169 M€

operation: 136 M€/year

HEADQUARTERS

CERN
Geneva, Switzerland

WEBSITE

<http://home.cern/>

DESCRIPTION

The Large Hadron Collider (LHC) at CERN is the highest-energy particle collider in the world. The LHC experiments (ALICE, ATLAS, CMS and LHCb) have produced a large number of beautiful physics results, summarised in more than 2.000 publications in peer-reviewed scientific journals as of today. The highlight is the breakthrough discovery of the Higgs boson by the ATLAS and CMS experiments in 2012. This discovery marked the start of a major programme to measure this particle's properties with the highest possible precision with a view to testing the validity of the Standard Model and searching for new physics at the energy frontier. To extend its discovery potential, the LHC will be upgraded to the High-Luminosity LHC (HL-LHC).

The HL-LHC will be implemented over the coming decade in order to increase the data sample for ATLAS and CMS by an order of magnitude compared to the integral collected by the end of 2023. To benefit fully from the increased data sample in terms of scientific production, the LHC detectors will also need to be upgraded, together with the computing infrastructure required to handle the substantially increased data rates. The full exploitation of the LHC, including the HL-LHC, was identified as the highest priority for European particle physics, in the update of the European Strategy for Particle Physics approved by the CERN Council in May 2013. The HL-LHC project is considered a high-priority component also in the national roadmaps of many countries across the world, including the USA.

ACTIVITY

The accelerator and detector systems for the HL-LHC project will take close to a decade to complete. The accelerator relies on a

number of innovative technologies including a combination of cutting-edge superconducting magnets, ultra-precise superconducting radiofrequency cavities for beam rotation, as well as high-power superconducting links with zero energy dissipation. In addition, the higher luminosity sets novel constraints on vacuum, cryogenics and machine protection, and will require new concepts for beam collimation and diagnostics to maximise the physics output of the collisions. The success of experiments at the HL-LHC will rely upon innovative instrumentation such as radiation-hard detectors, high-granularity calorimeters, and large-area silicon trackers, together with state-of-the-art infrastructures and large-scale data-intensive computing.

The first physics goal is to push further the validation of the Standard Model at the energy frontier, in particular by measuring, with the highest possible precision, the properties of the Higgs particle and the longitudinal components of the massive vector bosons, with a view to identifying any deviations from the Standard Model predictions. The second goal is to check whether the Higgs particle is accompanied by other new particles at the TeV energy scale, which could play a role in addressing outstanding questions in particle physics, such as the nature of dark matter and the

matter-antimatter asymmetry in the Universe.

IMPACT

The LHC is a unique international infrastructure dedicated to studying the fundamental constituents of matter and their interactions. The high luminosity upgrade of the existing LHC will allow full exploitation of its scientific potential and will map out the scientific programme up to 2035 and possibly beyond. The scientific community at CERN consists of over 13 000 users from around the world, of whom a large majority work on the LHC.

The HL-LHC and its associated facilities will require a constant stream of supplies and services, including civil engineering and the systems and equipment needed to build and operate the accelerator and the experiments. Collaboration with many types of industries and businesses will be required in order to pursue the physics goals of the HL-LHC. Society will benefit greatly from the knowledge and technology that will be developed during the HL-LHC project. Many young physicists and engineers trained during the project will transfer their expertise to society and industry. Whether in the field of accelerators, detectors or computing, the HL-LHC is a major undertaking that will impact many technologies that are of relevance for other Research Infrastructures and for the *Big Data* and computing paradigm.



Institut Max von Laue - Paul Langevin

*THE CONTINUOUS
UPGRADE OF THE
WORLD'S FLAGSHIP
CENTRE FOR NEUTRON
SCIENCE*

TYPE single-sited

LEGAL STATUS ILL, EIROforum member

POLITICAL SUPPORT

lead entity: ILL

The following countries are members of ILL

member countries: AT, BE, CH, CZ, DE, DK, ES, FR, IT, PL, SE, SK, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2007-2011
Preparation Phase

2020
Operation Start

2012-2019
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 188 M€

design: Not Available

preparation: Not Available

construction: Not Available

operation: 97 M€/year

HEADQUARTERS

Institut Max von Laue - Paul Langevin
Grenoble, France

WEBSITE

www.ill.eu



materials science (20%), physics including magnetism and nanoscience (36%), other (instrumentation, cultural heritage, environment; 4%). ILL's Industrial Liaison Unit provides a single and specialised point of contact for any potential user from industry and services, offering industrial clients a choice of specific modes of access ranging from quick-access proprietary research or a combination with academic access for maximum innovation.

ILL adopts a pioneering data access policy to allow the access and treatment of the data generated at the institute, following FAIR data principles. After initial priority access to the data for the scientist(s) carrying out the experiment, the data is publicly accessible and reusable. ILL also endorsed the principles of the EOSC Declaration of 10 July 2017.

IMPACT

The economic impact of the implantation of the ILL in Grenoble is very important for France and the Auvergne-RhôneAlpes region in terms of direct and indirect jobs and activities. Installations at ILL are used by more than 50 French and European companies for R&D work. The implementation of the instrumentation upgrade programmes of ILL will reinforce the potential performances of the R&D tools and favour the competitiveness of the companies specialized in precision mechanics, vacuum and engineering, neutron guides and neutron choppers. Technologies developed by ILL and companies in partnership are often subsequently used by national and international facilities and laboratories.

DESCRIPTION

The Institut Max von Laue - Paul Langevin (ILL) is an international research centre at the leading edge of neutron science and technology, to support researchers in a variety of fields – condensed matter physics, chemistry, biology, nuclear physics and materials science – and make their combined know-how available to the scientific community. ILL operates the most intense reactor source in the world, supplying neutrons to a suite of highperformance instruments that are constantly developed and upgraded. The continuous instrumentation upgrade programmes aim at increasing the signal to noise performance, adapting the instrumentation to the changing research environment and offering new innovative techniques.

Entered in the ESFRI Roadmap 2006, ILL developed programmes to support the overall upgrade of its instrument suit. The successfully implemented upgrade programme Millennium and the ongoing Endurance programme strengthen the world-leading position and provide for the future scientific needs of users in Europe and beyond.

ACTIVITY

ILL offers neutron measurements to the scientific community employing 39 instruments installed on the existing source of neutrons at ILL, 29 operational instruments managed by ILL and 10 instruments handled by external consortia. Each piece of the instrument suite is designed to be state-of-the-art in each particular research field and undergoes major as well as continuous upgrades to fulfil the world-reference role. ILL's staff have expertise and experience in neutron production (reactor physics, reactor design and operation, cold and hot source design and operation), neutron beam delivery (beam tubes, neutron guides including supermirror guides), neutron optics (collimators, monochromators, neutron velocity selectors and choppers), neutron detection and the complete range of neutron instruments for scientific research and sample environment. 1.400 researchers from over 40 countries visit ILL each year, performing over 850 experiments and producing about 600 publications that put ILL at the leading edge of neutron science covering all the relevant scientific domains: soft condensed matter (14%), nuclear and particle physics (5%), biology (9%), chemistry (12%),

THE LARGEST RADIO
TELESCOPE ON EARTH TO
EXPLORE THE UNIVERSE
AND THE ORIGINS OF LIFE



UNITED KINGDOM

SKA

Square Kilometre Array

TYPE single-sited

LEGAL STATUS

POLITICAL SUPPORT

lead entity: UK

prospective member countries: AU, CA, CN, ES, FR, IN, IT, NL, NZ, SE, ZA

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE



ESTIMATED COSTS

capital value: 1.000 M€

design: Not Available

preparation: Not Available

construction: 674 M€

operation: 77 M€/year

HEADQUARTERS

Jodrell Bank
Lower Withington, United Kingdom

WEBSITE

www.skatelescope.org

DESCRIPTION

The Square Kilometre Array (SKA) is a global effort to build the largest radio telescope on Earth, with eventually over one million square metres of collecting area. SKA will be able to look back into the furthest reaches of the cosmos to study the first structures in the Universe, helping to understand some of the most fundamental questions in physics, as well as probing the nature of gravity and cosmic magnetism and exploring the origins of life itself.

The SKA Organisation (SKAO), that became a legal entity in 2011, coordinates the design and the policy making for the SKA. In 2012, the members of the SKAO agreed on a dual site location for the SKA telescope in the deserts of South Africa and Australia, while the site for the Headquarters – established in the UK – was decided in 2015. The Construction Phase will take place from 2020 to 2027 – with early science in 2025 – providing an operational array of telescopes capable of carrying out some of the key science set by the community, before scaling up to the full SKA by 2030s.

ACTIVITY

The first phase of SKA (SKA-1) will use ~200 dishes and ~130.000 low-frequency antennas that will enable astronomers to monitor the sky in unprecedented detail, and to survey the entire sky much faster than any system currently operating. The total collecting area of the full SKA will be well over one square kilometre, or 1.000.000 square metres, obtained with thousands of mid- to high-frequency steerable dishes, each of 15 metres in

diameter in South Africa, and around half a million digitally-steerable low-frequency antennas in Australia. The SKA will truly be at the forefront of scientific research with a broad range of exciting science such as observing pulsars and black holes to detect the gravitational waves predicted by Einstein's General Relativity, looking at how the very first stars and galaxies formed after the Big Bang, better than any experiment so far, helping scientists to investigate the nature of the mysterious dark energy, trying to understand the vast magnetic fields which permeate the cosmos, and exploring the origins of life itself.

Moreover, the SKA will challenge information technology developments at the vanguard of the emerging era of Big Data and High Performance Computing. The data analysis software needed will leap a generation in sophistication. The SKA is expected to become the largest public, research data project in the world, producing in its first phase, raw data totalling more than five times the estimated global internet traffic of 2015.

IMPACT

To date, there are ten nations funding the SKA with membership across five continents: Australia, Canada, China,

India, Italy, the Netherlands, New Zealand, South Africa, Sweden and the UK, which represent about 40% of the world's population. Over 100 research and industrial organisations are working together to design the initial phase of the SKA with over 600 researchers and engineers involved around the world. Impact is foreseen through the hosting the SKA Headquarters and telescopes, by increasing activity in pre-construction at the telescope sites in South Africa and Australia, and by involving industry for developing technology solutions in meeting the challenges of SKA. The SKA project is also expected to generate substantial innovation in key technology areas such as Information and Communication Technology (ICT) and renewable energy as well as to impact on knowledge transfer and human capital development.

A high profile project like SKA truly excites scientists, and the general and non-specialist public worldwide. In fact, astronomy appeals to our natural curiosity, but it is also a stepping-stone to many other fields of science and technology development, including engineering, aerospace, mathematics and the natural sciences, all of which will have profound impact on our future economy and society.

SPIRAL2

Système de Production d'Ions Radioactifs
en Ligne de 2e génération

*THE INSTALLATION TO
ACCELERATE AND DELIVER
VERY HIGH INTENSITY
LIGHT AND HEAVY-ION
BEAMS OF STABLE AND
EXOTIC NUCLEI*

TYPE single-sited

LEGAL STATUS GANIL

POLITICAL SUPPORT

lead country: FR

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006**TIMELINE**

2005-2010

Preparation Phase

2019

Operation Start

2010-2019

Implementation/Construction Phase

ESTIMATED COSTS

capital value: 281 M€

design: 11 M€

preparation: 3.9 M€

construction: 266 M€

operation: 6 M€/year

HEADQUARTERS

GANIL
Caen, France

WEBSITE

www.ganil-spiral2.eu



FRANCE

spectrometers, etc.). The production of high-intensity RIB of neutron-rich nuclei will be based on fission of Uranium target induced by neutrons, obtained from a deuteron beam impinging on a graphite converter (up to 10^{14} fissions/s) or by a direct irradiation with a deuteron, ^3He or ^4He beam. The post acceleration of RIB in the SPIRAL2 project is assured by the existing CIME cyclotron, which is well adapted for separation and acceleration of ions in the energy range from about 3 to 10 MeV/u for masses A~100-150.

IMPACT

The impact of SPIRAL2 in the structuring of the European Research Area is enabling a scientific programme based on unique high-intensity beams of light, heavy-ions and neutrons delivered well suited to address the most challenging nuclear and astrophysics questions aiming at the deeper understanding of the nature of atomic nucleus. SPIRAL2 will contribute to the physics of nuclear fission and fusion based on the collection of unprecedented detailed basic nuclear data, to the production of rare radioisotopes for medicine, to radiobiology and to materials science.

The SPIRAL2 facility is an intermediate step towards EURISOL, the most advanced nuclear physics research facility presently imaginable and based on the ISOL principle. The realisation of SPIRAL2 will substantially increase the know-how of technical solutions to be applied not only for EURISOL but also in a number of other European and world projects.

DESCRIPTION

The Système de Production d'Ions Radioactifs en Ligne de 2e generation (SPIRAL2) is a new facility to extend significantly the actual possibilities of Radioactive Ion Beam (RIB) physics and related applications. SPIRAL2 will produce the only ion beams of their kind in the world to support research from hadron and isotope therapy to the physics of the atom and its nucleus, from condensed matter to astrophysics. The study of the properties of nuclei forming these beams or their interactions with stable nuclei is a rapidly developing field of contemporary nuclear physics, astrophysics and interdisciplinary research. Novel research in nuclear physics at the limits of stability will be covered at SPIRAL2, including the study of the r and rp-process nuclei, shell closure in the vicinity magic numbers as well as the investigation of very heavy elements. Further research areas will be material sciences, radiobiology, research for hadron and isotope therapy, energy, environment, social sciences, health, engineering, space, ICT as well as Inter and multi-disciplinary research in radiobiology.

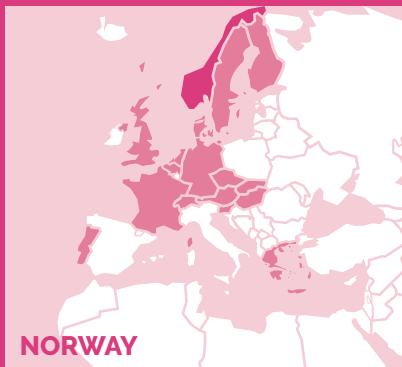
SPIRAL2 is part of the GANIL infrastructure, which is the largest research infrastructure in Lower Normandy (Caen, France). Under construction since 2005, it will deliver science from 2019 as a

scientific and technologic complement to the existing infrastructure.

ACTIVITY

The SPIRAL2 project is based on a multi-beam driver in order to allow both ISOL and low-energy in-flight techniques to produce RIB. SPIRAL2 comprises a linear accelerator (LINAC) and experimental areas with three halls for experiments with high flux of fast neutrons (Neutron for Science, NFS), with very high intensity beams of heavy-ions (Super Separator Spectrometer, S3) and with low-energy exotic nuclei (DESIR) produced at S3 and with SPIRAL1 facility. The construction of a new injector of the SPIRAL2 Linear Accelerator is planned in order to expand a range of available high-intensity beams up to Uranium. In addition, a Radioactive Ion Beam (RIB) production building is foreseen to produce RIB with an intensity that exceed by factor of 10 to 100 intensities available today worldwide. The superconducting light/heavy-ion LINAC, with a potential of about 40 MV capable of accelerating 5 mA deuterons up to 40 MeV and 1 mA heavy ions up to 14.5 MeV/u, is used to bombard both thick and thin targets. The beams could be used for the production of intense RIB by several reaction mechanisms (fusion, fission, transfer, etc.) and technical methods (ISOL, IGISOL, recoil

A LARGE SCALE,
INTEGRATED AND
SUSTAINABLE PLATFORM
FOR DATA SERVICES TO
THE SOCIAL SCIENCES



NORWAY

DESCRPTION

The Consortium of European Social Science Data Archives (CESSDA) is a distributed Research Infrastructures serving as a large scale, integrated and sustainable platform for data services relevant to the social sciences. It supports high-quality, national and international research and cooperation by bringing together social science data archives across Europe, with the aim of facilitating social, economic and political research, and allowing researchers to gain a better understanding of the challenges facing society today, thus contributing to the production of effective solutions.

In the ESFRI Roadmap since 2006, CESSDA has been listed as success story in the Roadmap 2010. CESSDA became a limited company under Norwegian law (CESSDA AS) in 2013 and a European Research Infrastructure Consortium (ERIC) in July 2017. Presently 16 countries are Members of the Consortium and one country is a formal Observer. Additionally, social science data archives from nine other European countries are cooperating, taking part to some activities or aiming at membership.

ACTIVITY

Members of CESSDA nominate a national Service Provider to be responsible for delivering the relevant services. These Service Providers have a primary responsibility to provide data services to their own country, but they are also explicitly funded to provide pan-European activities. The Service Providers are the main resource for CESSDA, and CESSDA is responsible to integrate the work of the Service Providers by establishing a one-stop shop for data location, access, analysis and delivery. Each Service

CESSDA ERIC

Consortium of European Social
Science Data Archives

TYPE distributed

LEGAL STATUS ERIC, 2017

POLITICAL SUPPORT

lead country: NO

member countries: AT, BE, CZ, DE, DK, EL, FI, FR, HU, NL, PT, SE, SI, SK, UK

***observer:** CH

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2007-2010
Preparation Phase

2013
Operation Start

2011-2012
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 117 M€

design: 4 M€

preparation: 2.7 M€

construction: 78 M€

operation: 39 M€/year

HEADQUARTERS

CESSDA ERIC
Bergen, Norway

WEBSITE

www.cessda.eu

Provider has different overall objectives, but in general they have a responsibility for acquiring data from data creators – government, researchers, commerce, etc. – and preparing those data for long-term access. Service Providers also carry out a curation function, which means that data is always fit for contemporary use, and are available for discovery and re-use. In essence each Service Provider ensures that data are always available for social science research purposes. CESSDA encourages standardisation of data and metadata, data sharing and knowledge mobility across Europe, streamlining the activities of all the Service Providers, and ensuring equality of data use across boundaries. CESSDA plays an active role in the development of standards and, even more importantly, encourages and facilitates the use of metadata standards for documenting and publishing the existing inventories of research data available from national as well as cross-national data resources in Europe.

Put together, the overall ambition is to organise a range of data collections and to coordinate common activities across different national institutions. The institutions will increasingly function as a network in a flexible technical architecture, using standard open protocols and interfaces, designed to contribute to the emerging European and global information

commons. The vision for CESSDA is thus to develop a system for data service provision that is open, extensive and evolvable. CESSDA will also attempt to maximise the use of its Service Providers' data holdings while maintaining the rights of subjects and relevant intellectual property rights.

IMPACT

CESSDA has already an impact on the social sciences and related research communities. CESSDA Data Catalogue provides a single interface to thousands of unique datasets from social science data archives across Europe, thus widening access to data, permitting European comparative research and proving an input into numerous scientific publications. CESSDA also has an impact on its area of work by providing effective leadership and acting as a catalyst for change across its area of interest – data curation in its broadest sense – by allowing transfer of knowledge and tools across the consortium and reducing duplication of certain activities.

All CESSDA's objectives have at their heart the end-user of the data holdings of the various Service Providers. Every objective ensures that the rights of the data subjects and the responsibilities of the data owners are managed appropriately. CESSDA supports Open Data but only in cases where the rights of the subjects and the data controllers are respected.

CLARIN ERIC

Common Language Resources and Technology Infrastructure

A UNIQUE SINGLE SIGN-ON ACCESS TO ALL DIGITAL LANGUAGE RESOURCES AND TOOLS FOR HUMANITIES AND SOCIAL SCIENCES



TYPE distributed

LEGAL STATUS ERIC, 2012

POLITICAL SUPPORT

lead country: NL

member countries: AT, BG, CZ, DE, DK, EE, EL, FI, HR, HU, IT, LT, LV, NO, PL, PT, SE, SI, (DLU)

***observers:** FR, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2011
Preparation Phase

2012
Operation Start

2011-2015
Implementation/Construction Phase

ESTIMATED COSTS

capital value: Not Available

design: Not Available

preparation: 4 M€

construction: Not Available

operation: 14 M€/year

HEADQUARTERS

CLARIN ERIC
Utrecht, The Netherlands

WEBSITE

www.clarin.eu

Provider Federation; E-Centres – External Centres offering central services without being part of any national consortium. Institutions in countries which are not part of CLARIN ERIC can become a CLARIN Centre of type C and K.

CLARIN also works closely together with research communities in creating and expanding a knowledge infrastructure that can support developers of language resources and tools, as well as the end-users of the available data and services. In total over 100 institutes across Europe are involved and more will be involved.

DESCRIPTION

The Common Language Resources and Technology Infrastructure (CLARIN) is a distributed RI that provides easy and sustainable access for scholars in the humanities and social sciences to digital language data – in written, spoken or multimodal form – and advanced tools to discover, explore, exploit, annotate, analyse or combine them, independent of their location. To this end CLARIN is building a networked federation of language data repositories, service centres and centres of expertise, with single sign-on access for all members of the academic community in all participating countries. Tools and data from different centres are interoperable, so that data collections can be combined and tools from different sources can be chained to perform complex operations to support researchers in their work.

CLARIN became a European Research Infrastructure Consortium (ERIC) in February 2012. Since then several countries have joined either as full Member, or as Observer. The ultimate goal is to include all EU and associated countries as well as third countries in or outside Europe.

ACTIVITY

CLARIN distributed Research Infrastructure is made out of several types of centres. The operation, maintenance and continuous

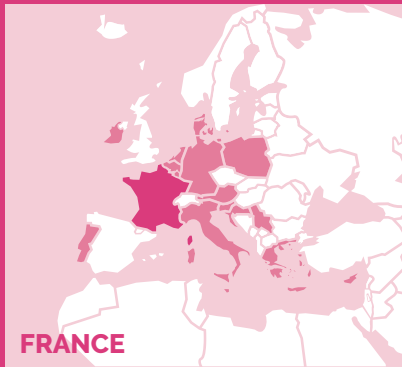
expansion of the infrastructure is carried out in the participating countries at the individual CLARIN centres – currently over 40, which have to meet clearly defined technical and organizational criteria, ensuring the coherence of the whole infrastructure. The backbone of CLARIN is provided by technical centres, in particular Service Providing Centres or CLARIN B-Centres, for short. These units, often a university or an academic institute, offer the scientific community access to resources, services and knowledge on a sustainable basis. Therefore, there are strict criteria to become a CLARIN B-Centre: it should be based on a stable technical and institutional foundation. The Assessment Committee checks these requirements during an assessment procedure, while the technical coordination among the centres takes place in the Centre Committee. Currently there are around 20 certified B-centres and several more centre candidates. This list is constantly growing as new members are joining CLARIN ERIC. Other centre types are: C-Centres – Metadata Providing Centres, their metadata are integrated with CLARIN but they need not to offer any further services; K-Centres – Knowledge Centres, part of the CLARIN Knowledge Sharing Infrastructure; T-Centres – Trust Centres, providing access to protected resources via the Service

IMPACT

CLARIN stimulates the reuse and repurposing of available research data, thereby enabling scholars in SSH – including digital humanities – to increase their productivity and, more importantly, open new research avenues in and across disciplines that address one or more of the multiple societal roles of language: as a carrier of cultural content and information, both synchronically and diachronically, as a reflection of scientific and societal knowledge, as an instrument for human communication, as one of the central components of the identity of individuals, groups, cultures or nations, as an instrument for human expression, or as an object of study or preservation. Through the access and discovery services,

CLARIN increases the potential impact of data and tools produced with publicly funded projects. Working with CLARIN data and tools will increase the skill levels for data analysis tasks among the new generations of SSH students, which is likely to be welcomed by the data science sector.

A NETWORK TO ENHANCE AND SUPPORT DIGITALLY ENABLED RESEARCH AND TEACHING ACROSS THE ARTS AND HUMANITIES



FRANCE

DARIAH ERIC

Digital Research Infrastructure for the Arts and Humanities

TYPE distributed

LEGAL STATUS ERIC, 2014

POLITICAL SUPPORT

lead country: FR

member countries: AT, BE, CY, DE, DK, EL, HR, IE, IT, LU, MT, NL, PL, PT, RS, SI

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2011

Preparation Phase

2019

Operation Start

2014-2018

Implementation/Construction Phase

ESTIMATED COSTS

capital value: Not Available

design: Not Available

preparation: 3.7 M€

construction: 3.3 M€

operation: 0.7 M€/year

HEADQUARTERS

DARIAH ERIC
Paris, France

WEBSITE

www.dariah.eu

DESCRIPTION

The Digital Research Infrastructure for the Arts and Humanities (DARIAH) enhances and supports digitally-enabled research and teaching across the arts and humanities. DARIAH is a network of people, expertise, information, knowledge, content, methods, tools and technologies from its member countries. It develops, maintains and operates an infrastructure that sustains researchers in building, analysing and interpreting digital resources. By working with communities of practice, DARIAH brings together individual state-of-the-art digital arts and humanities activities and scales their results to a European level. It preserves, provides access to and disseminates research that stems from these collaborations and ensures that best practices, methodological and technical standards are followed.

DARIAH was established as a European Research Infrastructure Consortium (ERIC) in August 2014. Currently, DARIAH has 17 Members and many cooperating partners across eleven non-member countries.

ACTIVITY

DARIAH integrates digital arts and humanities research and activities from across Europe, enabling transnational and transdisciplinary approaches. In particular, it provides value to its members and stakeholders through the validation and sharing of data, services and tools; by providing training and education opportunities; by enabling 'bottom-up' organisation around emerging research needs; and through the exercise of foresight and policy engagement. Through these activities, DARIAH promotes the

further development of research methods in the arts and humanities, documenting the state-of-the-art, supporting the preservation and curation of research data with a focus on particular challenges including diversity, provenance, multimedia collections and granularity, and acting as a coordinator and integrator for a diverse community of practice.

Structurally, DARIAH operates through the Europe-wide networks of the Virtual Competency Centres (VCCs) and their constituent working groups. Each of the four VCCs is cross-disciplinary, multi-institutional, international and centred on a specific area of expertise. VCC1, the e-Infrastructure, is responsible for DARIAH's technological foundations. It maintains a digital environment that allows community-developed data and tools to be shared and ensures the quality, permanence and growth of technical services for the arts and humanities. VCC2 is the Research and Education Liaison and acts as the primary interface with the research and teaching communities. VCC3 deals with Scholarly Content Management in the various stages from creation, curation, and dissemination, through to the pooling of scholarly digital resources and results for reuse. VCC4 focusses on Advocacy,

Impact and Outreach, interfacing with key influencers in and for the arts and humanities. Within this structure, DARIAH has over 20 dynamic working groups to integrate national services under specific operational categories.

IMPACT

DARIAH has impact on four interconnected domains: research, education, culture and economy. The consortium supports the sustainable development of digitally-enabled research in the arts and humanities by building services for researchers working with ICT-based methods. It helps them to further advance their research and ensures the long-term accessibility of their work, thus directly contributing to the understanding of the cultural, economical, social and political life in Europe and beyond. In addition, it offers teaching material as well as teaching opportunities to develop digital research skills.

DARIAH is at the forefront of a changing knowledge discovery market and possesses significant strength in this field through its partners. DARIAH also demonstrates how traditional humanities research skills play a prominent role in the digital age, and how such skills can be deployed in a commercial setting.

ESS ERIC

European Social Survey

A CROSS-NATIONAL
SURVEY TO ASSEMBLE,
INTERPRET AND
DISSEMINATE DATA ON
SOCIAL ATTITUDES AND
BEHAVIOURS



UNITED KINGDOM

TYPE distributed

LEGAL STATUS ERIC, 2013

POLITICAL SUPPORT

lead country: UK

member countries: AT, BE, CY, CZ, DE, EE, FI, FR, HU, IE, IT, LT, LV, NL, NO, PL, PT, SE, SI

***observer:** CH

prospective member countries: IS, RS, SK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

1996-1999

Design Phase

2002-2012

Interim/Transition Phase

2013

Operation Start

1999-2001

Preparation Phase

2010-2012

Implementation/Construction Phase

ESTIMATED COSTS

capital value: Not Available

design: Not Available

preparation: 6.4 M€

construction: 2.3 M€

operation: 2.5 M€/year

HEADQUARTERS

ESS ERIC
City, University of London
London, United Kingdom

WEBSITE

www.europeansocialsurvey.org

2 and 5 of the ESS, gathered either side of the economic downturn. Issue 4 focuses on Europeans' understandings and evaluations of democracy using data from Round 6 of the ESS and issue 5 looked at personal and social wellbeing based on Round 6 data. Issue 6 was published using Round 7 data gathered from the rotating module on health inequalities. Issue 7 uses ESS data on immigration from Rounds 1 and 7.

New rounds launched more recently still need to be analysed. In Round 8 ESS investigated attitudes to *Grand Challenges* such as climate change and energy security and the future of the welfare state. Forthcoming topics in Round 9 include justice and fairness and the timing of life.

IMPACT

ESS is designed for use primarily by the academic community. However, the data itself and publications using the data which are produced by academics are also used to provide direct and contextual evidence across a range of non-academic bodies, both governmental and agencies. ESS has helped inform the work of other surveys in Europe in terms of methodology and questionnaire content including the European Quality of Life Survey, the European Values Survey and the International Social Survey Programme. ESS data and methodology are used in academic teaching in many countries.

In addition, the ESS has a programme of knowledge transfer directly with policy makers and has held seminars at the European Parliament, Italian parliament and OECD, European Commission amongst other locations. As part of ESS SUSTAIN (H2020 GA 676166) Technopolis was commissioned to carry out a wide-ranging impact study of ESS; the report (September 2017) is available via the ESS website (www.europeansocialsurvey.org).

DESCRIPTION

The European Social Survey (ESS) is an academically driven cross-national survey that has been conducted across Europe since its establishment in 2001. Every two years, face-to-face interviews are conducted with newly selected, cross-sectional samples. The ESS RI assembles, interprets and disseminates data on social attitudes and behaviours that are gathered in each of the participating countries. It responds to the academic, public policy and societal needs to understand social stability and change within the European context. The topics of the ESS include: citizen involvement and democracy, family and working life, personal and social wellbeing, attitudes to and experiences of ageism as well as trust in institutions. The survey allows for new topics to be introduced over time via an open academically-led competition.

The ESS was established as European Research Infrastructure Consortium (ERIC) in November 2013. Currently, 21 countries are Members, there is 1 Observer country and 2 Guest countries.

ACTIVITY

The European Social Survey ERIC organises data that are gathered in each of the participating countries in accordance with specifications issued by the Director of the ESS ERIC. The main aims of the

ESS include: i) to chart stability and change in social structure, conditions and attitudes in Europe and to interpret how Europe's social, political and moral fabric is changing; ii) to achieve and spread higher standards of rigour in cross-national research in the social sciences, including for example, questionnaire design and pre-testing, sampling, data collection, reduction of bias and the reliability of questions; iii) to introduce soundly-based indicators of national progress, based on citizens' perceptions and judgements of key aspects of their societies; iv) to undertake and facilitate the training of European social researchers in comparative quantitative measurement and analysis; v) to improve the visibility and outreach of data on social change among academics, policy makers and the wider public.

In 2011, ESS launched a new series of ESS Topline Results, which are concise cross-national summaries of particular topics covered in the questionnaire. Topline publications are written by the groups of academics whose rotating module was selected for the ESS. Issue 1 in the series focuses on justice findings using data from Round 5 of the survey. Issue 2 focuses on welfare attitudes in Europe using data from Round 4 of the survey. Issue 3 focuses on the economic crisis, quality of work and social integration using data from Rounds

MULTIDISCIPLINARY AND
CROSS-NATIONAL PANEL
DATABASE OF MICRODATA
OF INDIVIDUALS AGED 50
OR OLDER



GERMANY

DDESCRIPTION

The Survey of Health, Ageing and Retirement in Europe (SHARE) is a multidisciplinary database of microdata on health, socio-economic status, social and family networks of more than 120.000 individuals from 27 European countries plus Israel, aged 50 or older. SHARE aims at documenting and better understanding the repercussions of demographic ageing for individuals and the European society as a whole, and forming a sound scientific basis for countermeasures adopted by health and social policy. SHARE's scientific method is based on a panel design that grasps the dynamic character of the population ageing process in all relevant aspects. Rigorous procedural guidelines and program ensure an ex-ante harmonized cross-national design. The data are harmonised with the US Health and Retirement Study (HRS) and the English Longitudinal Study of Ageing (ELSA) and are accessible free of charge to the scientific community.

SHARE was identified as successfully implemented in the ESFRI Roadmap 2010 and was the first RI to be established as European Research Infrastructure Consortium (ERIC) in March 2011.

ACTIVITY

To date, SHARE has collected six panel Waves – 2004, 2006, 2010, 2013, 2015, 2017 – of current living circumstances and one wave of retrospective life histories – 2008, SHARELIFE; the main data collection of Wave 7 took place in 2017 and the release of Wave 7 data is scheduled for spring 2019. With the public release of updated data on panel Waves in March 2018, the data available to the scientific community are based on more

SHARE ERIC

Survey of Health, Ageing and Retirement in Europe

TYPE distributed

LEGAL STATUS ERIC, 2011

POLITICAL SUPPORT

lead country: DE

member countries: AT, BE, CY, CZ, EL, FR, HU, IL, IT, NL, PL, SE, SI

***observer:** CH

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2007-2010
Preparation Phase

2011
Operation Start

2010-2012
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 250 M€

design: Not Available

preparation: Not Available

construction: Not Available

operation: 18 M€/year

HEADQUARTERS

SHARE ERIC
Munich, Germany

WEBSITE

www.share-project.org

than 297.000 interviews administered on about 120.000 respondents and collected in 28 countries. A comprehensive overview of the up-to-date data sets of the different SHARE waves as well as additional data sets are available via the SHARE Research Data Center.

SHARE is also engaged in several additional data dissemination activities: easySHARE, a simplified dataset for training and teaching purposes, and the Job Episodes Panel, a refined panel dataset spanning the entire working life of SHARELIFE respondents, were both released already in 2013 and updated recently. In 2017, SHARE released an update of the Job Episodes Panel, now including information on migration histories, fertility histories and relationship histories, as well as contextual variables on pension institutions.

SHARE has stimulated the publication of about 950 journal articles since the first data release in 2005, or more than 70 per year on average. Trends in publication number are showing that the scientific output is increasing over time. By Q1 2018, SHARE has more than 8.000 officially registered data users. Most of the users are from European countries, but there is also an increase in scientific operators from the US and other countries worldwide which may partly be due to the comparability

of SHARE data with other international ageing surveys, such as HRS in the US, ELSA in the UK, and others. Most users of SHARE reside in Germany; Netherlands is second, before the UK and the US.

IMPACT

Many of the SHARE findings have strong policy implications with large economic and societal impacts. SHARE with its broad data on the economic, social and health situation of European citizens enables Member States to base difficult economic and social decisions on evidence rather than beliefs. The SHARE data permit an accurate account of who gains and who loses economically from a policy change because the data capture the life circumstances of Europe's citizens which vary so much not only within, but also between Member States.

SHARE has developed innovative software for electronic survey operations, including designing questionnaires, translating them, administering them to respondents, monitoring fieldwork, and creating the databases. In addition, SHARE has innovated the health measurement in large population surveys by introducing physical performance measures – grip strength, chair stand, peak flow – and dried blood spot sampling (DBSS) using devices and materials from small/medium-size companies.

PRACE

Partnership for Advanced Computing in Europe

THE TOP LEVEL OF THE EUROPEAN HIGH PERFORMANCE COMPUTING ECOSYSTEM



TYPE distributed

LEGAL STATUS AISBL, 2010

POLITICAL SUPPORT

The following countries are members of PRACE

lead countries: FR, DE, IT, ES, CH

member countries: AT, BE, BG, CY, CZ, DK, EL, FI, HU, IE, IL, LU, NL, NO, PL, PT, SE, SI, SK, TR, UK

The full list of research institutions involved must be found in the website of the RI

ROADMAP ENTRY 2006

TIMELINE

2008-2010
Preparation Phase

2010
Operation Start

2011-2020
Implementation/Construction Phase

ESTIMATED COSTS

capital value: 500 M€

design: Not Available

preparation: 20 M€

construction: Not Available

operation: 60 M€/year

HEADQUARTERS

PRACE AISBL
Brussels, Belgium

WEBSITE

www.prace-ri.eu

and extend advanced training which so far provided more than 18.800 person-training days; preparing strategies and best practices towards Exascale computing; coordinating and enhancing the operation of the multi-tier HPC systems and services; and supporting users to exploit massively parallel systems and novel architectures. A high level Service Catalogue is provided. The activities are designed to increase Europe's research and innovation potential especially through: seamless and efficient Tier-0 services and a pan-European HPC ecosystem including national capabilities; promoting take-up by industry and new communities and special offers to SMEs; implementing a new flexible business model for PRACE 2; proposing strategies for deployment of leadership systems; collaborating with the ETP4HPC, CoEs and other European and international organisations on future architectures, training, application support and policies.

DESCRIPTION

The Partnership for Advanced Computing in Europe (PRACE) is a pan-European supercomputing Research Infrastructure providing access to world-class computing and data resources and services through a peer-review process, for large-scale high-impact scientific and engineering applications at the highest performance level across all disciplines. PRACE also seeks to strengthen the European users of High Performance Computing (HPC) in industry through various initiatives. PRACE has a strong interest in improving energy efficiency of computing systems and reducing their environmental impact.

PRACE is established as an International not-for-profit Association under Belgian Law (AISBL) with seat in Brussels. It has 26 Member countries whose representative organisations create a pan-European supercomputing infrastructure. A total of 7 supercomputers and their operations accessible through PRACE are provided by 5 hosting members: France, Germany, Italy, Spain and Switzerland.

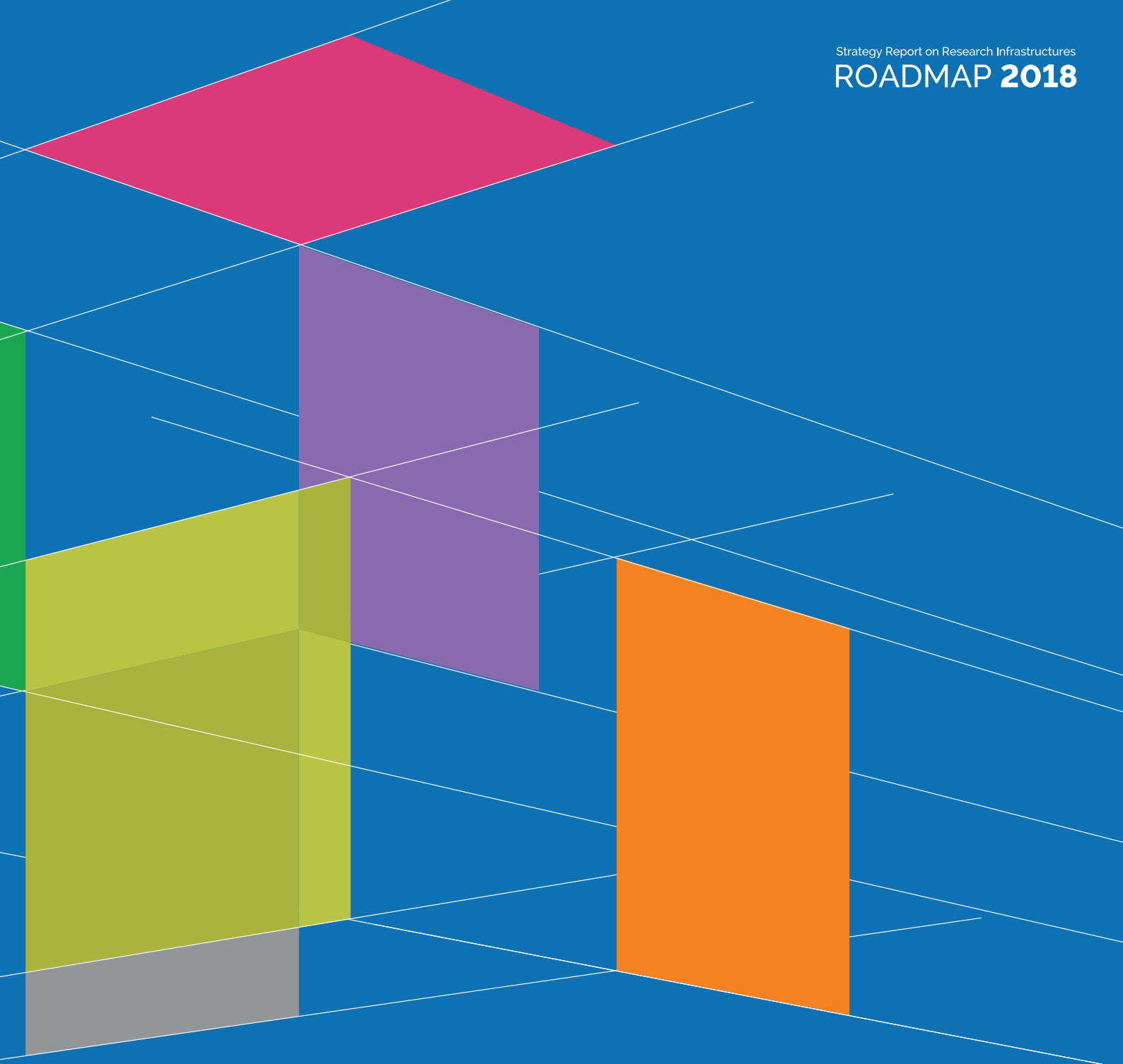
ACTIVITY

The computer systems and their operations accessible through PRACE are provided by 5 PRACE members (BSC representing Spain, CINECA representing Italy, ETH Zurich/CSCS representing Switzerland, GCS representing Germany and GENCI representing France). Four Hosting Members (FR, DE, IT, ES) secured funding for the initial period 2010-2015. In 2016, a 5th Hosting Member – ETH Zurich/CSCS (CH) – opened its system via the PRACE Peer Review Process. In pace with the needs of the scientific communities and technical developments, systems deployed by PRACE are continuously updated and upgraded to be at the apex of HPC technology.

Currently, the fifth PRACE Implementation Phase is coordinated by Forschungszentrum Jülich (DE). The objectives of PRACE-5IP are to build on and seamlessly continue the successes of PRACE and start new innovative and collaborative activities proposed by the consortium. These include: assisting the transition to PRACE 2 including an analysis of Trans National Access; strengthening the internationally recognised PRACE brand; continuing

IMPACT

European scientists and engineers need to exploit more broadly high-end HPC and connection with many ESFRI RIs is to be strengthened to maximize the impact on the ERA and on broad applications in industry and services. PRACE actively interfaces with XSEDE – the Extreme Science and Engineering Discovery Environment (USA), RIKEN (Japan) and Compute Canada, and also with GÉANT – the pan-European data network for the research and education community, EGI – the European Grid Infrastructure, EUDAT – the European data infrastructure and HBP – the Human Brain Project.



ANNEX

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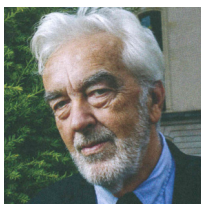
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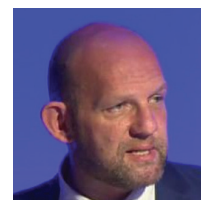
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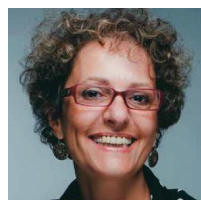
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