INTERNATIONAL RESEARCH INFRASTRUCTURE LANDSCAPE 2019

A European Perspective

RISCAPE

Mapping the Research Infrastructure Landscape

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Report composition

The full report is available at

https://riscape.eu/riscape-report/

The printed version only contains the Main Report

Main report

(Introduction, Scope and Methods, Domain analyses, Conclusions, Appendix 1: Acknowledgments)

Created by RISCAPE consortium,
Edited by Ari Asmi and Jostein Sundet

Appendices

Appendix 2 RISCAPE Questionnaire
Appendix 3 Environmental RI listing
Appendix 4 Bio-medical RI listing & additional information
Appendix 5 Physics RI listing
Appendix 6 Energy RI listing
Appendix 7 Astronomy and Astro-particle RI listing
Appendix 8 Social sciences initiatives listing
Appendix 9 CH, DH and Languages major research centres listing
Appendix 10 e-infrastructure RI and initiative listing

Interview data

As the detailed interview response information also includes personal information (names, positions) of the RI operators responding to the questionnaire and interviews, the interview data is available only on request. Detailed requests for this material can be directed to riscape-material@helsinki.fi

The data moderator is Ari Asmi (University of Helsinki).

Commentaries, corrections or questions

Please direct comments on the Report and its appendices to riscape-feedback@helsinki.fi

RISCAPE team

University of Helsinki, INAR, Finland
https://www.helsinki.fi/

Ari Asmi (ari.asmi@helsinki.fi)
Mika Rantanen

European Social Survey ERIC (ESS ERIC)
https://www.europeansocialsurvey.org

Lorna Ryan

Integrated Carbon Observation System (ICOS ERIC)
https://www.icos-ri.eu

Emmanuel Salmon

The European Clinical Research Infrastructure Network (ECRIN)
https://www.ecrin.org/

Christine Kubiak
Serena Battaglia

The Institute Laue-Langevin (ILL)
https://www.ill.eu/

Miriam Förster
Julie Dupré
Hannah Walter
William G. Stirling (external)
Kurt Clausen (external)

University of Turku, Finland Futures Research Centre, Finland
https://www.utu.fi/

Mikkel Knudsen
Marianna Ferreira-Aulu
Elizaveta Shabanova-Danielyan
Weiqing Wang
Jyrki Luukkanen
Jari Kaivo-oja

Netherlands Institute for Radio Astronomy (ASTRON)
https://www.astron.nl

Carla Baldovin
Marjan Timmer
Rob van der Meer
Rene Vermeulen

Consortium of European Social Science Data Archives (CESSDA ERIC)
https://www.cessda.eu

Ivana Versic

Servizi Didattici e Scientifici per l'Università di Firenze (PIN)
https://www.pin.unifi.it

Franco Niccolucci

EGI (EGI)
https://www.egi.eu

Gergely Sipos
Roberta Piscitelli

Independent editor

Jostein Sundet

RISCAPE Stakeholder Panel members

Maria Uhle
Carthage Smith
Laurent Ghys
Glenn Moloney
Simon Lin
Rafael De Andrés Medina
Ronald Stark
Algis Krupavicius
Antonio Sgamellotti
Robert McGreevy
Jostein Sundet
Mark J. Dietrich

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INTRODUCTION

Research Infrastructures (RIs) is a key element of modern research. Scientists, research groups and even institutions are no longer always able to provide the tools needed for modern-day research goals. However, creation of Research Infrastructures requires significant investments and special competences, leading to the need for national and multinational collaborations creating shared and collaborative research facilities. In Europe, this challenge was identified relatively early with the creation of the European Organization for Nuclear Research (CERN) in the mid-1950s for particle physics research, and ESO (European Southern Observatory) for astronomy in the early 1960s. Both of these large Research Infrastructures needed investment beyond the scale of individual countries and proved joint investments for common research goals. In Europe, this creation of common facilities also supported the initiation of a joint European Research Area, and set the example of joint funding, shared resources and facilities for other fields of sciences to follow. To support creation of other similar European-scale science facilities, the European Strategic Forum for Research Infrastructures (ESFRI) was founded in 2002, helping in formalising and establishing deep and committed collaboration for expensive but critical Research Infrastructures, where they were needed, in all fields of science.

ESFRI develops a common European strategy and process for Research Infrastructure development and creation, and oversees the operations of the European major RIs throughout their lifecycle. This process has been particularly successful in coordinating Europe-wide collaborations of smaller facilities towards common distributed RIs with sustained funding and service models, making it possible to create globally important RIs in the scientific disciplines where they were not available before. RIs are no longer a special tool only for traditional hard sciences.

Many, or even most, of the scientific problems, and their often-associated societal challenges, are not specific to countries or regions. Science by its nature thrives on international collaboration. Similarly, RIs are typically national or regional, but the need for such facilities reaches far beyond the national borders. In some fields of science, there is a history of global joint planning of RI development and sharing of facility access across the borders, leading to increased scientific productivity and cost-effectiveness. In some other fields, much work is still needed to facilitate alignment and collaboration of RI. The first step towards these goals is to establish a knowledge base about the current status of the global facilities - a motivation for a global landscape analysis of the major research infrastructures.

Recently, several European initiatives have worked on creating an inventory of European facilities. The ESFRI landscape analysis concentrated on the largest, European or global scale, RIs. The MERIL projects mapped mostly the smaller but still important facilities in Europe. Several scientific areas (or domains) have also undertaken the task of mapping facilities specific for their needs. However, going outside of European facilities and viewing the overall availability of Research Infrastructures globally has been much less studied, with the particular exceptions of analyses by both OECD and G8 GSO. It is now timely to widen the view to outside Europe to gain systematic and accurate knowledge of “ESFRI-like RIs”.

Although large scientific facilities are developed around the world, the information about them is not usually found in one place. Thus, a consistent analysis of the landscape is needed. Such landscape analysis can give insights into what the current cover of research support structures is on e.g. a given scientific domain, service type, or geographical area. More detailed analysis can also shed light on operational details, ways to follow scientific impacts, funding models and many other features of such facilities, which can lead to better understanding of collaboration and alignment possibilities for researchers, research infrastructures, and science funding bodies. The RISCAPE landscape analysis tries to address many of these questions.

The RISCAPE analysis has provided new insights on the global landscape and the operations, services and organisation of RIs globally, but the work faced several challenges. The scoping of the landscape goals led to a concentration on larger, more established research facilities – of the same level and general type as ESFRI initiatives. This means that many interesting and potentially relevant, e.g. smaller or commercial facilities are not necessarily covered within this analysis. This concentration enabled the use of more detailed information collection, in the form of an organised interview of RI operators, which revealed a much more complete view of the facilities involved. At the same time, such methods also required direct contact with the RIs, which was not always successful. The analysis also has an intentionally European (and ESFRI RI) viewpoint, which will of course influence the types of facilities involved, and the information collected. From this perspective, the RISCAPE analysis can be considered internally consistent and indicative, but not a complete view of the global RI landscape.

This report is based upon the eight domain reports that have systemised the findings of the international mapping of their domains. In chapter 1 the landscape report first describes the framing and scope and the point of view used when drawing the landscape, in chapter 2 the methodology of RISCAPE is described. In chapters 3 to 10 the analyses of the findings in the domain reports are presented and chapter 11 is a set of observations and findings. At the end of the (electronic version) report one finds the appendices.

Ari Asmi
University of Helsinki, RISCAPE coordinator

Product of RISCAPE project. The project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730974

1. FRAMING AND SCOPE OF THE REPORT

Main contributors
Ari Asmi (University of Helsinki)
Jostein Sundet (Independent expert)

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The goal of the RISCAPE landscape report is to conduct an analysis of the Research Infrastructure landscape outside of Europe, with a European perspective based on the ESFRI infrastructure framework. In designing this landscape analysis, we found it crucial to specify the framing and the scope of the analysis to better understand how it can be used, who can find it useful and what kind of conclusions can be supported by the analysis.

Key questions for the final landscape report are:

- What kinds of facilities, networks and organisations are we interested in?
- What kind of data would be useful, available, and realistic to get?
- How can errors be avoided in data collection?

RISCAPE project goal

The RISCAPE Project aims to provide a systematic, focused, high quality, comprehensive, consistent and peer-reviewed international landscape analysis report on the position and complementarities of the major European RIs in the international Research Infrastructure landscape.

1.1 Framing, users, and use cases

The ESFRI perspective set the scale of the Research Infrastructures (RIs) to be analysed and also reflects the efforts (at least in Europe) of the last two decades. The project goals (see box above) specify that the analysis is to be comprehensive and cover all ESFRI Infrastructures, the methodology must be consistent, and it must have the necessary provenance to explain the conclusions. In this study we investigate complementarities between the European and non-European RIs.

To support the final landscape report structure and coherence, the RISCAPE Project team was augmented with a stakeholder panel. This consisted of senior research infrastructure experts with expertise in most of the RISCAPE science fields, with representatives of international funding agencies, international organisations, and regional European funders, all with knowledge of RIs. The stakeholder panel met in several virtual and physical meetings to consider the targets of the study, the scope of the project, methodology (including the content of questions), and to evaluate the initial results and early conclusions.

The primary user groups identified for the RISCAPE report are the European agencies (national and regional) and research performing organisations funding the Research Infrastructure development, the ESFRI, and international organisations such as OECD. The secondary user groups are the managers and operators of European and non-European research facilities and infrastructures, who are interested in the service provision, co-operation opportunities, and potential for joint international developments. Although the RISCAPE methodology and data is collected with these two user groups in mind, the data is relatively general and should be widely applicable for others as well.

Based on this selection, the RISCAPE consortium planned the report format, and adjusted the methodology process. In dialogue with the stakeholder panel, the project teams decided to concentrate on the following use cases:

- Increased knowledge of the international RIs to help European and other strategic developments on Research Infrastructures. In particular, to find complementarities between European and international actors, identify opportunities and provide a base level for national or European evaluations. This goal is useful for the two target groups, but most important for the primary user group.

- Highlight possibilities for collaboration between European and international facilities, particularly in the context of alignment of solving global challenges, global service access, increased efficiency and scientific excellence. This goal is oriented more towards the research infrastructure/research performing organisation user cases but is also applicable for funding agencies and similar organisations, e.g. in their planning of potential new programs.

Several other use cases (e.g. scientists, RI development outside of Europe, policy makers, etc.) were considered to be supported by the collected data but they were not directly included in the process of defining the scope and methodology.

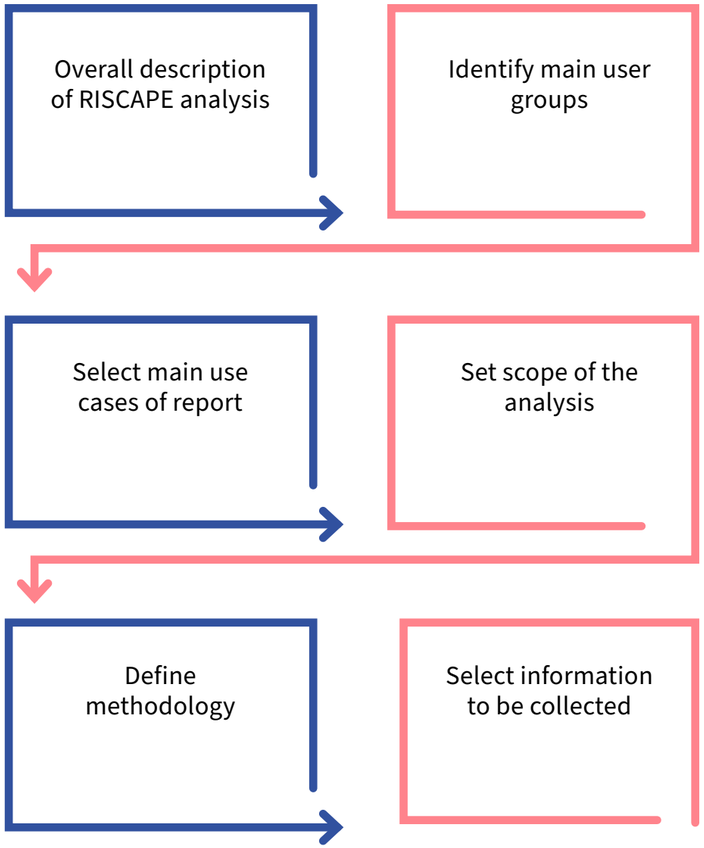

Figure 1.1 *Flowchart of the RISCAPE methodology preparation via identifying the user groups and use cases.*

1.2 RISCAPE domain team composition

European RIs of the ESFRI size and scope are, in Europe, often joined in disciplinary clusters with support from the European Commission. These clusters are common platforms for the infrastructures to share experiences, develop interoperable services and strategies. One important pillar in the RISCAPE Project, was to engage these European ESFRI research infrastructure clusters to help create analysis teams, refine the methodology, and prepare the information gathering for their respective domains. For the domains where there was no cluster project at the time of the project preparation, the above domain tasks were negotiated with a recognised domain expert.

The use of the already existing RI clusters to structure the analysis, and do the information gathering, has many advantages as the clusters and infrastructures have themselves acquired internal knowledge and connections within their respective fields of study. They are versed with the challenges and methodologies of their disciplines, the RI field and relevant stakeholders, and know the language, terminology, and scientific culture of the domain in question.

1.3 Scope of the analysis

The intent of the RISCAPE report is to create a landscape report for research infrastructures outside Europe and thus, the first challenge is to define what constitutes an RI in the context of this analysis. The RISCAPE Project team spent considerable time and effort considering this question. Two internal workshops and one stakeholder panel meeting were organised to tackle this issue, in addition to desk research of the definitions and use found in the literature (see box next page). The project team decided to use a definition with the following attributes: 1) it must valid also outside Europe, 2) the selection can be made by relatively simple analysis, 3) but still be similar enough to a European view of RIs to make the use cases of the analysis useful.

After considerable time with analysis and consultations, the following RISCAPE definition was adopted that is in-line with most existing definitions, aligned with the project objectives, and also fulfils the user group requirements and the main use cases.

A RISCAPE Research Infrastructure is a facility, organisation, or network that fulfils the following:

1. It has science or scientific research as the main driver of its activities. This requirement comes from the need of finding complementary facilities to the ESFRI (and similar major infrastructures) Europe, which – as science-oriented organisations – are best mirrored by facilities concentrated on the same goals.

2. It provides research services to users outside of the organisation itself. This requirement has a similar background as the previous one but is also more fundamentally based on the European view of shared research facilities, and the RI as a service provider.

3. It has an operational time horizon longer than the typical research projects in the field in question. This longevity is crucial for the use cases considered, as any short-term projects or initiatives would make the collected information quickly obsolete. Also, as the longevity is typical for the scale of operations required for European ESFRI infrastructures, the identified potential complementarities should be more meaningful.

4. It promotes excellence and is of significance for the science field in question. This requirement was needed in order to have some degree of similarity to the European ESFRI landscape facilities, all of which are important at a European (i.e. regional) level. The requirement was, in some science fields, also needed to reduce the number of facilities to analyse. However, this is a difficult criterium to evaluate in an independent and transparent manner. But, this subjectivity was considered to be acceptable in the analysis due to the practical requirements.

These four attributes were then used to guide the overall methodology and the requirements for facilities to be included in the landscape report. However, during the process it became clear that for some scientific fields' strict use of these criteria lead to very few facilities to analyse. And thus, for some domains, facilities that did not completely fulfil the criteria could also be included. However, these cases are clearly documented in the report.

WHAT CONSTITUTES A RESEARCH INFRASTRUCTURE?

The term Research Infrastructure is a very challenging one, as the use of the term varies strongly, even inside Europe. However, finding a working definition for the term is crucial to the landscape report. The term is used in different contexts internationally, and can have different meanings and connotations to different communities. RISCAPE did a literature analysis of the usage of the term in scientific and policy literature and found some commonalities of the use of the term:

- A dominant term in all the definitions is that the RI is meant for **research or science purposes**, often including qualitative terms such as "top-level" or "cutting-edge." This means in practice that even though there would be additional goals for an RI, the necessary condition is that it is concentrated on supporting science. Only rarely are other goals such as innovation (notably in Horizon 2020 definition), education, or dissemination mentioned. Of note is the Australian NRC argument to remove RIs from their consideration if research is only a "small component" of the activities.

- The term institution, or organisation is also used in some of the definitions, but not universally. Instead terms such as **facilities, resources or services** (among others) are used, which clearly indicate more a result or service-oriented description of the RI instead of concentration on an organisational status. The types of **single-sited, distributed and virtual RIs** are common in the definitions. This suggests that these three categories are widely used to characterise the RIs. This could be influenced by the ESFRI definition but is suitable for many purposes. These are also clearly visible in the OECD terminology.

- Almost all definitions also mentioned specifically **examples of infrastructures**. Particularly, mentions of **instrumentation, collections** (physical and data) and **collaborative networks** are used. Also software, communication tools and human resources as a part of Research Infrastructures are also mentioned in some of the descriptions.

- The term **unique** is used by some of the definitions (such as the ESFRI), suggesting that each RI must be somehow distinguishable from others and of a particular nature, or particularly significant. Similar sense of need of importance in an RI is visible from terms, such as "more-than-national relevance", "indispensable", or "major" etc.

- Only a few definitions explicitly mention terms related to a public nature of RIs. Instead the term "access" is often used. Of particular interest is the Australian definition in that it specifically mentions that for a RI to be considered a "National Research Infrastructure", there must be "**a diverse range of users from more than one institution or sector**". However, the public nature of RIs is more often mentioned in accompanying information.

Although **longevity** is not often mentioned in the short-form definition of a research infrastructure, it is implicitly involved both in the ESFRI definition and in the literature use of the term.

2. METHODOLOGY

Main contributors
Lorna Ryan (ESS ERIC)
Ari Asmi (University of Helsinki)

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2.1. The RISCAPE methodology

The collection of information for the RISCAPE report requires a consistent methodology to meet the project goals and to make a comprehensive and useful report. The methodology was created by the RISCAPE project team and was further developed in consultation with the stakeholder board.

To establish a suitable approach for the methodology, a set of attributes was specified. The methodology must be:

- *transparent* (i.e. well-defined, documented and the process could be repeated using the same methodology),
- *meaningful* (suitable for purpose, collects relevant information),
- *practical* (the information can be collected with the resources available, the information is possible to obtain),
- *discipline-agnostic but -aware* (enough similarity between fields of science, tolerance for domain-specific differences), and
- *error tolerant* (possibility to detect erroneous information or misunderstandings).

The RISCAPE project partners refined the methodology into a comprehensive set of procedures (figure 2.1) during a series of workshops.

2.1.1 Discovery of potential research infrastructures

The first step in the RISCAPE analysis is the discovery of potential organisations that could be characterised as research infrastructures. The RISCAPE project utilised several tools for this purpose, each with their own advantages and disadvantages:

1. **Using the ESFRI RIs (and similar) as a source of information.** As the RISCAPE consortium was RI experts, closely connected to the ESFRI RIs, the use of their organisational knowledge was the first source of information. Each domain expert involved their respective European RI and RI clusters (and in some cases, their stakeholders), to give information, contact points, and tips on potentially useful facilities working in their field outside of Europe. This approach has several positive features: the knowledge is based on the scientists and managers working in the field and is based on the fact that the European RI leadership is typically drawn from the scientific community using the facilities. Notably, the intent was to collect all leads for potential facilities to limit self-censoring of results. Thus, the information is based on the visibility of these facilities to the European scientists in the field of study, which can be considered both as a positive and a negative aspect of this method.

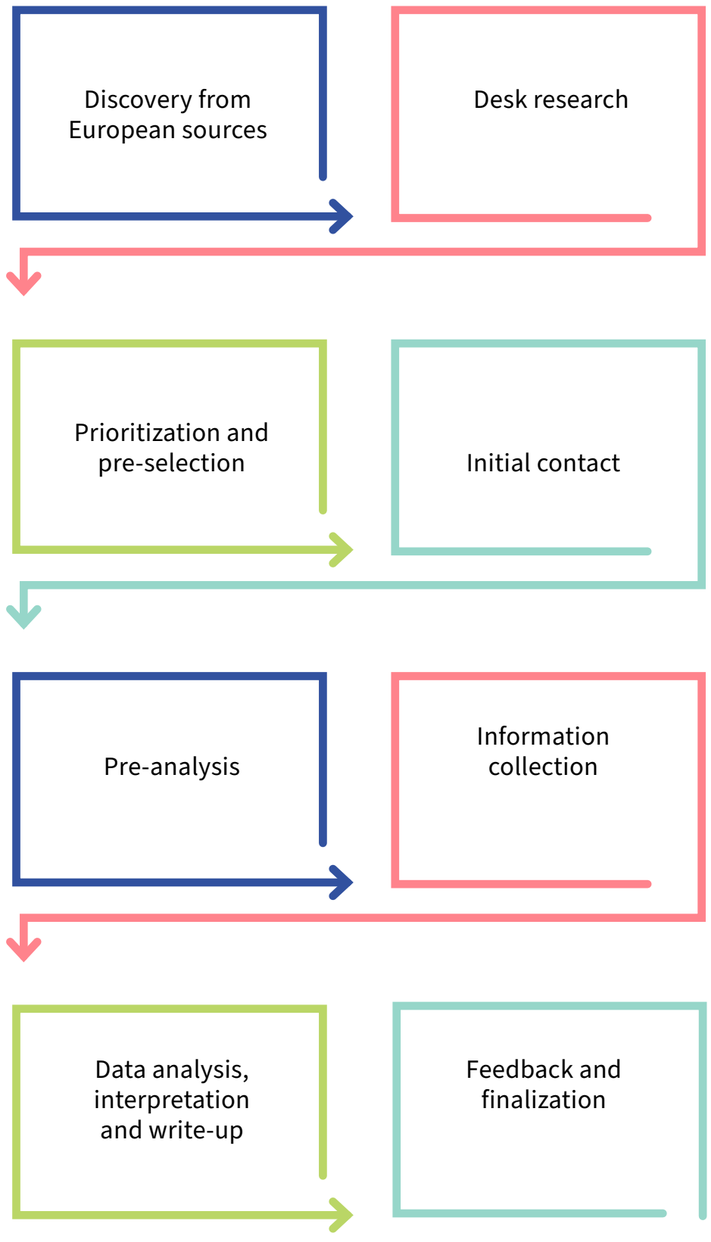
2. Some of the domains studied also used **expert panels, special expert consultations and workshops** to collect this information. The approach needed a transparent way to engage the experts and to evaluate their responses. Workshops and consultations might unravel additional information outside of ESFRI and RI knowledge, and facilitates the potential of finding actual gaps in the European RI landscape in respect to the international offering.

3. **Literature analysis.** Analysing national roadmaps, infrastructure strategies, available science prioritisation documents, reports from the international organisations on research infrastructures, and even in some cases scientific literature, was one of the key methods to collect the initial list of potential research facilities for this study. In some fields, like in astronomy and particle physics, the existing international databases of facilities were used.

4. Information collection from **international facilities.** During the interviews (see below), one of the questions asked was related to other facilities in the field. This method was used to capture knowledge of these facilities from the international respondents.

5. Direct discussion with **country representatives**. In some cases, the project also included directed discussions with country representatives (normally ministerial or funding agency level) for potential leads in their country.

These steps led to a number of potential facilities per scientific field, which were then discussed with the stakeholder panel and within the European cluster projects for comments and clarifications.



Fugure 2.1 *Overview of the RISCAPE methodology*

2.1.2 Desk research

Prior to actual analysis, the RISCAPE domain experts did a rough analysis of the identified RIs. This was done based on the RI webpages, discussions with European RI facilities, and on reports and documents. This was intended to be a quick mapping of the structure and operation of the RI, and discovery of potential contact points, if these were not clear from the initial identification.

2.1.3 Prioritisation and pre-selection

Based on the desk research results, the RISCAPE domain experts evaluated each RI. If an RI was characterised as a RISCAPE research infrastructure it was included in the landscape analysis. This procedure was intentionally intended to be relatively loose to make it less likely to miss key facilities in the analysis. Only in one field, Physics, did the RISCAPE domain experts need to consider more strict criteria. The additional evaluation was done using independent domain experts.

2.1.4 Initial Contact

After identifying a potential RI, the project partners sent an email invitation to the RI to participate in the survey. Email addresses were typically collected from the site web pages (if existing) or from the previous steps in the analysis. The email was formal and similar in content, but each domain expert could also personalise the message in consideration to the field and facility involved. The invitation explained the purpose of the study, the methodology, the analysis steps and normal regulatory information (e.g. length of interview, security of their personal data, possibility to evaluate answers and decline answering). In several cases, personal contacts from the European RIs were used and this increased the response rate significantly. If no response was received, the contact attempt was repeated two more times. If there was still no response, other methods (such as utilising European contacts) were attempted if feasible. If still no contact was possible, the contact attempts were recorded, and the basic information was retained about the facility. Sometimes only web-based information was used, however, this is clearly indicated in the domain specific reports.

2.1.5 Pre-analysis

After contacting the facility and preparing an interview (or questionnaire), the RISCAPE partners pre-analysed the facility, using information found in internet websites and reports. In practice, the questions were prefilled in by the RISCAPE interviewer and then sent prior to the interview to the respondents. This was done to:

- make sure that the respondents know which kinds of questions are asked and are prepared for them,
- save time during the interview especially on the more basic questions regarding contact information, full name of the facility etc.,
- reduce the chance of misunderstanding the questions.

2.1.6 Information collection

In most cases, the main methodology for information collection was a controlled (directed) interview, where the interviewer and respondent went through the questionnaire (see box RISCAPE questionnaire) and discussed answers, and (if needed) the purpose of the questions. This approach was chosen to make sure that the respondent understood the question, and to ensure that the collected data matched the intent of the respondent. Each respondent was informed beforehand about the nature and terms of the interview, and on the use of the data collected. They were also formally informed about their rights not to answer any question, and finally to confirm the results recorded. Most of the interviews were done remotely via a web-conference platform, and most of the RISCAPE partners used a centrally-provided questionnaire platform for information collection. In some cases, the interview was done in person, e.g. in a conference, with a similar overall questionnaire structure. The results were collected and edited and then sent to the respondent for fact checking. In the physics domain, the interviews were done using an online questionnaire platform due to the large number of respondents. In the case that the RISCAPE domain expert found potential misunderstandings or errors in the answers, the respondents were contacted separately for clarifications.

2.1.7 Data analysis, interpretation and write-up

After the information harvesting, the RISCAPE teams evaluated the answers from the perspective of the domain landscape analysis. Evaluation of the geographical coverage of the facilities indicated the availability of research services globally. More detailed analysis was done on particularly interesting findings, and on important domain-specific aspects. Particular emphasis was put on finding complementarities (see box, complementarities) to European RIs in each domain, and on identifying potential collaboration targets. For this reason, specific models of complementarity were discussed in the RISCAPE community and with the stakeholder panel, as well as a list of potential interesting common analysis points. The overall structure of the individual domain reports was centrally coordinated, but a significant amount of freedom was given to the overall composition of the individual reports to properly capture the specificities of the domain and the results obtained.

2.1.8 Feedback and finalisation

As the last part of the analysis, the domain report was further discussed by domain experts and with the landscape report editor and the RISCAPE project team. The content and final conclusions of the report were finalised, and key general findings were selected for the final landscape report. This phase also included a fact-checking peer review done by an external expert.

RISCAPE questionnaire

The RISCAPE questionnaire is a set of questions intended for a thorough analysis of an RI, and to find key aspects for different use cases in the user communities. The preparation of the questions was done within the RISCAPE consortium and was further discussed with the stakeholder panel. Overall, the number of questions was limited by the practical time limitations for an interview, and likelihood to get a response. Typically, the interview took about one hour, which can be considered to be a practical maximum for this kind of survey. Additionally, the questions were also limited in content to avoid questions with sensitive implications.

The questions were built around the following categories and types of information collected (full list of questions is in the web annex of the report):

- Identity of the respondent (3 questions): name, title, contact information
- General information (6 questions): facility name(s), website, address, contact, type
- Funding and scale (4 questions): primary funding, approx. construction and operating costs
- Longevity and plans (5 questions): statutes, time horizon, business plans, long-term funding
- Mission and goals (6 questions): mission statement, science orientation, science support, specific goals
- Services (7): service catalogue, types of services, access methods, accessibility to outside, use of capacity, extent of external use of services, user quotas
- European access (2): Current use of EU researchers, existing agreements with EU countries
- Data (2): data policy, open licences
- Impact (6): scientific impact, socio-economic impact, impact reports, altimetric, user statistics, indicators
- Position and future (7): roadmap status, development plans, geographic coverage, central and secondary facilities, extension plans
- Capabilities and interaction (3): technical capabilities, service provision to other facilities, dependence on external providers
- Complementarity (3): comparison to EU facilities, collaboration possibilities, global initiatives

Most of the questions included an open comment field for clarifications, if needed. Each question was also supported by a short description to guide the interviewers and respondents.

In addition to this, the web platform recorded basic metadata of the answer (edit times, etc.).

2.2 Known biases

The landscape analysis of RISCAPE, using the method described in this section, has many advantages, but also clear limitations. Some of the main limitations are listed here and should be considered when using the landscape report as a basis for decisions or further work.

- The chosen discovery and identification methods are good for finding "known knowns" – i.e. facilities already known by the European RIs. This means in practice that there is a risk to miss facilities that are in countries or regions not currently collaborating with European RIs. However, this is somewhat mitigated by the overall international nature of science: if major facilities are not known at all by European researchers, they are not very visible in the literature and conferences of the domain in question. However, these risks are probably more present in disciplines with a lesser degree of international collaboration, or which are very fragmented in nature. Additionally, subdomains that are completely absent in the European landscape are likely to be missed in this approach.

- The desk research and information collection are biased towards facilities which have English-language websites and can respond to English emails. Only the RISCAPE energy team actively used local language help in the interviews of Russian, Brazilian and Chinese facilities, which significantly improved the response rate.

- The language and cultural barriers to answer questions could be a partial explanation of the relatively low response rate (reported for each section separately). Indeed, in some areas it was difficult to explain the benefits of participating in the survey to potential respondents. Thus, it is important to know that some major facilities could only be evaluated via publicly available information and, thus, we cannot claim full coverage in any of the scientific fields in question.

- Ontology is a constant challenge in these kinds of studies. The use of structured interviews helped somewhat, but in general some of the terms (including "research infrastructure") had in some cases very different or even loaded meanings.

- The analysis concentrated mostly on facilities which correspond to the RISCAPE definition of a research infrastructure – itself based on a very Euro-centric approach to research infrastructures. In some countries, a more private sector-based approach, a collection of projects, or individual facilities serving only their own scientists or other solutions can provide similar roles which are not (intentionally) covered by this analysis.

However, the RISCAPE methodology has clear advantages in comparison to some other studies. The report is global in scope, the methodology is intended to be as generic as possible, and most of the scientific fields can use it more or less as-is. The main tool – structured interviews – has proven to be generally very applicable for this kind of study. This analysis method was found to be relatively resilient to misunderstandings originating from cultural or language reasons. A detailed generic on-line questionnaire was also used for some domains where direct interviews were believed not to be feasible due to resource constraints.

Complementarities of research infrastructures

The complementarities of European and non-European research infrastructures can be evaluated in many ways. In RISCAPE, the project partners and Stakeholder panel considered the following three aspects of an RI as a rather general model of complementarity.

1/ **Geographic complementarity**, where the infrastructures work in different areas of the world, complementing each other's services with regionally important aspects. This is a relevant complementarity only in the fields where the location matters, such as in environmental sciences, astronomy or social surveys. This kind of complementarity can also in some cases be competitive, if similar services are provided in the same location.

2/ **Technical complementarity**, where the infrastructures provide similar services, but with different technical capabilities, or additional capacity. These kinds of complementarities are common in many fields, and joint planning for extension of global capacity can have very good development prospects – assuming access issues can be solved. This is very typically evident in many Physics and Engineering fields. Sometimes this kind of complementarity is also competitive, when the facilities have a "build race" to improve their capacity over the competitors.

3/ **Challenge complementarity**, where the infrastructures provide different services to answer the same challenge from different perspectives. This is closely related to the technical complementarity above but can be sometimes clearly seen in e.g. very different ways to solve the same sustainable development goals or to answer key medical challenges.

In addition to complementarities, the RISCAPE analysis evaluated their data to find potentially interesting trends on many other subjects suggested by the Stakeholder panel, such as:

- Governance types of facilities (projects, government organisations, loose networks)
- Geographical distribution of RIs
- Methods for following the impact of the research infrastructures
- Differences in access methods, mention of private sector use
- Sustainability models for RIs
- Data access and policies

3. ENVIRONMENTAL RESEARCH INFRASTRUCTURES

Main contributors
Emmanuel Salmon (ICOS ERIC)
Ari Asmi (University of Helsinki)

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3.1 Domain Overview

In the ESFRI 2018 Roadmap[1] (as in the previous ones), the field of environmental sciences is divided into four subdomains, each one dealing with a part of the Earth system: atmosphere, hydrosphere (including the marine and oceanic facilities), biosphere (ecosystems) and the geosphere (solid earth). This classification is used throughout this report considering that in Europe, as well as elsewhere, some Research Infrastructures (RIs) deal with multiple subdomains.

The research areas in environmental subdomains are closely interlinked. With ESFRI as a starting point of RISCAPE, a total of 22 European Infrastructures were selected as the basis for the RISCAPE analysis in environmental sciences. These European ESFRI Research Infrastructures are listed in table 3.1. The number of Environmental RIs in the ESFRI list is relatively high due to the number of disciplines involved. Many of the RIs are observational, with distributed facilities located in a wide geographical area and some support experimental facilities. International collaboration is the de-facto mode for many of the Research Infrastructures in this area, as the challenges they address are often global in nature. Similarly, multidisciplinarity is often critical to answer environmental challenges.

The European landscape of environmental RIs is strongly embodied in the ENVRI cluster. ENVRI is a cooperation framework that has been built on almost 10 years of successful collaborative projects, with the ENVRI-FAIR being the current one. The Board of Environmental Research Infrastructures (BEERi) established under ENVRI has been an instrumental forum for the cooperative work between RIs, and a major asset for this landscape report.

Table 3.1. *European Research Infrastructures serving as a base for analysis (* A: atmosphere, B: biosphere, G: geosphere, H: hydrosphere, X: cross-domain ** ESFRI 2016 Roadmap – L: landmark, P: project, E: emerging project)*

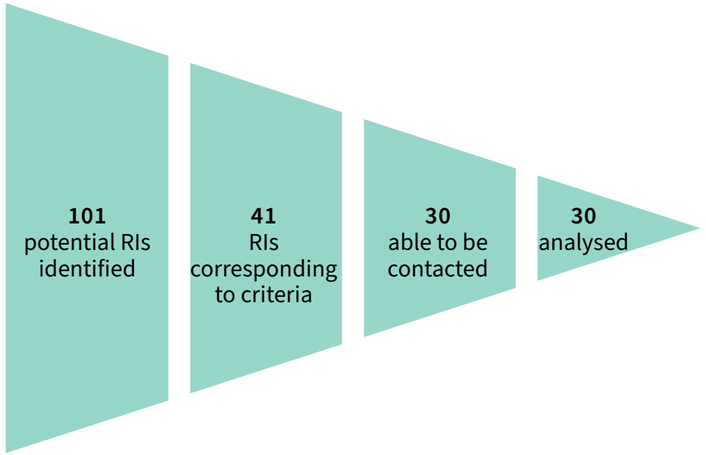
Short name	Name	Subdomain*
ACTRIS	Aerosols, Clouds and Trace Gases Research Infrastructure	A
AnaEE	Infrastructure for Analysis and Experimentation on Ecosystems	B
AQUACOSM	Network of Leading European Aquatic Mesocosm Facilities Connecting Mountains to Oceans from the Arctic to the Mediterranean	H
ARISE	Atmospheric Dynamics Research Infrastructure in Europe	A
DANUBIUS	International Centre for Advanced Studies on River-Sea Systems	H
DiSSCo	Distributed System of Scientific Collections	X
EISCAT_3D	Next Generation European Incoherent Scatter Radar System	A
eLTER	Integrated European Long-term Ecosystem Research Network	B
EMSO	European Multidisciplinary Seafloor and Water-Column Observatory	H
EPOS	European Plate Observing System	G
EUFAR	European Facility for Airborne Research in Environmental and Geo-Sciences	X
Euro-Argo	European Contribution to the International Argo Programme	H
EUROFLEETS	New Operational Steps towards an Alliance of European Research Fleets	H
EuroGOOS	European Global Ocean Observing System	H
GROOM	Gliders for Research, Ocean Observation and Management	H
IAGOS	In-service Aircraft for a Global Observing System	A
ICOS	Integrated Carbon Observation System	X
INTERACT	International Network for Terrestrial Research and Monitoring in the Arctic	B
IS-ENES2	Infrastructure for the European Network for Earth System Modelling	X
JERICO	Joint European Research Infrastructure Network for Coastal Observatories	H
LifeWatch	e-Science and Technology European Infrastructure for Biodiversity and Ecosystem Research	B
SIOS	Svalbard Integrated Arctic Earth Observing System	X

[1] ESFRI Roadmap 2018, http://roadmap2018.esfri.eu

3.2 The methodological approach

The methodology used in the section follows the RISCAPE methodology (as described in section 2) closely. After consulting with the ENVRI community RIs, a relatively large list of potential, in-ternationally interesting facilities, networks and Research Infrastructure-type organisations was collected. For each of these organisations, a high-level contact was identified, mostly with the help of their website. An email was sent to these persons, presenting the RISCAPE project and its objectives and requesting the possibility of an interview. The main topics of the interview were indicated. Optionally the person could forward the request to another whom they might judge more relevant for the interview, which happened in a limited number of cases. No RI declined the invitation after being contacted. A second email was sent to confirm a time slot for the interview and with more details on the questions and the RISCAPE interview disclaimer. The interviews were carried out virtually or over the phone. An organisation was contacted three times via emails before removing them from the analysis. The number of organisations identified as an interesting RI was 209 but the number of organisations analysed was 30.

There are many important environmental observation systems which are not considered in this analysis, particularly satellite remote sensing systems, governmental environmental pollution monitoring (e.g. air quality monitoring, etc.), and standard meteorological observations. They were excluded partly since they are outside the ESFRI landscape (as for satellite observations), and partly since they must be operated primarily for research purposes. There is some degree of grey area though, as some environmental observations done by the ESFRI RIs in Europe, are done by governmental monitoring networks in other regions.



3.3 The International landscape

The latest ESFRI Roadmap states that the environmental domain *“is of global dimension by nature and close collaborations on Earth system research are already established worldwide”* [2]. It also lists some of the areas where global cooperation is crucial for Europe: the achievement of the UN Sustainable Development Goals, the standardisation of data protocols and the sharing of best practices all over the world. The role of the ENVRI cluster in connecting European and international RIs is also acknowledged.

3.3.1 Atmospheric Research Infrastructures

Advanced Modular Incoherent Scatter Radar (**AMISR**) is a programme for a modular, mobile radar facility used by research scientists and students. The current facilities consist of three radar faces, located in Poker Flats, Alaska and in the Resolute Bay, in the Canadian High Arctic, on high magnetic latitudes. The operations concentrate on investigating the energy and momentum transfer in all layers of the Earth’s upper atmosphere, accessing critical data on the complex physical processes that comprise the sun, magnetosphere, and ionosphere. The main products are remote access to the sites and data products from conducted experiments. The remote access is controlled by an informal review process, with expert evaluation if needed. All experimental data becomes freely available for users after processing. The collaboration with European EISCAT (and **EISCAT_3D**) is integral to the operations (due to distributed data system MADRIGAL), and is active with other European organisations, such as the European Space Agency.

Passenger plane observations of CO2 and other greenhouse gases are available from the Japanese **CONTRAIL** programme, which operates a set of observational instruments installed on regular commercial passenger service aircraft (in total 10 aircraft), from Japan towards Europe, Asia, Hawaii and North America. The organisation has been operational since 2005 but has recently (2018) updated their data access policy for open access to all users, although not all recent data is available yet. The programme concentrates on CO2 data with continuous measurement equipment, but also includes observations with samplers of other greenhouse gases. Although the programme is project-based, they have been continuously operating since 2005 as back-to-back five-year operational projects. **CONTRAIL** and European **IAGOS** have an open dialogue and shared data resources, making them relatively complementary systems, having slightly different observation payloads but complementary geographic coverage.

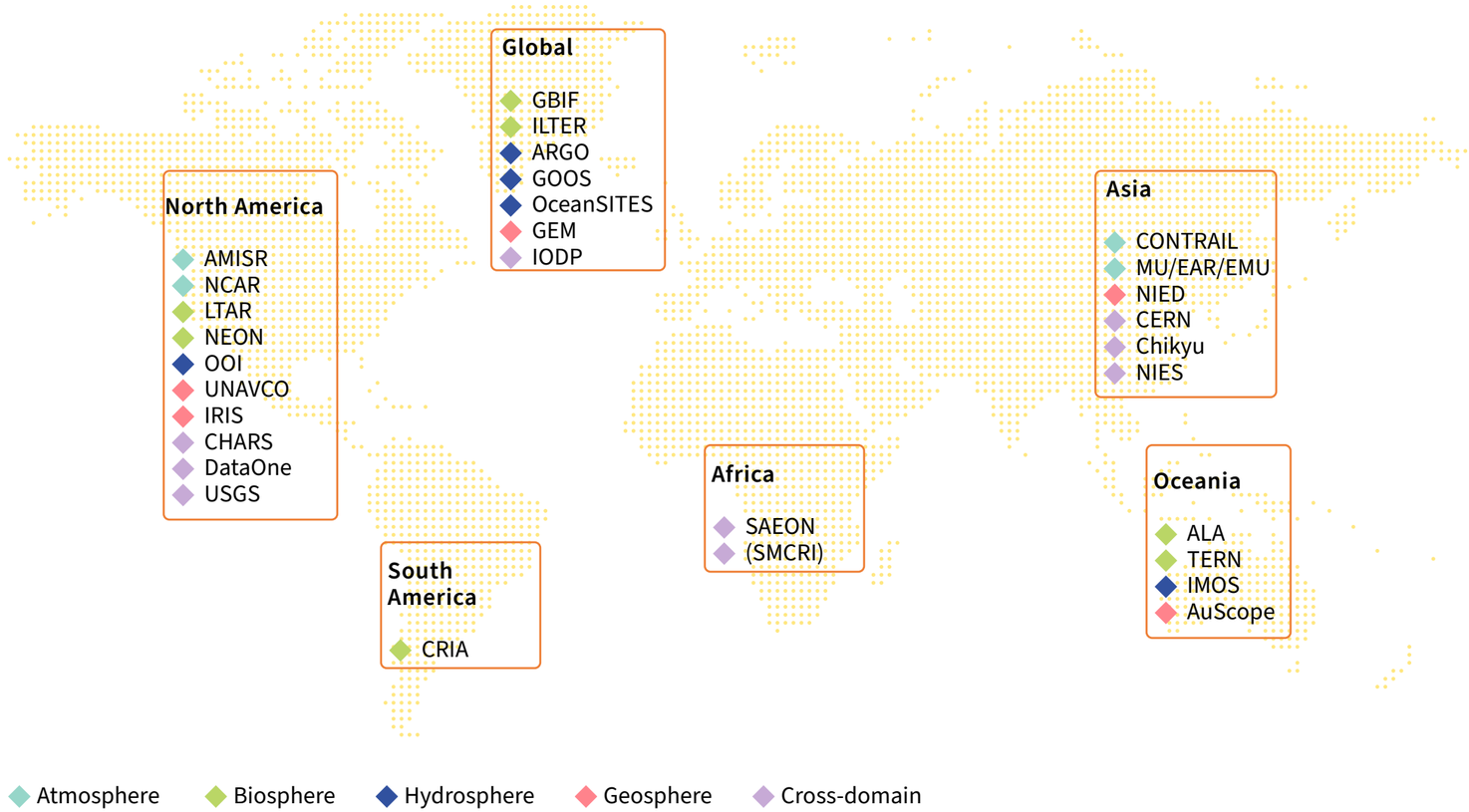
MU/EAR/EMU (Middle and Upper Atmosphere Radar / Equatorial Atmosphere Radar / Equatorial Middle and Upper Atmosphere Radar) is a combination of several, mostly Japanese funded and operated, facilities to study dynamical processes, such as vertical and/or latitudinal couplings, in the atmosphere. The operating organisation is the Research Institute for Sustainable Humanosphere (RISH) in Kyoto University. The oldest part is the **MU** component, which is the first large-scale MST radar with a two-dimensional active phased array antenna, located in Shigaraki, Japan, that started operations in 1984. The **EAR** (2001) is a large distributed Doppler radar facility located in West Sumatra, Indonesia, operated in collaboration with the National Institute for Aeronautics and Space (LAPAN) of Indonesia. The **EMU** facility is co-located with an upcoming facility with 10 times the sensitivity of **EAR**. This is an equatorial geographic complementary to the high latitude **EISCAT_3D** system in Europe. However, no formalised agreements

[2] ESFRI Roadmap 2018: 152, http://roadmap2018.esfri.eu

between them exist at the moment. Most of the research services are based on providing for special experiments, but standard observational data is available online one year after the experiments. Access to observation time on the system is excellence-based and available for outside researchers. RISH also collaborates closely with the **PANSY** radar in Antarctica, run by the Japanese National Institute for Polar Research and the University of Tokyo.

NCAR (the National Centre for Atmospheric Research) in Boulder, Colorado is funded by the US's National Science Foundation (NSF), and is a major centre of operations for US academic climate, solar and atmosphere research. They operate seven laboratories and an educational and outreach programme. The laboratories include atmospheric chemistry observations and modelling (ACOM), climate and global dynamics (CGD), a computational & information systems laboratory (CISL), an Earth observing laboratory (EOL), a high altitude observatory (HAO), Meso- and microscale meteorology (MMM) and a research applications laboratory (RAL). NCAR offers a wide range of research services, which include numerical models and results (Earth system, weather research and forecasting, multiscale modelling and climate models), research campaign support via research aircraft, lower atmosphere observing facilities, in-situ chemistry instrumentation, the Mauna Loa solar observatory, and the Fabry-Perot upper atmospheric winds observing network. In addition, they provide three specialised laboratory facilities for meteorological calibrations (EOL), the NCAR vacuum tunnel scattered light test chamber and ACOM laboratory chambers for gas-phase and aerosol process studies. The NCAR data facilities serve both their own observations and projects, and they provide specialised software for analysis, data assimilation and visualisation, and scientific computing services.

There is a high level of potential complementarity with European facilities, with similarities in services with e.g. **IS-ENES** (Earth System research) and **EUROCHAMP** (laboratory chambers), and even European e-infrastructure service providers, although from a disciplinary perspective. Of particular interest is the **NCAR** very high payload and a long-range research aircraft. This could be considered as technical complementarity with similar European research facilities such as **EUFAR** initiative and German national DLR facilities. **NCAR** data products are openly available within six months of observation (such as climate data, solar observatory data, etc.), and NCAR encourages supported projects to have an open data policy.



However, the current **NCAR** policy requires that the users have a current NSF-funded project to be able to access some products (e.g. the aircraft mentioned above).

3.3.2 Solid Earth Research Infrastructures

In Australia, the **AuScope** is a facility for world-class Research Infrastructure services for Earth system researchers, particularly the (deep) Earth crust. **AuScope** coordinates large single-sited facilities, virtual laboratories, access platforms to simulation and provides access to geophysical or geochemical laboratories and observational networks (such as seismic arrays). The facilities are provided by 22 member organisations across Australia and are divided into six programmes (Geodesy and Geodynamics, Earth Imaging, Geophysical Observatory, Earth Composition, Subsurface Observatory and National Virtual Core Library), with central data discovery and analytical tools provided by **AuScope**. Much of the effort is concentrated on researchers, industry and education with open, and standardised data services. All of the services are available to researchers for free (regardless of nationality), with an excellence-based access review for resource-limited facilities. The complementarities on service development with European **EPOS** initiative are numerous and significant collaboration with them has already been initiated.

Global Earthquake model (**GEM**) is a global initiative to achieve earthquake resilience worldwide and to become the most complete source of reliable and open earthquake risk resources. Although

they are a non-profit organisation in Italy, they operate a global data service, aiming to transfer fundamental scientific observations into services applicable for decision making particularly on understanding the hazards and risks associated with earthquakes. The most relevant global framework for **GEM** is the Sendai Framework for Disaster Risk Reduction (**UNISDR**). They also provide the Openquake platform (software, datasets and tools) for researchers and managers. These services can be also considered to support researchers worldwide and **EPOS** is a partner.

The US **IRIS** (Incorporated Research Institutions for Seismology) is a consortium of 125 US institutions dealing with seismology, with affiliates all over the world. **IRIS** operates science facilities for the acquisition, management, and distribution of seismological data and its programmes contribute to scholarly research, education, earthquake hazard mitigation, and verification of the Comprehensive Nuclear-Test-Ban Treaty (**CTBT**). They provide laboratory services, remote sensing (Global Seismographic Network), support temporary networks, data centre services and resources for education and outreach. Access to physical facilities is for (NSF) grant holders, but data is freely available. The collaboration with European facilities exists in the **COOPEUS** and **COOP+** frameworks, and within the interdisciplinary Earth Data Alliance.

The Japanese **NIED** (Natural Research Institute for Earth Science and Disaster Resilience) provides basic and fundamental research and development in the field of disaster resilience science and technology. They promote multi-faceted disaster resilience science and technology for preempting disasters, stopping damage from further escalating, and recovery and rehabilitation from disaster damage. The **NIED** is a distributed facility, consisting of seven basic research divi-sions and six fundamental R&D centres. The main facilities include three types of high precision and performance seismic observation networks, **S-net** and **DONET** cabled seismographs and tsunami networks, **MLIT XRAIN** radar network for monitoring torrential rain, Kyoshin monitor for visualisation of ground motion, **J-RISQ** real-time earthquake damage model, **JSHIS** earthquake hazard service, and **V-net** volcano observation network. However, the most unique is the **E-Defence** three-dimensional earthquake testing facility, rainfall simulator for landslide research, and Cryospheric environment simulator for snow research. Access to the observational data is free (for research and societal users), and the facility access is available to external researchers based on excellence-based review. However, each facility has their own charging policy. They also support many direct civic defence activities in Japan.

University NAVSTAR Consortium (**UNAVCO**) based in Boulder, CO is a US non-profit university- governed consortium that facilitates geoscience research and education using geodesy. They support research efforts in geosciences using tools related to geodesy but can also be used in other disciplines of geoscience. They consist of a consortium of over 100 member institutions (US) and over 80 associate members (US and international), with services on geophysical instruments (GNSS/GPS receivers and antennas, geodetic imaging, laser strainmeters, borehole in-struments and meteorological instruments), associated technologies (monuments, communication and network monitoring), as well as data (real-time or near-real-time), software, processing and modelling and visualisation tools. They also support a range of education and outreach initiatives. Most data are openly available except for some radar and satellite data. Access priority is for NSF-funded researchers who also can apply for additional support via internal peer-review. Commercial surveyors is a major user community for their data products. They coordinate some of their activities with EPOS but have no current, formal agreement.

3.3.3 Marine and aquatic Research Infrastructures

Integrated Marine Observing System (**IMOS**) is an Australian initiative for systematic and sus-tained multiscale and multi-disciplinary observations of the Australian marine environment. They have a wide set of observations covering the oceans around Australia: e.g. **Argo** network, calibra-tion and validation of satellites (e.g. ocean colour), use of commercial ships, gliders and animal tracking. **IMOS** is also present on the continental shelf and along the coasts with a "national back-bone" of instruments. Almost all parts of **IMOS** are operated as national facilities, this to avoid competition between national institutes. The data is freely available to users and they operate their own data facility with information including the general public.

The mission of **OceanSITES** is to collect, deliver and promote the use of high-quality data from long-term, high-frequency observations at fixed locations in the open ocean. **OceanSITES** is a programme under the WMO-IOC Joint Technical Commission for Oceanography and Marine Meteorology. It is specialised on Eulerian time series to monitor the evolution of geophysical properties at a certain place, e.g. using mooring cables. The head office is in Switzerland, but the or-ganisation is global, covering all major oceanic regions with an emphasis on the equatorial region. Data range from the air/sea interface to the sea floor and data services include visualisations. Physical access is possible via allowing researchers' instrumentation at the deep-water sites. **OceanSITES** have informal connections to European **EMSO**.

The Ocean Observatories Initiative (OOI) is a US initiative and is a network of interactive, globally distributed sensors with near real-time data access. The OOI was commissioned in 2016. They cover regions in the east of Greenland and New England and the Washington/Oregon shelf and slope and the Gulf of Alaska. They offer both physical and virtual access. The data is open. Inclusion of new instrumentation requires a comprehensive approval process including a peer-review. Services have no explicit limitations for non-US researchers.

3.3.4 Ecosystems and biodiversity Research Infrastructures

Atlas of Living Australia (**ALA**) is an open access virtual Research Infrastructure for Australia's biodiversity data. Biodiversity information and standardised data are freely accessible for governmental entities, decision-makers and researchers. **ALA** aggregates data from collections, establishes national species lists and makes tools to help biodiversity collections and to identify gaps. Their main services are to provide virtual tools, data sets, data ingestion and standardisation for biodiversity researchers, government and land managers, as well as communities and schools. Currently, about 30% of the usage is by the research sector. Services are openly and freely available, with some restrictions on e.g. endangered species information. They also provide information on Australia's natural history collections.

Brazilian **CRIA** (Centro de Referência em Informação Ambiental) has a mission to disseminate open access biodiversity information for the enhancement of science, education and policy-making. CRIA is responsible for the information system of Brazil's Virtual Herbarium, one of the National Institutes of Science and Technology. **CRIA** is a virtual Research Infrastructure responsible for developing

information systems and tools (e.g. speciesLink) for biodiversity analysis. They provide data sharing of biological collections, tools for data cleaning, and production of additional data products such as maps. The services are free and open access. There are similarities to the European **LifeWatch** programme with geographical complementarities. They have informal cooperation with **LifeWatch**, and a number of national and international organisations, as well as participation in several EU-Brazil collaborative projects.

The Global Biodiversity Information Facility (**GBIF**) is an organisation for easy and free access to biodiversity data. They serve as a global evidence base for where species have been recorded, maintain a virtual database to assist taxonomists and allow researchers to work seamlessly in biodiversity research. Their main office is in Denmark, but the organisation is global, with 59 countries as members (typically delegated to scientific institutions). They collect and support tools hosted by national nodes and data publishers, work on data transfer and processing, taxonomy standardisation and data curation, as well as visualisation and data discovery. In Europe, **GBIF** is closely aligned with **LifeWatch** and **DiSSCo**.

The Long-Term Agroecosystem Research Network (**LTAR**) is a US Department of Agriculture initiative for enhancing the sustainability of agriculture and agricultural research. They concentrate on a systems-level approach to challenges and on evaluating the differences between current and new aspirational agricultural practices. They also work on plant genetics, including research on the interactions of environment by management. The facilities are within the US, and have research collaborations with Canada and Mexico, and many project-based international collaborations. The main products are data from the long-term experiments (in some cases spanning over a hundred years) which are openly available for research.

The NSF National Ecological Observatory Network (**NEON**) provides open, continental-scale (North America) data that characterise and quantify complex, rapidly changing ecological processes. The Observatory is designed to support greater understanding of ecological change and to enable forecasting of future ecological conditions. **NEON** collects and processes data from field sites located across the continental US, Puerto Rico and Hawaii over a 30-year timeframe, and provides free and open data that characterise plants, animals, soil, nutrients, freshwater and the atmosphere. These data may be combined with external datasets or data collected by primary investigators to support the study of continental-scale ecological change. **NEON** is funded by NSF and operated by the Battelle institute. The current connections to European facilities are numerous particularly in the field of greenhouse gas observation with **ICOS**.

The Terrestrial Ecosystem Research Network (**TERN**) is Australia's land ecosystem observatory, which monitors change in land ecosystems and provides data and infrastructure for researchers in the field. The data collection is for biodiversity, carbon and water. The main products are openly and freely available data (both from **TERN** as well as from state/government bodies) and virtual tools (including computing), protocols, physical collection of samples, and site access. The physical access is decided case-by-case by the contributing sites. The data is unique and has complementarities with many European and global infrastructures in the field as **AnaEE**, **TERENO**, **ICOS**, **iLTER, EUFAR**, among others.

3.3.5 Multidisciplinary Research Infrastructures

The Chinese Ecosystem Research Network (**CERN**) is a network of 23 institutes with a China-wide coverage. CERN's mission is to enhance the scientific research of ecology and related disciplines in China, to provide long-term and systematic scientific data collection and to support policy-making for environmental protection, including wise use of resources and sustainable development. **CERN** provides nationwide monitoring of ecosystems and research to understand the mechanisms of ecosystem changes and to demonstrate best ecosystems management practices. They operate a central synthesis centre (e.g. responsible for data management), and five sub-centres on Water, Soil, Atmospheric, Biology and Aquatic ecosystems. They provide mainly data services (particularly long-term observations e.g. on soil organic carbon) for external users, with a one-year embargo for data. Access to some of the datasets requires an application procedure. Special effort is being placed on making more datasets available in English. **CERN** contributes to **iLTER**, discusses with **NEON** in the US and is similar to **ICOS**.

The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) operates a D/V Chikyu research vessel which provides both commercial and scientific missions (often combined) on sea floor drilling (core samples). The scientific samples are maintained by **IODP** (see below), and the ship provides services for researchers, although currently mostly for Japanese researchers, even though international collaboration is considered important.

Polar Knowledge Canada (**POLAR**) operates the Canadian High Arctic Research Station (**CHARS**) campus in Cambridge Bay, Nunawut. It is a part of the Canadian Network of Northern Research Operators. The science that **POLAR** conducts and supports aims at obtaining a baseline for environmental data to provide a picture of Arctic environments. **CHARS** is a hub for scientific research whose aim is to create new knowledge for the Canadian Arctic (including economic and environmental stewardship). The **CHARS** provides physical access to research facilities, although the station is not yet fully functional.

The NSF-funded Data Observation Network for Earth (**DataOne**) aims at enabling universal access to data regarding life on Earth and the environment that sustains it. They harvest metadata repositories of environmental data and federate them into a one-stop-shop and support the preservation of such data. **DataOne** operates in community building, education, promotion of FAIR and open data principles. They cover a wide variety of environmental data repositories and also include repositories from other fields such as social sciences and archaeology, and other data aggregators. The services are free to use, but federated repositories might have own rules.

The International Ocean Discovery Program (**IODP**) is a global research collaboration with 23 countries of ocean going facilities that retrieve data and samples (sea floor and deeper), e.g. by drilling the sea floor. The activities of **IODP** belong to four themes: climate, deep life, planetary dynamics, and geohazards. IODP operates three core repositories for the physical samples, at Texas A&M University, in Japan (Kochi) and in Germany (Bremen). Three entities operate the drill ships and platforms, Texas A&M for **JOIDES** (with NSF funding), Japan for Chikyu (see above) and **ECORD** for the European mission-specific platforms. The samples of the core repositories are dispatched according to the ocean-region where the expeditions take place. The programme provides physical and data access. For physical access there is a selection process twice a year based on the scope of the expedition, however the operator country makes the final selection of personnel. The physical access is limited to **IODP** affiliate countries, with a quota according to their contribution.

The data has a one-year embargo, and is open thereafter. The core repositories provide additional services directly to researchers. IODP has an internal publication series where all major results are published. Many European countries are part of the **IODP**.

The National Institute for Environmental Studies (**NIES**) in Japan comprises seven research centres and the Centre for Global Environmental Research (**CGER**) is one of these. **CGER** focuses on climate change and global warming, it is multi-disciplinary, and is active in atmosphere, ocean, terrestrial ecosystems and biosphere. They operate atmospheric observation stations in Hokkaido, Okinawa and Mount Fuji, three forest stations for CO2 flux monitoring and several contracts with cargo ships for the measurements of pCO2 in ocean. The main product is data, including satellite data (**GOSAT**), and many online and offline analysis tools. Access is based on different database policies, but most require an access application for use. **NIES** has strong collaboration with international programmes such as WMO/GAW, **SOCAT** and **Fluxnet**, and connection to European research institutions and Research Infrastructures such as **ICOS**.

The South African Environmental Observation Network (**SAEON**) is an institutionalised network of departments, universities, science institutions and industrial partners, with three main goals: long-term observation to understand impacts of climate changes, maintaining data infrastructure for environmental and Earth observation data, and outreach and capacity building and education programmes for environmental research. They are in the process of becoming a national facility and operate as a distributed observation facility (South Africa and its extended economic zone) with strong virtual services. Climate observations cover the Southern Ocean, Sub-Saharan Africa and adjacent oceans. The Shallow marine and coastal Research Infrastructure (**SMCRI**) is establishing an array of instruments and physical platforms around the coast of South Africa and sub-Antarctic islands. **SAEON** provides physical instrumentation and observation platforms, data archiving, data system management, and virtual tools for policy and decision support. Their virtual services (including data) are free and openly available. SAEON is more concerned with synthesis and societal benefits than deep disciplinary knowledge but is an active collaborator with many ESFRI RIs, particularly **ICOS** and **eLTER**.

United States Geological Survey (USGS) operates a wide range of observation sites and instru-mentation in the US and globally, with over 240 science centres in the US. They also provide re-pository for multiple scientific resources, such as models, analysis products, geospatial products and maps, providing information on solid earth (e.g. geology, resources, volcanos, earthquakes, geomagnetism), biology and ecosystems, environmental health, natural hazards, water systems and ecology. They also provide remote sensing data, including satellite observations. The data products are subject to national open data policies. They have a high level of international usage of their data services and been active in many international collaborative projects.

European Research Infrastructures in International Organisations

Some of the European ESFRI infrastructures are critical regional components of a correspond-ing international organisation or network which makes identifying the border between “European” and “Non-European” challenging. In the RISCAPE analysis, particular cases were, Argo (with European component Euro-Argo), iLTER (eLTER), and GOOS (EuroGOOS). As the European infrastructures are, in practice, the European components for these initiatives, the international integration, interoperability and collaboration is implicit to their operations, and their inclusion in this analysis was not considered in the use cases.

3.4 Particular findings

3.4.1 Role of and nature of environmental RIs

The Research Infrastructures interviewed showed a large diversity, in terms of goals, scientific domains, legal statuses, governance, and funding schemes. However, when it comes to the main objective of the RIs they are all science-driven organisations. It is also important to note that sev-eral RIs state that they are mainly supporting science, but they also indicate that some individuals involved in the operation of the RI can do – and often do – research on their own. This is also the situation in many European RIs where the operators of the infrastructure are often scientists, usually affiliated with research organisations (universities or research centres).

Only one infrastructure (**GEM**) stated that their main focus was on the transfer of scientific knowledge into applications, to take fundamental science and make it applicable for decision making. If some RIs mentioned this activity in their portfolio, it was often as a secondary task, while the organisation is primarily involved in performing or supporting research.

It seems that the goals of RIs are also related to how infrastructures are organised in the respec-tive countries. In Japan, where many RIs are national agencies or more or less directly overseen by ministries, it seems that more importance is on the research performing dimension. All Japanese RIs indicated that they are as much involved in performing science as in supporting it.

Differences can be observed in the operational nature of RIs, i.e. whether they concentrate on providing data, products and services, or have a more coordinating role. This is especially true in the hydrosphere domain, where organisations like **OceanSITES** can be seen as more operational, whereas **GOOS** considers its role to coordinate an operational infrastructure and to establish links between research and policy-making. Similarly, **IODP** is a collaboration framework for research rather more than a programme. On the other hand, but for similar reasons, **SAON** does not con-sider itself a Research Infrastructure but a facilitator.

The time horizon of an RI is rarely specifically mentioned when the RI is created but most of them have started their existence with a long-term commitment of their major stakeholders for 10 to 25 years. Almost all have multi-annual funding.

The vast majority of the interviewed RIs state that they are distributed or a combination of distributed and virtual, because they collect data on a distributed network but make the data available virtually. Here, the operational mode of the RI is again a crucial element. Only five identified RIs consider themselves as purely virtual and one as single-sited (the **Chikyu** vessel). But even in this case, the interview shows that Chikyu performs its activities over a large variety of areas and is, in a certain way, a distributed RI. The organisation type and structure provide some challenges for such categorisation, e.g. **AuScope** and **NIED** that operate large single-sited key facilities, pro-vide virtual data services/platforms/ laboratories, but also monitor distributed observational net-works.

The status of the interviewed organisations varies a lot, including private non-profit company (**CRIA**), private company receiving public funding (**AMISR**), consortium of universities (**UNAVCO**), consortium of partners with different status (**CONTRAIL**), foundation (**GEM**), intergovernmental "ERIC-type" organisation (**GBIF**), governmental research institute (**NIES**), infrastructure operating inside a national agency (**DONET** or Chikyu in JAMSTEC). This seems to have no significant influence on the essence of an RI.

3.4.2 Goals and Grand challenges

The reason to establish an RI can differ between countries. The RIs in Japan point to their societal role, in the US they stress their responsibility to contribute to educational programmes and activi-ties. On the other hand, when considering Grand Societal Challenges, the analysis did not show large differences and it was difficult for the interviewees to understand what was meant and to relate their RI to one specific challenge. The national context can also have an influence on the stated purpose of the RI. The **AuScope** is important for Australia where the economy is strongly dependent on resource mining. The activities of **NIED** are contributing to countries like Japan where earthquakes and other natural disasters can be devastating.

3.4.3 Access to RIs

Openness seems to be a keyword for environmental Research Infrastructures. All interviewed RIs providing data referred to data as fully accessible to users (mainly researchers) in a repository or data portal. This usually involves a short period ("moratorium" or "embargo") where the scientists can use the data for scientific publications before they are available to all users. There can also be restrictions for RIs who generate data for industrial partners.

Many RIs that provide access to facilities or services for a limited resource (research vessels, plat-forms, modelling), stated that the reviewing is usually done during the grant application process. This is particularly the case for the US, where researchers specify the RIs they plan to use when they apply for NSF research grants. However, there are cases where access to resource-demanding service is restricted to e.g. specific nationalities, or collaborations. Although inde-pendent review boards seem to be the standard method for granting access for qualified researchers, some facilities also seem to use informal and ad-hoc methods for access.

3.4.4 Impacts

Basically, all RIs state that assessment and evaluation of their impact is increasingly important and asked for by their stakeholders. As put by one interviewee, "there's constant pressure to be relevant". However, most RIs had no ready-made solution to estimate the impact of their services, particularly regarding the socio-economic impacts.

> **"There is a constant pressure to be relevant."**

Scientific impact usually consists of metrics related to data and publications: individual user track-ing (to evaluate how many and where they are), data downloads, number of publications using the data or quoting the RI, citations of these publications, number of patents, among others. Some RIs require researchers to acknowledge the origin of the data in their scientific articles. Other indicators mentioned were the participation in scientific events (particularly in plenaries or as conveners of sessions), the number of abstracts submitted to the major international conferences for environmental sciences, as well as the number of invited speakers working for the RI or associated with it. This kind of scientific assessment is mostly done internally. Some RIs interviewed, like **NCAR** or **LTAR**, indicated that they perform a periodic science review (every 5 years). The document, although not necessarily publicly available, measures the scientific output obtained from the use of data, the number of degree and PhD students involved, the articles published, the work done with educators. This evaluation of the RI is performed by a panel of external scientists. Another criterion for scientific impact is the long-term commitment of funders. In addition, funding obtained by researchers (grants) to use the data, products or services provided by an infrastructure can be an element that shows the scientific quality and relevance of the RI.

The societal impact of Research Infrastructures is considered to be very valuable but very difficult to assess. The proposed indicators that can be used to evaluate the societal impact of a Research Infrastructure vary. The uptake of information, data or scientific results coming from the RI into national reports, policies or strategies at a higher level of society are amongst the most frequently mentioned, although the time lag considerations are significant. The contribution of **AMISR** to the US National Space Weather Strategy and Action Plan, the adoption in Japan of a new tsunami model modified with data provided by Chikyu, the use of **DataONE** data on bird migration in the "State of the birds" report produced by US North American Bird Conservation Initiative, or the application in China of best management practices for ecosystems recommended by **CERN** are practical examples of demonstrated impact. Outcomes from RI translated into concrete societal solutions, policies and plans is a major goal for Infrastructures, however it is very challenging to succeed in making these links. For example, **GBIF** has started an external review including an impact assessment which will be performed by **CODATA**. In one interview there was also a mention of the example of the Western Australian Biodiversity Science Institute that reflected on its impact through an exercise to develop the Index

of Biodiversity Surveys for Assessments[3]. A first version of the study showed that the added-value for the Australian mining industry of biodiversity data provided by infrastructures could be estimated to about AUD1.5 M/yr. An unmediated contact with communities that are not the direct users of the infrastructure is also a way to try and have an impact on society. This is the case e.g. of VIP visits of high-level officials to **CERN** facilities, town hall events organised by **IODP** at AGU meetings, but also for most RIs of coverage in media, lectures for citizens and students, science cafés, everything that increases the visibility of the RI and the work it does, although the link from visibility to societal impact is not well characterized.

Technology developments can also be a outcome indicating the broader impact of a RI. RISH (that operates **MU/EAR/EMU**) developed small radars that were implemented by the Japanese meteorological services to improve their forecasting ability. More generally, it seems to be easier to assess societal impact when the infrastructure not only produces data but also tools and services. This is the case for GEM or IRIS that provides risk assessment models and maps that can be used by countries or local governments.

3.4.5 Funding

The RIs are different in scope, organisation and size, and the funding models also vary significantly. What seems common to all is the long-term perspective associated with their funding schemes. Most interviewees mention that, even if budgets are always annual, their RI is involved in funding cycles in the range from 5 to 7 years (up to 10 years in China), with an initial commitment by the founding stakeholders generally for 10 to 25 years. The funding is almost always national (except for the international programmes like **GOOS**, **SAON** or **IODP**), usually from one main source. This is often a single national funding agency, such NSF in the US, NRF in South Africa, NCRIS in Australia, direct ministry funding such as often in Japan. But the financial structure can be also more complex, with different national sources, as for **CERN**. Funding can be a challenge for RIs like **CRIA** that are privately-owned and receive no national (federal) money from the Brazilian government. But being a privately-run actor is not *per se* an obstacle if you are supported by national funders, like in the case of **AMISR**.

Rarely, RIs mentioned that they (or their funders) seek a diversification of funding mechanisms. For instance, **NIED** aims at developing more information products and mentioned that some of these products may come with a price in the future. The users of NCAR facilities who do not ben-efit from an NSF grant are also charged a full-cost fee (for the others, the fee is included in the awarded grant). However, more generally, the RIs expect additional funding from their traditional providers of resources. **GEM** is again an exception and is more actively looking for new partners and sponsors, especially from new sectors (insurance companies, energy companies operating dams or nuclear facilities, etc.) who could benefit from enhanced tailor-made products and models for risk assessment.

The range for the total cost of construction of an Infrastructure varies from approximately $10 m for **DataONE** to several hundred million, but many interviewees point out the difficulty of pricing the construction of an infrastructure that has developed over decades (in an extreme case since 1879 for USGS). As the question was formulated "if you were building your organisation today, what would be the approximate construction costs?", many answered that the actual costs over the years are certainly very different from what they would be today. Usually, current costs would be lower.

3.4.6 Cooperation

Some of the questions were related to the existing or wanted cooperation with other Research Infrastructures, especially in Europe. The replies state that cooperation is commonly science-driven: the research projects, the scientific quest are the reasons to engage in a cooperation with a partner. Moreover, this type of cooperation is mainly pushed by the scientists themselves, and most of the existing collaborations happen without a formalised agreement, on a researcher-to-researcher and project basis. When agreements are signed, they are mostly Memoranda of Under-standing, the expression of a "common good will". As a form of cooperation, many interviewees mention only a regular dialogue. The object of cooperation mentioned in the interviews is most often related to scientific improvements: the extension of the geographical coverage (**CONTRAIL**), the increase in scientific relevance with multi-aircraft campaigns (**NCAR**), the planning of combined radar observations, etc. For **GBIF**, having more providers of data from China or Russia would be very beneficial, but some practical or legal obstacles exist when it comes to signing an official cooperation or membership agreement. It is interesting to note at this point that **GBIF** dedicates approximately $1 m every year to its networking activities. For **AuScope**, increased collaboration on common standards with similar infrastructures is warranted.

A success factor often mentioned is the community engagement, i.e. the cooperation at the national level, within the scientific communities. This can then be combined with the political will (e.g. through roadmaps and associated funding). **NEON** is a good example, as the infrastructure was a combination of a top-down initiative from NSF and active demands from the research community.

It is also interesting to note that the regional dimension of Infrastructures is almost completely missing. Some RIs are global actors like **IODP** or **GOOS** or have a natural regional dimension (like **CHARS**) but there are otherwise few national RIs with a regional dimension or activities. **AMISR** in the US has common facilities with the Canadian neighbour, **NCAR** and **LTAR** collaborate with Canada and Mexico. **SAEON** has projects to expand the activities of its data infrastructure to leverage the work done at **SAEON** for other African countries and to host their data or the data produced in individual projects related to Africa (like **SEACRIFOG**[4]). **NIES** is operating monitoring stations in Russia and IRIS, through their international affiliate members, can be active globally. The general impression is that the activities of the RIs analysed remain mainly at the national scale. The highly international approach of the European Union seems to be one of a kind.

The will for more formalised cooperation, particularly with European partners, did not appear as a priority. Even when the organisations underline the importance of cooperation, they appear to be content with current situation and rely on the research projects involving international partners (scientists). This might be explained by the complexity of international agreements and reluctance of organisations to engage in likewise complex negotiations.

Finally, it should be noted here that there are currently efforts to increase cooperation between Research Infrastructures at the global level in specific scientific fields (like **GERI** for the terrestrial ecosystem observations) or more broadly (like **FIERI** for all environmental infrastructures), and the need for more cooperation between continents is generally acknowledged.

[3] www.dwer.wa.gov.au/ibsa

[4] www.seacrifog.eu

4. HEALTH AND FOOD RESEARCH INFRASTRUCTURES

Main contributors
Christine Kubiak (ECRIN ERIC)
Serena Battaglia (ECRIN ERIC)

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4.1 Domain overview

This domain pertains to the Health and Food Research Infrastructure, in this report also referred to as life science. In Europe, the Health and Food sector includes research infrastructures in biological, agri-food and medical sciences. This international landscape is described according to the Health and Food ESFRI Research Infrastructures, although the Infrastructures' scope and mission might differ.

In Europe, the Health and Food domain includes seven ESFRI Landmarks, six Projects (table 4.1) and two emerging projects (**METROFOOD**, **EU- IBISBA**). These cover discovery and development in many disciplines including health challenges, marine biology, structural biology, chemical libraries, and animal models through imaging, human biobanks, translational research and clinical trials. Of the 16 European RIs considered in the Health and Food domain, 13 Research Infrastructures RIs are collaborating in **CORBEL**, a cluster project, funded by H2020 Grant n° 654248. The cluster project is working to provide shared services for life sciences. The 13 RIs in the **CORBEL** are characterised as follows:

- Distributed infrastructures, with a central facility coordinating the activities of national hubs
- Accessible for users from academic and industry research communities
- Open to researchers from European countries
- Providing access to services, data or resources, as well as access to major equipment

All RIs offer services for external users, ranging from consultation and expertise, access to data and biological samples, use of data analysis tools, to access to physical facilities (e.g. highly specialised microscopes) plus support from technicians and operational services. Researchers from academia and industry can access facilities, technologies and expertise. In the **CORBEL** cluster project, a Catalogue of Services provides a list for all 13 biomedical RIs at a glance, with the objective to help researchers navigate the services.

Two of the infrastructures are described in other chapters. The European RI **AnaEE** (Infrastructure for Analysis and Experimentation on Ecosystems) is part of the environment analysis, and a more comprehensive description can be found in chapter 5. The Australian RI Population Health Research Network (PHRN) is described in the social sciences domain (chapter 8).

ESFRI Landmarks and Projects		
Short name	**Name**	**ESFRI status**
BBMRI (Biobanking)	Biobanking and BioMolecular resources Research Infrastructure	Landmark + ERIC
EATRIS (Translational research)	European Infrastructure for Translational Medicine	Landmark + ERIC
ECRIN (Clinical research)	European Clinical Research Infrastructure Network	Landmark + ERIC
ELIXIR (Genomics)		Landmark
EMBRC (Marine biology)	European Marine Biological Resource Centre	Project
EMPHASIS (Plant phenotyping)	European Infrastructure for Multi-Scale Plant Phenotyping and Simulation for Food Security in a Changing Climate	Project
ERINHA (Pathogens)	European Research Infrastructure on Highly Pathogenic Agents	Project
EuBI (Imaging)	Euro-BioImaging	Project
EU-OPENSCREEN (Drug discovery)	European Infrastructure of Open Screening Platforms for Chemical Biology	Landmark + ERIC
INFRAFRONTIER (Mouse phenotyping)	the European Research Infrastructure for the development, phenotyping, archiving and distribution of mammalian models	Landmark
INSTRUCT (Structural biology)	Integrated Structural Biology Infrastructure	Landmark + ERIC
ISBE (Systems biology)	Infrastructure for Systems Biology Europe	Project
MIRRI (Microbial resources)	Microbial Resource Research Infrastructure	Project

Table 4.1 *Overview of the ESFRI Landmarks and Projects.*

4.2 The methodological approach

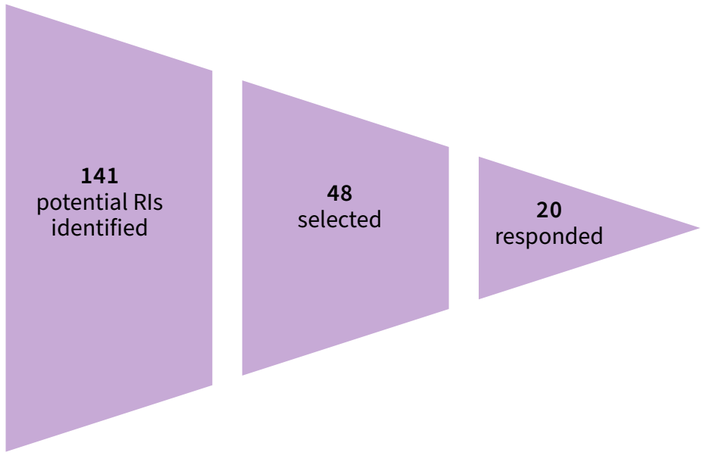
The methodology used to acquire information for the domain is explained in chapter 2. The flow chart in chapter 2 describes the steps taken to gather relevant information about the RIs in question.

For this domain there is no specific sub-domain partitioning, but the analysis and discussion is based on the 13 RIs in the **CORBEL** cluster. To identify organisations to be potentially included in the landscape analysis, the European Research Infrastructures were asked to provide contact information of organisations collaborating with the European ones or that are relevant in the scientific field. If contacts were not provided, or not available, web searching and/or information from the stakeholder panel were used to identify relevant RIs (see the Annex). The information was organised according to their scientific field and regions of the world (Africa, Asia –including Russia, Oceania, North America and Latin America).

Out of the 141 international organisations identified, 52 fulfilled the Research Infrastructure criteria defined by the RISCAPE project (see chapter 2). The following methodology was used to collect information:

- When a direct contact was provided by the European partners, the person identified was contacted by email with an introduction of the RISCAPE project and the request for an interview; in the other cases, the same message was sent to the generic address or to the Director of the organisation
- In case of a positive answer, the full questionnaire was sent in advance to the respondent to be interviewed
- In the absence of an answer, three reminders were sent; in addition, the request was sent to another contact person (when it was possible to identify one) and the same process with three reminders was applied
- After the interview, the filled questionnaire was sent to the respondent to check the accuracy of the information collected and to amend or complete if necessary, before uploading the questionnaire on the Limesurvey platform.

In cases where an interview was not possible, desk research was carried out in order to collect at least partial information as specified in the Annex. It is important to mention that no one refused to participate in the survey, and that all answered without expressing concerns about questions or confidentiality.



4.3 The International landscape

Although the landscape analysis was not meant as an exhaustive mapping exercise, it reflects a good understanding of the Health and Food landscape of research and research infrastructures in the different world regions. The results presented are based on the information available. In chapter 4.4 we allow for some general remarks on the overall research system organisation.

The 48 RI organisations included in the landscape analysis cover all the Health and Food disciplines, as defined in Europe, and are found in the five regions. Accurate information for Africa could not be collected except for South Africa. Likewise, accurate information about Russia was very difficult to find.

The number of organisations identified in the five regions are:

- (South) Africa -4
- Asia (including Russia) -16
- Oceania - 11
- North America -12
- Latin America -4 and
- One global network, internationally recognised as a Research Infrastructure (**IMPC**, International Mouse Phenotyping Consortium).

An overview of all the 141 RIs found is found in online Appendix 4 (in appendix A4.1 to appendix A4.13), with contact information and these are, as indicated above, sorted according to Health and Food discipline and region (country). Detailed descriptions of the findings for each ESFRI RI science are given in the following paragraphs.

4.3.1 Clinical research

As in Europe, several organisations and/or departments within universities or hospitals are working in the area of clinical research. Infrastructures similar to **ECRIN** exist in almost all the world regions, although with some differences in mission, focus and scope.

In Japan (**ARO** Council), Korea (**KoNECT**), US (**NCATS**) and Australia (**TIA**), the organisations identified are distributed, and supported by governmental funding, as in Europe. However their mission is more focused on supporting medical innovation and as such covering translational research and, for the US and Australia, limited to early clinical research phases. The South African **SAMRC** is distributed and its mission is to both conduct and fund medical research, which represents a major difference to Europe. In New Zealand, **MRINZ** is single-sited, but operating a network of facilities nationally and internationally. Its focus is to conduct research with the potential to lead to improvements in clinical management both in New Zealand and internationally and to provide high quality scientific evidence. Canadian **CDRD** is a distributed infrastructure, fully independent not-for-profit society, reporting to the government. Although mainly funded by the federal government of Canada with some private investments, the main mission of CDRD is to explore commercial opportunities, develop products and build new biotech companies. They act as a global bridge that translates discoveries into innovative therapeutic products & improved health outcomes. **SCRI** is a national academic research organisation in Singapore dedicated

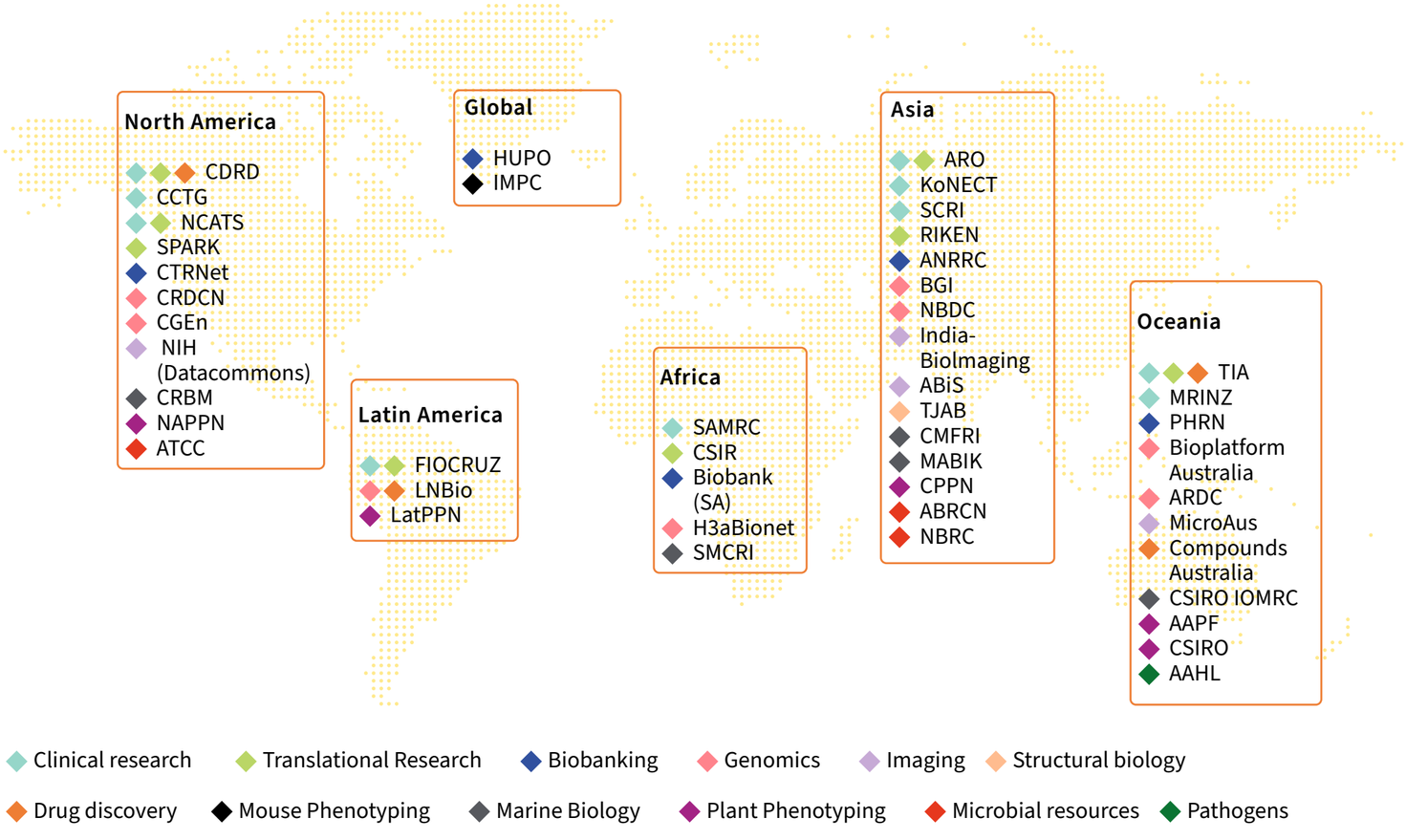


Figure 4.1 *Overview of the analysed Health and Food Research Infrastructures*

to enhancing the standards of human clinical research, with the mission to spearhead and develop core capabilities, infrastructure and scientific leadership for clinical research in Singapore.

4.3.2 Translational research

The **ARO** council in Japan, **Konect** in Korea, **NCATS** in the US and **TIA** in Australia focus on medical innovation and are all supporting or performing translational research and early clinical research phases (**NCATS** and **TIA**). In the US, the organisation **SPARK** was created in Stanford to serve local academic projects' translation, to bridge the gap between academic discoveries and products that benefit patients. **SPARK** is now a distributed infrastructure with 60 institutes around the world. In addition to access to facilities (high throughput screening, animal facilities etc), **SPARK** expertise and activity rely on over 150 experts from the industry.

SPARK impact

The return on investment is more than $5 per dollar invested. 50% of the projects entered into clinical studies or licencing.

4.3.3 Biobanking

In this area, the landscape is quite fragmented with biobanks, and most of the identified organisations do not correspond to the RISCAPE criteria. Nevertheless, the model of **BBMRI** in Europe, bringing together all the main players from the biobanking field – researchers, biobankers, industry, and patients – to boost biomedical research and make new treatments possible, exists to some extent in Canada (**CTRNet**) and Asia (**ANRRC**).

CTRNet was created in 2004 and operates as a not-for-profit consortium of leading provincial tumour banks and programmes that furthers

Canadian health research. **CTRNet** provides interested researchers with a streamlined process to obtain quality human tissue and human tissue products from member tumour banks. **CTRNet** has both direct and indirect outcomes on Canadian health research in particular by strengthening local banking efforts consistent with national standards through the development of Standard Operating Procedures, by creating a single electronic portal of access to tissues and clinical information, by promoting the exchange of administrative and scientific best practices, and by promoting translational research in Canada.

ANRRC has 107 member institutes from 16 Asian countries; it was established in September 2009 out of the initiative of the RIKEN BRC in Japan, the **IMCAS** in China and the **KNRRC** in South Korea. The objective is to promote cooperation and networking among Biotechnology Research Centres in the Asia-Pacific Region. The scope is broad: animal, plant, microbial, and human materials or resources.

In South Africa, a Biobank infrastructure, similar to the one existing in Europe, is listed in the 2016 South African National Roadmap. The infrastructure is under development, and thus was not interviewed.

4.3.4 Genomics

In South Africa, **H3aBionet** is distributed with 28 different nodes based in 16 African countries and 1 in the USA. **H3aBionet** provides local research facilities, datasets and specialised research tools that are open to every researcher worldwide. The primary funding is from the National Institute of Health (NIH) completed by in-kind contribution from individual nodes.

Bioplatform Australia is also a distributed organisation funded by commonwealth government funding focusing on health and medical research, agriculture and ecology. Bioplatform Australia is offering local facilities, datasets and specialised research tools and services. Several collaborations for genomics alliances have been established and they plan to continue expanding services, increasing data sites capacity, investing in emerging technologies. The collaboration with Europe is considered as important especially for agriculture and food methods.

In this area, several other relevant RIs were identified (**BGI** in China, national Bioscience Database Center in Japan, CRDCN and **CGEn** in Canada, NIH data commons in the US, **ARDC** in Australia and **LNBio** in Brazil). However, it was not possible to perform interviews with those organisations and the information collected through desk research was not sufficient for the landscape analysis.

4.3.5 Imaging

The area is quite well represented in other world regions and the infrastructures identified cover both biological and biomedical imaging, similar to Europe. In Japan, **ABiS** is a distributed organisation and is one of the Platforms for Advanced Technologies and Research Resources aiming to facilitate life sciences by providing scientists access to resources from animal models to state-of-the-art instruments, research materials and technical support. ABiS provides technical support for data images analysis as well as training. The National Centre for Biological Science (NCBS) in India hosts a major, single-sited imaging facility (India-BioImaging), with funding based on governmental contribution and user fees.

Microscopy Australia is a distributed organisation, with facilities mainly located in the larger universities. The federal government department is the main source of funding, however only considered as an incentive for collaboration and co-funding. Universities hosting the facilities are supporting with in-kind contribution and users pay fees. The focus is not only bioimaging but also on materials, health, food and energy and a broad range of research and industry users are supported. Compared to the European RI model, the major difference is the funding model: Microscopy Australia funds people to run high-end instruments as well as the instruments themselves. This ensures high expertise to make sure to produce high quality results. **India-BioImaging** and Microscopy Australia, together with Euro-BioImaging are part of the Global BioImaging initiative.

Global Network

Founded in 2015, Global BioImaging is an international network of imaging infrastructures and communities. It started as a project built on three collaboration frameworks between the nascent Euro-BioImaging infrastructure, Microscopy Australia (previously AMMRF), the National Imaging Facility and India-BioImaging and its objective is to provide guidelines for the community around the world, exchange experiences and build capacity internationally.

4.3.6 Structural biology

In this area, all the identified organisations are departments of universities or institutes and, therefore, do not correspond to the RISCAPE criteria. Interestingly, most of the facilities identified in Latin America established a bi-lateral collaboration with the European Research Infrastructure **INSTRUCT-ERIC**, mainly for staff exchange and training programmes. To confirm the RISCAPE selection criteria, one interview was, however, performed with the **Tianjin International Joint Academy of Biomedicine** in China, which provides local research facilities and datasets. The organisation is single-sited and mainly funded by the government and although most of the services are offered to external researchers, the organisation is currently not open to EU researchers and has no collaboration established with external organisations.

4.3.7 Drug discovery

The screening platforms in India, China and Japan are mostly local platforms/research groups with their own research agenda, rather than research infrastructures. A similar ecosystem exists in the US. In Australia, **Compounds Australia** and **TIA** cover the drug discovery domain, the former - single-sited - focusing on health and agriculture primarily, and human and animal health, the latter - distributed -mostly on the development of new therapeutics for human health. Likewise, the **CDRD** in Canada, a distributed Research Infrastructure mainly funded by the federal government, aims to be a global bridge that translates drug discoveries into innovative therapeutic products and improved health outcomes. The Brazilian **LNBio**, also distributed, is dedicated to support cutting-edge research and innovation focused on biotechnology and drugs development, following five thematic programmes: cancer biology, neglected diseases, cardiac biology and metabolism, and microorganisms and plants. It is funded by the Brazilian Ministry of Science, Technology and Innovation (MCTI).

4.3.8 Systems biology

Although the discipline is not new, the Infrastructure for Systems Biology in Europe (**ISBE**) was launched quite recently (2012) as one of the ESFRI projects and it is currently running in its preparatory phase. Its mission is to interconnect national systems biology centres to provide their collective expertise, resources and services as easily accessible for all European researchers. This model of single point of entry into pan-European services does not seem to have a counterpart in the world regions analysed; as a matter of fact, several centres and facilities were identified in Asia, Northern America and Oceania, in general hosted by universities, but not organised around an overarching structure comparable to the European one.

4.3.9 Mouse phenotyping

Despite the existence of several institutes and research organisations dedicated to mouse phenotyping, the group did not identify a Research Infrastructure corresponding to the European **INFRAFRONTIER**. The mouse phenotyping community is, in fact, structured as an international consortium of institutes and centres (with regional components: **INFRAFRONTIER** in Europe, Asian and Australian Mouse Phenotyping Consortia), called **IMPC**, globally recognised as a global Research Infrastructure, with the mission to create a comprehensive catalogue of mammalian gene function freely accessible worldwide.

4.3.10 Marine biology

Many research institutes and few research infrastructures were identified for the landscape analysis, but the vast majority was excluded either because of the inclusion/exclusion criteria or because of the different research scope. The European Marine Biological Resource Centre (**EMBRC**), listed under the ESFRI Health & Food RIs, can be considered quite unique, at the interface between biomedical and environmental sciences. As such, **EMBRC** is involved in different clusters as **CORBEL** (life sciences), **ENVRI plus** (environment) and **EMBRIC** (sector-specific innovation). However, the non-European marine infrastructures identified are mostly focused on environmental and global change studies, as for instance the South African Shallow Marine Coastal Research Infrastructure (**SMCRI**). SMCRI is described in detail in the chapter 3. The Canadian Centre de Recherche sur les Biotechnologies Marines (**CRBM**) represents an exception in this landscape since it has a similar scope to **EMBRC's**, addressing health/wellbeing, nutrition, food security and environment challenges; in addition, **CRBM** has a strong focus on innovation, supporting public-private partnerships. Relevant organisations in the field are in India (**CMFRI**), Korea (**MABIK**) and Australia (**CSIRO IOMRC**), all sharing the mission of preserving marine biodiversity and promoting biotechnologies; however further information other than via desk-search could not be collected.

4.3.11 Plant phenotyping

The European Infrastructure for Plant Phenotyping (**EMPHASIS**) is a distributed Research Infrastructure that provides access to facilities and services addressing multi-scale plant phenotyping to analyse genotype performance in diverse environments and quantify the diversity of traits. Listed in the ESFRI roadmap in 2016, it is now in the preparatory phase. In Australia **APPF** was listed in the National Research Infrastructure Roadmap 2016 and is supported by the federal government of Australia via the **NCRIS**. APPF is a distributed leading plant phenomics facility that underpins innovative plant phenomics research to accelerate the development of new and improved crops, healthier food and more sustainable agricultural practice. **NAPPN** is an association of plant phenotyping organisations across North America, where there are

Therapeutic research
(drug discovery/translational research/ clinical research)

TIA comprises 13 sites distributed around the country; it was established in 2008, funded by the federal government of Australia via the National Collaborative Research Infrastructure Strategy (NCRIS). Its mission is to support translating health discovery to develop new therapeutics for human health; in particular the activities covered are product development, new therapies, post-discovery, potential new therapeutic products and phase I testing. **TIA** has a MoU with the European RIs **EATRIS** (translation research) and **EU-OPENSCREEN** (drug discovery). In Brazil, **FioCruz** is a large distributed organisation composed of 16 scientific and technical units (plus one office in Mozambique) that are focused on research, innovation, technological development and extension in the health field. Its mission is to produce, disseminate and share knowledge and technologies to contribute to the promotion of health and quality of life of the population; in comparison with the European landscape, **FioCruz** has a broader scope, covering the whole medical research pipeline, from drug discovery, to validation and development. The Foundation runs more than a thousand researches and technological development projects.

efforts to coordinate activities, but without a systematic roadmap. In China the situation is different: **CPPN** is a network of scientists and the private company Phenotrait provides services and data to scientist belonging to **CPPN** and other customers located in China; the mission is to work with phenotyping network and community, to promote the use of best agriculture technologies and improve crop breeding. In Latin America, the network **LatPPN** is still under creation, with the aim to strengthen research capabilities, train scientists on several aspects of phenotyping methodologies, and enable international access of resources and research facilities.

All the above-mentioned infrastructures and networks, although with different degrees of maturity, are part of the International Plant Phenotyping Network (**IPPN**), an association representing stakeholders from academia and industry interested and involved in plant phenotyping across the globe. The goal is to increase the visibility and impact of plant phenotyping and enable cooperation by fostering communication between stakeholders in academia, industry, government, and the general public.

4.3.12 Pathogens

ERINHA, the pan-European distributed Research Infrastructure dedicated to the study of highly infectious emerging and remerging diseases, brings together European high containment and complementary research facilities and expertise required to perform cutting-edge research in shorter timeframes, to quickly react to outbreaks. Currently ERINHA is the only Research Infrastructure of its kind in Europe and worldwide and therefore the group did not identify similar organisations outside Europe, with the sole exception of the CSIRO Australian Animal Health Laboratory (**AAHL**), which has a similar organisation and mission, with in addition a special focus on animal health.

4.3.13 Microbial resources

A few relevant organisations were identified but could not be interviewed: the Asian Biological Resource Centres Network (**ABRCN** - covering China, Japan, Korea, Thailand, Philippines), **ATCC** in the US and the natural sciences collection facility in South Africa (listed in the Roadmap 2016 and therefore under development). The **NBRC** in Japan started its operation in 2002 as the Biological Resource Centre based on the OECD policy recommendation named the "Biological Resource Centre, underpinning the future of life sciences and biotechnology". The mission of NBRC is to support and facilitate the development of bio-industry through collecting, preserving, and distributing various genetic resources along with functional information and other useful information (non-commercial use). NBRC is funded by the Japanese government through the Ministry of Economy, Trade and Industry (METI).

4.4 Specific domain findings

By considering the distribution of the organisations per discipline, it is interesting to note that some of the organisations have a broader scientific coverage compared to the European ones: for instance **TIA** (Therapeutic Innovation Australia) and **CDRD** (Centre for Drug Research and Development – Canada) cover drug discovery, translational research and to some extent clinical research; in Japan RIKEN, as the most large and comprehensive organisation for basic and applied sciences, covers several disciplines (among others: translational research, drug discovery, systems biology and mouse models). Two regions are missing in the landscape analysis: Russia and Africa. The European RIs do not have relevant contacts in Russia and even the Stakeholder Panel could not provide useful information regarding the Health and Food research area in that country. Regarding Africa, the system appears quite scattered and not structured in a defined network, with however few players participating in global initiatives.

4.4.1 Structure of the international RIs

In terms of organisation, in comparison with the ESFRI, most of the organisations are distributed (65 %) and the remaining one single-sited (35 %). No virtual organisation. Interestingly, one of the respondents described its infrastructure as single-sited, despite the existence of several centres and regional offices that were considered as collaboration units rather than nodes of distributed Research Infrastructure. In this case and based on the understanding of the organisation and RISCAPE definition, the infrastructure was considered as distributed and the participant as responding on behalf of the coordination unit.

4.4.2 Funding models

A majority of RIs are directly funded by the government or by governmental agencies. This governmental funding can be the unique source of funding (65%) or can be combined with other sources, either public or private and including the users' fees. Only one of the identified RI (PhenoTrait) is funded by private funds. "In-kind" contribution was not a specific question in the questionnaire and was difficult to assess, even if it was mentioned by several RIs.

4.4.3 Construction costs

To estimate the scale of the organisation, the RIs were asked to provide the approximate construction costs, as "if the organisation was to be built today". Those estimated construction costs range from less than €1 m to almost €200 m. Those figures are only indicative however they reflect the wide range of infrastructures in the biomedical and life sciences sector. This is comparable with the construction costs figures available for the European RIs (€0.7 m to €175 m).

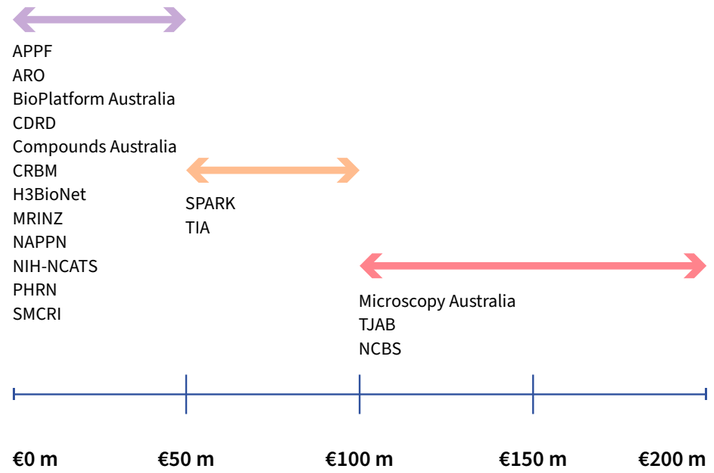


Figure 4.4 *Construction costs, estimates*

4.4.4 Operational costs

Regarding the running costs, they also reflect the diversity of the organisations, in terms of type and size, and range from €1 to €10 m/year with only four RIs reporting running costs above €10 m/year. This is also comparable to the running costs reported by the European RIs. Again, the figures collected have to be taken carefully as the running costs provided do not cover the same categories of costs and whereas salaries and equipment are usually included, building costs (rental) or specific instruments were not always considered as part of the running costs. In addition, one third of the RIs are part of a larger organisation and are not reporting standalone costs.

4.4.5 The grand societal challenges

As expected, the majority of the RIs aims to answer the health, demographic change and wellbeing grand challenge. For 40% of them, in addition to health, they also contribute to food security, agriculture and environment grand challenge. For three RIs, the main targeted grand challenge to respond is food security, sustainable agriculture and environment. The majority of the research infrastructures interviewed is mandated to both perform and support science, although supporting science is the priority for 76% of them (19 RIs out of 25).

4.4.6 Sustainability and roadmaps

All the infrastructures have a business plan or a strategic plan and for most of them the time Horizon is five years although the funding schemes might be not be multi-annual and aligned.

4.4.7 Future services

Most of the RIs mentioned that they plan to develop facilities, mostly by adding new services or adapting the services to the users' needs or through geographical expansion. The main developments are the investment in emerging technologies to remain at the forefront, increase of the capacity or integration within the infrastructure of existing expert facilities and, upgrading facilities and instruments. In addition to those services, training is also provided and highlighted by several RIs whether dedicated to researchers using the facilities/services or open to the scientific community. All types of access are provided by the RIs, and most of them offer a combination. Just one RI (**NBRC**) has only virtual access.

4.4.8 Access policies

More than half of the RIs reported a peer review-based access policy. The evaluation is then performed by an independent board, however in most of the cases being internal to the organisation. Access to some RIs also rely on the peer review process provided by funding agencies in order to avoid duplication. In the other cases, the access is based on the feasibility of the project, the availability of the resources or of the facilities or on fees. RIs are open to external researchers, however only a few RIs were able to provide data related the fraction of services available to access from external parties (and even less able to provide figures about the fraction of services really used by external parties). For those that were able to answer, half of the RIs reported having more than 75% of the services available to external parties and the remaining half range from less to 25% to 75%.

4.4.9 Service policies

In most of the cases, the RIs services are available to external parties and no additional quotas or limitations apply to external users. Only one RI mentioned that the access is restricted to users having established a collaboration with internal researchers. There are no specific access requirements for researchers from European organisations. From the 20 RIs answering, only 3 RIs reported that European researchers would not be able to access their facilities.

4.4.10 International collaboration

Almost 75% of the RIs have or had scientific collaboration or exchanges with European organisations (individual institute or university) but less than half have already established collaboration or have signed a collaboration agreement with a European RI in the same field. In rare cases and surprisingly, respondents did not spontaneously mention or know the European RI existing in their field. This can be explained by the quite recent development of the European RIs and the long-lasting scientific collaboration existing between some organisations.

Population health

In Australia, the **PHRN** was established in 2009 and implemented through the NCRIS, an initiative of the Australian federal government. The PHRN is a national network of nine sites coordinated by the Program Office located in Perth, Western Australia and comprising a network of Project Participants and Data Linkage Units located in each Australian state/territory. PHRN is a national organisation that enables linking administrative and health data collected by governments (including information on human resources, education, family issues etc.) for research purposes. This information is a valuable national resource which can be used to improve the understanding of disease, develop treatments and improve services and overall improve the wellbeing of Australian citizens. Given its broader scope, PHRN was also listed as a counterpart of European Social Sciences RIs.

Basic biological science

RIKEN is Japan's largest and most comprehensive research organisation for basic and applied science and a world leader in a diverse array of scientific disciplines. RIKEN's activities can be divided into four main categories: Strategic Research Centres (focusing on the life sciences and green innovation), Research Infrastructure centres (including Biotechnology Research Centres, centre for Life Science Technologies), Chief Scientist laboratories, etc. and Cluster for Industry Partnerships.

CSIRO is an Australian Government corporate entity, constituted by and operate under the provisions of the Science and Industry Research Act 1949. As one of the world's largest mission-driven multidisciplinary science and research organisations, CSIRO is focusing on the issues that matter the most: for the quality of life, for the economy and for the environment. CSIRO is responsible for managing National Research Infrastructure on behalf of the broader scientific community to help with the delivery of research. There are two types of National Research Infrastructure: National Research Facilities and National Biological Collections. As the national provider of a range of specialised laboratories, scientific and testing equipment and other research facilities, CSIRO provides science-ready facilities for use by Australian and international researchers through application and user-funded arrangements related to the facility.

4.4.11 Scientific impact

Most of the RIs assess their scientific impact through mainly quantitative metrics such the number of publications and impact factor, number of access, patents, number of trainees, number of start-ups created, and this is usually part of the annual report. In half of the cases, the evaluation is by internal reviewers and only few (three RIs) use external evaluation or a combination (internal plus external).

4.4.12 Societal impact

Regarding the socio-economic impact, many interviewees mentioned the difficulty to demonstrate the impact, especially as a direct impact. However, several indicators are used. For example, in translational research, the number of projects entering in clinical phase or the licencing. The return of investment, the number of jobs or companies created, the number of patients treated (for example in area such as rare diseases or paediatric), the development of guidelines or standards are also used to demonstrate the social-economic impact of the RIs. In addition to those quantitative metrics, qualitative data, such as narratives and success stories, were mentioned as valuable ways to illustrate the impact and the added value of the research performed within the RIs. Reports on scientific and socio-economic impact are publicly available for less than half of the RIs.

Mouse phenotyping

Despite the existence of several institutes and research organisations dedicated to mouse phenotyping, the group did not identify a Research Infrastructure corresponding to the European **INFRAFRONTIER**. However, there is an international consortium, **IMPC**, globally recognised as a Research Infrastructure, with the mission to create a comprehensive catalogue of mammalian gene function freely accessible worldwide.

Marine biology

Many research institutes and few research infrastructures were identified for the landscape analysis, but the vast majority was excluded either because of the inclusion/exclusion criteria or because of the different research scope. Indeed, the European RI **EMBRC**, listed under the ESFRI Health and Food RIs, can be considered quite unique, at the interface between biomedical and environmental sciences, whereas the non-European infrastructures identified are mostly focused on environmental and global change studies (ex. the **SMCRI**). One exception is represented by the Canadian **CRBM** which has a similar scope to EMBRC, with in addition a strong focus on innovation.

5. PHYSICAL SCIENCES RESEARCH INFRASTRUCTURES

Main contributors
Miriam Förster (The Institute Laue-Langevin)
Julie Dupré (The Institute Laue-Langevin)
Hannah Walter (The Institute Laue-Langevin)
William G. Stirling (independent expert)
Kurt Clausen (independent expert)

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5.1 Domain Overview

In the Physics domain, the Research Infrastructures are mainly single-sited. These are often large infrastructures requiring significant investment for construction (ranging from €100 m to €1 or €2 bn), with annual operation costs varying between €80 m up to €150 m. However, since RIs in the Physics domain often allow complementary opportunities for diverse fields, there are sometimes two (or more) facilities on the same site, to concentrate more RIs, or for the complementarity of the facilities, or to create a pool of excellence.

This domain report considers Research Infrastructures (RIs) in the Physics and Analytical Facilities category and includes seven well-defined subdomains, based on the ESFRI Roadmap 2018, namely:

- Synchrotron Radiation sources (SR),
- Free Electron Lasers (FEL),
- Neutron Sources (NS),
- High Power Lasers (HPL),
- High Magnetic Field facilities (HMF),
- Particle Physics (PP) and
- Nuclear Physics (NP)

The European Strategy Forum on Research Infrastructures (ESFRI), in the Roadmap 2018 – Strategy report on research infrastructures, identified 12 ESFRI landmarks and one ESFRI Project in the field of Physical Sciences and Engineering (Astronomy and Astro-particle Physics, Particle and Nuclear Physics, Analytical Physics). This domain report considers Research Infrastructures (RIs) only in the Physics and Analytical Facilities category, in contrast to the ESFRI Roadmap, as the Astro-particle Physics is treated as a separate domain (astronomical and Astro particle RIs and similar initiatives).

For the physics research infrastructure, it is important to note that the categorisation of the RIs pertains to their experimental technique (see table 5.1). This in contrast to what experimental techniques can be and are used to understand structures, constituents, physical/chemical reactions, etc. This is reflected in the description of the sub-domains that first describe the technique, and then in how this is used for various science areas, which are not necessarily physics.

For most of the subdomains the projects run at a facility are generally chosen via a peer review process, based on scientific excellence. A description of the subdomains is given in the next paragraphs.

5.1.1 Synchrotron Radiation sources (SR)

Synchrotron Radiation is produced by an electron beam, circulating at close to the speed of light, in a circular array of (bending) magnets (an electron synchrotron). Modern SR sources produce extremely bright, highly focused beams of photons in the X-ray wavelength regime; many medium to large countries have built such a facility, over the last 20 to 30 years. These are among the most 'popular' large scientific facilities and are generally large user facilities where scientists carry out their scientific projects using a range (up to 30-40) of specialised instruments ('beamlines'); each experiment typically lasts from one to several days.

A very wide range of scientific studies (from biology and materials science to cultural heritage studies and archaeology) done on SR sources are of interest, and thus, used by a large number of scientific areas.

5.1.2 Free Electron Lasers (FEL)

Free Electron Laser facilities providing radiation in the x-ray range is a relatively recent development. Pulses of electrons, accelerated in a linear accelerator, pass through long arrays of magnets (undulators) to produce very intense, laser-like beams of pulsed photons. While FEL devices operating at long wavelengths (infra-red and far infra-red light) have operated for some time, facilities producing intense X-ray beams are relatively new, with several new accelerator sources, many under construction). Experiments are conducted over a period of a few days.

FEL sources are opening up new areas of science, very bright pulses of femtosecond duration (10-15) second) allow direct observation of the dynamics of atoms and molecules, leading to a better understanding of how materials work. 'Snapshots' and 'movies' are providing a new fundamental understanding of biological processes and chemical catalysis and leading to crucial advances in drug design and development.

5.1.3 Neutron Sources (NS)

Most Neutron Sources are located within a large laboratory, only the Institute Laue-Langevin (ILL) and the future European Spallation Source (ESS) are stand-alone neutron facilities. There are two types of source: reactor-based (e.g. ILL) or accelerator-based (e.g. ESS). The costs of building and operating a new, state of the art Neutron Source are generally too high for small and medium size countries. Facilities are often multipurpose – with secondary use for isotope production, materials irradiation, positron beams for materials science at reactor-based facilities and muon beams at accelerator-based facilities for materials science and PP, irradiation facility, isotope production. The infrastructures are generally large user facilities where scientists visit the facility to carry out their scientific project at many (up to 20-30) specialised instruments, and each experiment typically lasts one to several days.

5.1.4 High Power Lasers (HPL)

Most High Power Laser facilities are organised and operated by university groups. The ultra-high peak power laser facilities are extremely large and expensive and often built for a specific purpose (i.e. fusion studies, military facilities, etc.). They open to academic use for a few percent of their capacity to study materials under extreme conditions. The European facilities coordinate their use and access through Laserlab Europe (33 leading European organisations from 16 countries).

The HPL RIs offer a wide range of research opportunities:

- Technological application of lasers: novel mechanisms for the generation of highly energetic particles, x-rays and gamma-rays, Laser Particle Acceleration, Particle Beam Interactions, Laser Cooling, Trapping, X-Ray Laser Physics, Materials Processing, Laser Remote Sensing, Combustion Diagnostics plus Novel Laser Development
- Energy related Research: Laser Plasma Physics, Fusion Science and Applications
- Analytical facility for Chemistry and materials science: Ultrafast Dynamics, materials under extreme conditions, Quantum Electronics, Biomaterials, Biomedicine, etc.
- Photonuclear Physics and its applications
- HPLs provide local experimental facilities and generally require physical access.

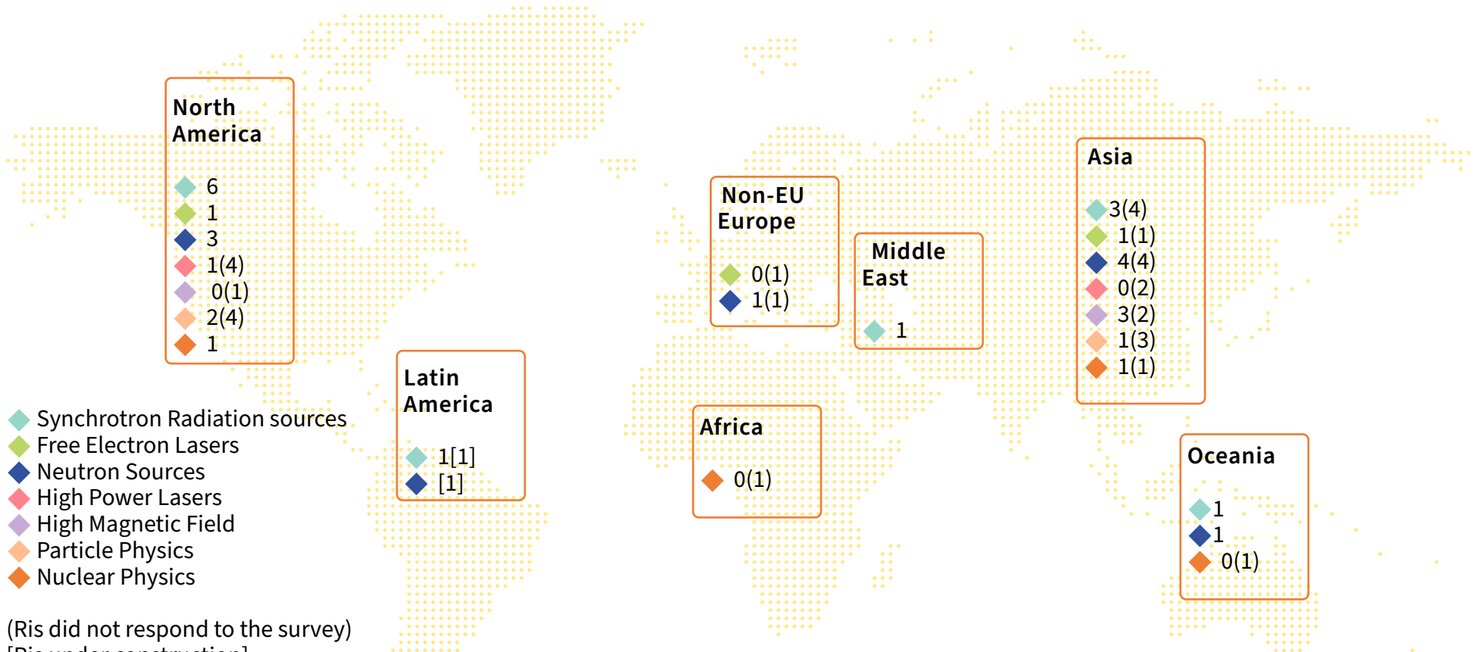


Figure 4.1 *Number of RIs in the Physics landscape report by the region.*

	Facility Size (S, M, L)	Maturity of techniques	User knowledge required	No of simultaneous experiments	Duration of typical measurement	Commercial use
SR	S → M	Mature	Medium	Many	Days → Weeks	regular/mature
FEL	S → L	Young	Detailed	Several	Days → Weeks	new/developing
NS	M → L	Mature	Medium	Many	Days → Weeks	some/mature
NP	S → L	Mature	Detailed	Several	Weeks → Months	some (isotopes)
HPL	S → L	Young → Mature	None → Detailed	One → Few	Days → Weeks	strong link
HMF	S → M	Mature	Medium	Several	Days → Weeks	little/developing
PP	L	Mature	Detailed	Few	Months → Years	little/equipment

Table 5.1 *summarises some of the characteristics of the different subfields considered. These include the size of the facility, the maturity of the principal techniques employed, the degree of specialist knowledge required of the facility user, the number of measurements that can be carried out simultaneously, the duration of a typical measurement, and the extent of commercial use.*

5.1.5 High Magnetic Field (HMF)

Different magnetic field technologies are employed to produce static magnetic fields up to 45 Tesla, pulsed fields up to 100 Tesla and higher pulsed fields using 'single-shot' magnets. Magnetic field is a powerful experimental parameter (like pressure, temperature, etc.), used to study, for example, the phase diagrams of magnetic materials, nanoscience, semiconductors, superconductors, and strongly correlated systems (leading to the development of advanced materials of technological importance). In addition, the development of high field techniques leads to improved NMR (nuclear magnetic resonance) and MRI (magnetic resonance imaging) instrumentation, used in chemical and medical analysis respectively.

5.1.6 Particle Physics (PP)

The Physics domain includes some of the Particle Physics facilities (the rest are described in the Astro-particle domain chapter). Even though the actual PP experiments are performed on single sited facilities – the instrumentation is, in general, designed and produced at particle physics or accelerator laboratories at universities or national laboratories around the world. The number of simultaneous experimental stations is low (often less than 10), experiments extend over many years and are carried out by a large number of scientists (ranging from ten up to several thousands) from the laboratories who have jointly built, maintained, and operated the huge and complex detectors and their infrastructure. The key directions of studies in this domain are often referred to as the 'High Energy Frontier', looking for new extremely high-mass particles, or as the 'High Precision Frontier', looking for deviations from the standard model. There are often secondary uses of the facilities, exploiting the beams from the accelerator complex.

5.1.7 Nuclear Physics (NP)

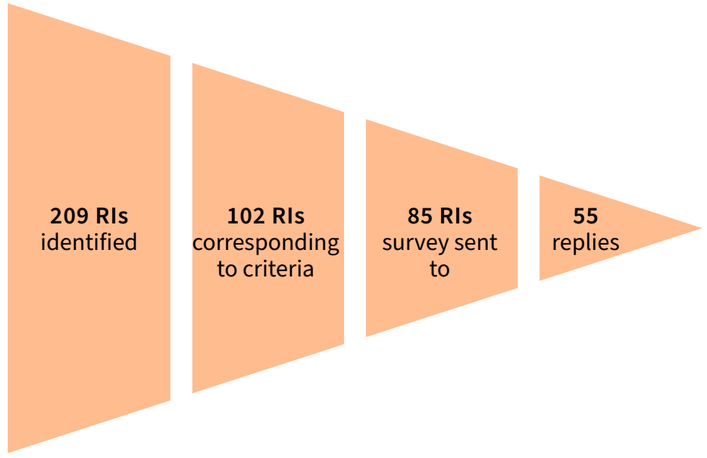
Nuclear Physics, or more generally, nuclear science facilities range in size from small university laboratories to very large national and multinational laboratories. Nuclear science facilities employ many different experimental techniques, and accelerators (Van de Graafs, cyclotrons, linear accelerators, etc.) that provide beams of high-energy electrons, protons and stable or radioactive heavy ions. The experimental projects tend to extend over longer periods, involving the external scientists in all aspects of the project (experiment and instrumentation design and installation, data gathering over a long period and data analysis).

Current studies include the structure of atomic nuclei far from the line of stability and the creation of super-heavy elements and address fundamental questions such as how the universe has evolved.

5.2 The methodological approach

The method of matching international RIs (in the respective subfields) with European RIs was not efficient in the Physics domain due to their difference in size, function, organisation, finance, etc. Given the large number of RIs across the world in the fields covered, several criteria were introduced to determine which RIs should be included in the report, and that reduced the number of RI considered to about half. The final list of International RIs (by subfield scientific area) was validated with the help of external experts, with the aim to obtain a representative RIs set of the Physics domain.

The RISCAPE questionnaire was sent to each facility identified in the final list of International and European RIs. All scientific subfield RIs received the same questionnaire. Individual links to the online questionnaire were sent with an explicative e-mail, usually to the head of facility. The questionnaire was completed online in either a single or several sessions. It was composed of two types of questions; closed questions (with tick box answers) and open questions implying narrative answers. Out of 85 questionnaires sent, 56 completed replies were received over a period of 8 months. Almost half (43 %) of the responding facilities answered immediately, a further 45 % responded after a first reminder, 8 % after a second reminder and 4 % after the third reminder. For non-responding facilities, up to six reminders have been sent in some cases, using an alternative contact (communication department or deputy directors). Some non-responding facilities stated clearly their unwillingness to answer. Considering the numerous reminders, it is reasonable to assume that the remaining 30 non-respondent RIs chose not to participate in this exercise. The Stakeholder Panel members validated the downscaling process and further suggested that, to be as inclusive as possible, RIs in the HPL and HMF sub-domains should be included in the study.



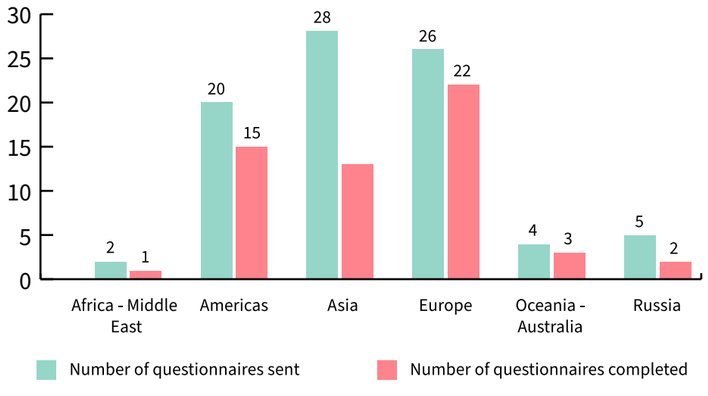


Figure 5.2 *Graphical representation of questionnaires sent versus completed by subfield. The disparity of numbers is representative of the numbers of existing RIs in the respective subfield.*

The on-line questionnaire was the best method to obtain detailed responses. Given the time schedule of the project and the large number of RIs to be considered, it was decided that an on-line questionnaire would provide clearer and more consistent responses and would be more efficient than telephone interviews. Nevertheless, telephone interviews might have avoided ambiguity in replies, and some misunderstandings might be attributed to cultural bias. The questionnaire was developed to fit a wide range of RIs (from the eight domains) and in many instances it was difficult to complete. For example, for High Power Laser RIs it turned out that the chosen methodology was not appropriate. There is a large and expanding number of facilities covering very broad areas of science and technology. The very big (HPL) facilities in general offer only a very small fraction of open academic access (HPL facilities are mainly used for fusion research and some military research) and the small facilities are often working as part of a university departments or groups. The long tradition of open access known from the other analytical facilities is generally not in place.

5.3 The International landscape

For the Physics domain this section does not give a description of individual RIs for each of the subdomains but is describing the general subdomain features for the European and international complementariness. Although, in the appendix one can find a list of all the RIs considered in the landscape exercise for the Physics domain. The identified RIs all fulfil the RISCAPE classification of a RI.

5.3.1 Synchrotron Radiation sources (SR)

There are excellent SR facilities around the world and 19 operating (non-European) SR sources were identified, of which 13 completed the RISCAPE questionnaire. Many of these 'International' facilities have specialised instrumentation that could be of interest to European researchers. Access to most of these RIs is via a peer-review proposal procedure. The facilities which completed the questionnaire were (with electron energy and number of beamlines indicated):

- **AS** Australian Synchrotron, ANSTO, Australian Nuclear Science and Technology Organisation (3GeV, 10+7 planned)
- **UVX LNLS** Laboratorio Nacional de Luz Sincrotron, Brazil (1.37GeV, 17)
- **CLS** Canadian Light Source (2.9GeV, 19+2 at APS)
- **PF** Photon Factory High Energy Accelerator Research Organization, KEK, Japan (PF: 2.5GeV, PAF:6.5GeV, 30)
- **SPring-8** Super Photon ring-8 GeV, Japan (8.0 GeV, 62)
- **SESAME** Synchrotron-light for Experimental Science and Applications in the Middle East, Jordan (2.5 GeV, 4+3 planned)
- **NSRRC** National Synchrotron Radiation Research Center, Taiwan (TLS:1.5 GeV, TPS: 3.0 GeV, TLS: 33 (+4 at SPring-8), TPS: 7 (Phase I))
- **SLRI** Synchrotron Light Research Institute, Synchrotron Thailand Central Lab, Thailand (1.2 GeV, 10 (+3 under construction)
- **ALS** Advanced Light Source, Lawrence Berkeley National Laboratory, USA (1.9 GeV, 44)
- **APS** Advanced Photon Source, Argonne National Laboratory, USA (7.0 GeV, 52)
- **CHESS**, Cornell High Energy Synchrotron Source, USA (5.3 GeV, 7)
- **NSLS II** National Synchrotron Light Source II, Brookhaven National Laboratory, USA (3.0 GeV, 29 +1 under development)
- **SSRL**, Stanford Synchrotron Radiation Lightsource, USA (3.0 GeV,20)

These facilities did not respond to the questionnaire, but were identified to match the RISCAPE criteria

- **BSRF** Beijing Synchrotron Radiation Facility, China (2.5GeV, 14)
- **SSRF** Shanghai Synchrotron Radiation Facility, China (3.5GeV, 14)
- **PLS-II** Pohang Light Source-II, S. Korea (3.0 GeV, 36)
- KSRS Kurchatov Synchrotron Radiation Source, Russia (2.5 GeV, 14)
- **SSTRC** Siberian Synchrotron Terahertz Radiation Centre, Russia (2.2 GeV, 12)
- **SSLS** Singapore Synchrotron Light Source National University of Singapore (0.7 GeV,7)

In addition, **LNLS - SIRIUS PROJECT** Laboratorio Nacional de Luz Sincrotron, Brazil, is being planned with 13 beamlines.

Europe is well equipped as far as SR sources are concerned. There are several excellent small-to medium (≤ 3 GeV) national sources and two large (≥ 6 GeV; one national and one multinational) sources. All provide specialised beamlines dedicated to specific scientific fields and techniques (macromolecular crystallography, soft condensed matter, imaging, spectroscopy, surface science, etc.). For example, the **BESSY II** source in Berlin has 35 operating beamlines, while the **DIAMOND** light source in the UK currently offers a choice of 39 instruments on 32 beamlines. The simultaneous operation of a multitude of beamlines or instruments for different scientific communities is one of the great strengths of modern SR sources. The multinational European Synchrotron Radiation Facility (**ESRF**) is undergoing a major reconstruction of its accelerator complex (the **ESRF** Extremely Bright Source project, employing a novel hybrid multi-bend achromat lattice design) that should provide the world's brightest SR beams. Similar storage ring upgrades are planned for sources within Europe and across the world; two such projects have been completed or are near completion (the **MAX-IV** source in Sweden and **SIRIUS** at LNLS in Brazil).

5.3.2 Free Electron Lasers (FEL)

There are several FEL facilities situated at laboratories around the world. Three FEL facilities in Japan, Korea and the USA fit the RISCAPE classification and there are eight others that did not fit the criteria. The identified facilities are, with electron energy, Light (X-ray) pulses per second, beamlines, experimental stations:

- **PAL XFEL** Pohang Accelerator Laboratory- X-Ray Free Electron Laser, S. Korea (10 GeV, 60,2 beamlines; 3 experimental stations), did not respond to questionnaire;
- **SACLA** SPRing - 8 Compact Free Electron Laser, Japan (8.5 GeV, 60, 3 beamlines; 5 experimental stations);
- **LCLS** Linac Coherent Light Source, USA (15 GeV, 120, 7 experimental stations);

In addition, there are significant new facilities being completed. With **SHINE**, Shangai High Repetition Rate XFEL and Extreme Light Facility, China, estimated start at 2025 and **LCLS II** Linac Coherent Light Source II, USA, estimated start at 2020, both with approximately 1 million pulses per second.

Europe has a range of FEL sources from well-established intense pulsed infrared free electron lasers to more recent X-ray FELs (both national and international). The smaller (infrared) FELs have been in operation for quite some time, since the 1990s for the **CLIO** and **FELIX** facilities in France and the Netherlands, respectively. The X-ray FELs are more recent; **FLASH**, the soft X-ray facility at DESY, Hamburg has operated for the user community since 2005 and is now complemented by a major international X-ray facility, the European **XFEL**, which started operation in 2017. In Italy, the Elettra Sincrotrone Trieste laboratory operates a soft X-ray FEL, FERMI, complementing the Elettra SR source. The FLASH accelerator feeds two soft X-ray beamlines, the XFEL currently operates six instruments on three beamlines. The **SwissFEL** at the PSI laboratory is the latest European FEL to operate at X-ray wavelengths, currently with one beamline (2 instruments) and a second planned for the near future. With facilities operating from the infrared, to the soft X-ray, to the hard X-ray regime, European researchers are well equipped with state-of-the-art FEL facilities.

5.3.3 Neutron Sources (NS)

Fifteen non-European RIs were identified, of which 9 completed the survey. The following facilities completed the information collection, with beam power, source type and number of instruments (if indicated) in parenthesis:

- **ACNS** Australian Centre for Neutron Scattering at ANSTO (20 MW, Reactor, 15)
- **CMRR**, China Mianyang Research Reactor, China (20 MW, Reactor, 11)
- **BATAN** Kartini Reactor – Yogyakarta The GA Siwabessy Multi-Purpose Reactor, TRIGA Reactor, Indonesia (15 MW, Reactor)
- **JRR-3** Japan Research Reactor No.3 , Japan, (20 MW, Reactor, 31)
- **PNPI** Petersburg Nuclear Physics Institute WWR-M reactor, Russia (18 MW, Reactor)
- **HANARO** High Flux Advanced Neutron Application Reactor, S. Korea (30 MW, Reactor, 27)
- **NIST** Center for Neutron Research, USA (20 MW, Reactor,27)
- **HFIR** High Flux Isotope Reactor Oak Ridge National Laboratory Neutron Sciences, USA (85 MW, Reactor, 13)
- **SNS** Spallation Neutron Source Oak Ridge National Laboratory Neutron Sciences, USA (1.4 MW, Spallation, 20)

In addition, the following facilities were identified, but did not complete the survey:

- **LAHN** Bariloche Atomic Centre, Argentina, under construction, (10 MW, Reactor)
- **CARR** China Advanced Research Reactor, China (60 MW, Reactor, 21)
- **CSNS**, China Spallation Neutron Source, China (CSNS-I 100kW; CSNS-II 500 kW, Spallation, 3 at start up)
- **BARC**, Bhabha Atomic Research Centre, India (100 MW, Reactor, 22)
- **J-PARC** Materials and Life Science facility, Japan (1 MW, Spallation Source, 18)
- **PNPI** Petersburg Nuclear Physics Institute PIK reactor, Russia (100 MW, Reactor, up to 50)

Europe is well equipped as far as Neutron Sources are concerned. However, the imminent closure of several national facilities will imperil this (relatively comfortable) situation. The **ESS**, scheduled for its first scientific users around 2023 will significantly improve the European situation; however, previous experience suggest that several years will be required before the **ESS** achieves its full operational potential. There are several (non-European) Neutron Sources of interest to European researchers, e.g. in Australia, Japan and the USA. The cost and time required to build new facilities means that within the next 10-15 years any compensation for the loss of capacity from the closure of old facilities will be to add capacity at the existing or upcoming facilities and increased use by European researchers of non-European facilities.

5.3.4 High Power Lasers (HPL)

For HPL Europe is currently in the lead, with Networks of facilities (**Laserlab** Europe), and a distributed High-Power Laser facility (**ELI**) underway. Through **Laserlab** Europe, many national/university laser facilities in Europe are open to the wider user community. Users can be casual users or experienced users requiring access to very specific equipment available at a given Laboratory or users who wish to gain experience and with the goal to build their own laser installation. Additionally, the International Committee on Ultra-High intensity lasers (**ICUIL**) promotes collaboration of 107 laser laboratories world-wide. For both European and non-European extreme facilities delivering only a very limited number of pulses per year, access is generally only open to general users for a few pulses per year (a few per cent), without open peer review-based access.

5.3.5 High Magnetic Field (HMF)

Several non-European High Magnetic Field facilities were identified - three laboratories in Japan, two in China and the multi-site National High Magnetic Field Laboratory in the USA (with laboratories in Gainesville, Los Alamos and Tallahassee). Three of these responded the survey (with field indicated)

- **WHMFC** Wuhan National High Magnetic Field Center, China (Pulsed fields up to 90 T)
- **HFLSM** High Field Laboratory for Superconducting Materials, Japan (Continuous fields up to 31 T)
- **AHMF** Center for Advanced High Magnetic Field Science, Japan (Pulsed fields up to 50 T)

These facilities were identified, but did not respond to the survey

- **NHMFL** National High Magnetic Field Laboratory (Tallahassee, Gainesville, Los Alamos), USA (DC fields up to 45 T)
- **CHMFL** Chinese High Magnetic Field Laboratory, China (DC fields up to 45 T)
- **IMGSL** International MegaGauss Science laboratory, Japan (Pulsed fields up to 87 T)

Europe has several effective High Magnetic Field laboratories, in addition to the many university laboratories with (relatively) high field magnet capabilities. Four major installations were identified. The Laboratoire National des Champs Magnetiques Intenses unites two sites in France; the Grenoble laboratory specialises in high static fields while the Toulouse site focuses on pulsed field magnets. There are other major high field laboratories in Nijmegen and Dresden.

5.3.6 Particle Physics (PP)

Eleven non-European RIs were identified, where 4 responded to the survey

- **TRIUMF** Canada's particle accelerator centre, Canada
- **B-Factory** KEK-High Energy Accelerator Research Organization, Japan

- **Budker** Institute of Nuclear Physics, Russia
- **TJNAF** - Jefferson Lab Thomas Jefferson National Accelerator Facility, USA

and seven RIs did not respond to the survey

- **BEPC/BEPCII** at IHEP Institute of High Energy Physics, China
- **J-PARC** Japan Proton Accelerator Research Complex, Japan
- **SLAC** National Accelerator Laboratory, USA
- **FERMILAB** Fermi National Accelerator Laboratory, USA
- **RHIC** Relativistic Heavy Ion Collider Brookhaven National Laboratory, USA
- **SNS** Spallation Neutron Source, USA
- **CSNS – HEP** China Spallation Neutron Source, China

PP RIs of the type examined in this domain are a subset of a family of global PP facilities. CERN is the leading collider RI in the world. Other European PP RIs are unique/leading in their respective areas. In other areas of Particle Physics, the RIs are located outside Europe but with access for European scientists.

5.3.7 Nuclear Physics (NP)

Nuclear Physics facilities employ many different experimental techniques. Five non-European RIs were identified, in Australia, China, India, South Africa and the USA, two responded to the survey:

- **BTANL** Beijing Tandem Accelerator Nuclear Physics National Laboratory, China (15 MW tandem accelerator; 100 MeV proton cyclotron; ISOL
- **ATLAS** Argonne Tandem Linear Accelerator System, USA (Superconducting linear accelerator for heavy ions

and three did not respond to the survey

- **IUAC** Inter-University Accelerator Centre, India (15 UD Pelletron; superconducting linear accelerator; low energy ion beam facilities
- **iThemba** Labs Laboratory for Accelerator Based Sciences, South Africa (A range of accelerators including, separated sector cyclotron; Injector cyclotrons; Tandetron; k=11 cyclotron; 6 MV tandem; low energy electrostatic accelerators
- **ANU** Australian National University, Australia (Heavy Ion Accelerator Facility: 14 UD Pelletron electrostatic accelerator; superconducting linear post accelerator

In addition to the large number of University laboratories where Nuclear Physics investigations are undertaken, several major laboratories in Europe were identified where long-term programmes of Nuclear Physics are underway. These laboratories are distributed across Europe - in Finland, France, Germany, Italy, Romania, Switzerland (and Russia). Between them, these RIs provide a range of experimental probes (high-energy electrons, protons and stable or radioactive heavy ions).

5.4 Findings

In this section general findings for the Physics domain is discussed. The description of the international landscape is based on the questionnaire and describes the challenges of the discussed topic for relevant sub-domains. The topics discussed are; access, data, funding modes, financial aspects, visions and roadmaps, impacts.

5.4.1 Access to research services

Differences in user access by subfield could be explained by the maturity and the number of facilities. The bigger the scientific community is, the more organised is the communication around user access programmes. Access mechanisms are presented through service catalogues. More information is available in user-dedicated website directories. Most of the websites are available (at least in part) in English. Access is provided primarily through a peer review process based on scientific excellence or within a scientific collaboration. One can note that in Asia, contrary to the USA, collaboration is more often a major access mechanism, compared to peer review. In general, it appears that existing European facilities fulfil most scientific needs except for special instruments that in some cases do not exist in Europe.

Almost 30 % of International facilities provide datasets to their users, 60 % provide specialised research tools or services and nearly 40 % computing services. They all provide local research facilities (e.g. laboratories). Virtual and remote access are more developed at North American facilities. There is a healthy exchange of scientists (and ideas) between European and international RIs; often, reciprocal arrangements exist between laboratories. However, funding for travel and subsistence can limit collaboration possibilities.

	PP/ NP	ARI (NS, SR, FEL)	HPL, HMF
Governance [OPERATION]	Global landscape / intergov-ernmental agreement	National or regional facilities / well developed collabora-tions between continents	Typical university groups which started to organize in distributed networks / mega facilities for nuclear weapons / fusion
ACCESS	Few / large collaborations / Experiments lasting years	Many / simultaneous user / experiments from hours to days	Many small groups / extreme experiments last hours to days
Challenges & Impact [OUTPUT]	Big fundamental questions (e.g. standard model)	Grand challenges in general / technical and scientific support	Extreme states of matter

Table 5.2: *Gives and overview that helps to showcase the variety of the different subfields of the Physics and Analytical RIs this present domain report refers to. It summarises the diversity in terms of the three main criteria, already mentioned under Section 2.1 (Operation, Access, Output).*

5.4.2 Data management

Data policies are more advanced in North America and Europe than on the other continents. The European Commission is actively supporting the implementation of data policies for European RIs. Responses to the questionnaire show that Open Access initiatives are ongoing and are more frequently implemented in Europe (this may be linked to the strong support by the European Commission) compared to the other continents. There are special costs associated with an open data system. First, the RI must put in place a system of access to the data, including validation procedures to protect the data, the RI and the original experimenters. In addition to make the data transparent and useful, sophisticated metadata must be available, as well as the data itself. All of this requires computing capacities and dedicated expert staff.

New state of the art PP, SR, FEL and NS RI will generate from a few to several tens of petabyte (10^{15} bytes) per year. The cost of providing the necessary meta-data, maintaining and providing access for data mining on such an amount of data, would necessitate substantial increases in both the operating costs of the data generating facilities and energy consumption. Developing a strategy for which data it is cost effective or sustainable to provide open access will be a challenge for most of the RIs.

5.4.3 Challenges and impacts

Almost all the facilities follow their scientific output (publications, theses, patents, etc.) systematically. These performance indicators are the most important indicators to funding bodies and partner organisations, and hence to the RI itself. Many of the RIs responded that they aimed to contribute to societal challenges including health, agriculture and food, energy, the environment and materials, and the bio-economy. As far as economic impact is concerned, this is not (often) noted to be a principal priority. However, many RIs mention industry as part of their user base. Economic impacts are multiple, and cover impact on the local environment (jobs, facility construction, equipment supply, etc.). There are cases of direct access for industries to the facilities.

Due to the nature of the research and technical capacities of the RIs, the direct impact of their research on societal themes is not always evident. However, these RIs have major indirect impact on their local environments. Not only do they provide a source of highly trained workforce for local industry and commerce, but also RIs in this class affect positively the local educational ecosystem through school visits, summer studentships and internships. They also boost the local high-tech (and hence national) economy by instrument and technique development, as well as direct equipment purchase.

5.4.4 Funding and costs

By far the most frequent source of funding is national funding (i.e. by the country within which the RI is located). A few facilities in Europe (including JINR in Russia and SESAME in Jordan) have multi-national funding (contributions by several member countries). There are also several in Europe that are partially funded by the European Commission through European structural and research funds (e.g. **ELI**).

As presented in the figure 5.3, based on answers received, the spread of scale for reconstructing costs is highly variable from one subdomain to another. Scale seems reduced for HMF and NP subfields. For NP, this can be partially explained by the fact that they are part of bigger RIs. Whereas FEL, PP, NS and SR facilities report reconstruction costs up to €2 bn, HMF facilities would be significantly cheaper to reconstruct, while PP infrastructure reconstruction costs would cover a very wide range (for example, to build **CERN** today would cost substantially more than €3 bn).

5.4.5 Roadmaps and perspectives

Almost all facilities mentioned existing roadmaps in their answers. Roadmaps exist at different levels – country specific, subdomain or technique specific. Most individual RIs acknowledge having mission statements. Long-term perspectives may be interpreted very differently depending on the subfield. In general, however, due to the nature of the Physics and Analytical RIs (major construction and operation costs, etc.), it is obvious that normally such facilities operate within long term planning environments (in respect of their size, operation costs and technical expertise). Long-term planning also has a role in maintaining the interest of the scientific (user) community and the funding organisations (as well as the community at large). In addition, stable, long-term planning is needed to maintain and develop theses expensive facilities.

5.4.6 Interaction with European RIs

SR and NS facilities are well spread over the world. For the other subfields, there are few facilities in South America, Oceania, Africa and the Middle East (no facilities were identified for PP and HMF, only one for FEL, and two corresponding to the RISCAPE criteria for NP). Perhaps the most significant result of the analysis of the questionnaires is the International RIs' degree of knowledge of, and interaction with relevant European RIs. In general, strong collaborations and interactions exist between RIs across the globe. A vast majority of RIs that answered our questionnaire already mentioned a European partnership and other collaborations. This is not surprising as modern physical science is essentially international in nature; scientists exchange information regularly with colleagues in other countries, so new collaboration possibilities may be limited. However, new or deeper collaborations remain possible with RIs in Asia, Africa and (probably) Russia.

5.4.7 Grand Societal Challenges

Many of the RIs responded that they aimed to contribute to societal challenges including Health and Food, Energy, Environment and Bio-economy (in addition to their programs of basic or fundamental science). USA facilities stressed the importance of following the priorities of their funding agencies (including energy research and national security). Where specific goals (technical, scientific, or social) are concerned, most RIs stressed those problems tailored to the RIs particular capabilities (e.g. ultrafast timescales for the XFELs, "everything that SR can address" for the SR sources; the same is the case for NS sources, nuclear structure and nuclear reactions for the NP facilities, and materials science for HMF). PP RIs are generally addressing fundamental physics questions. An interesting comment is the emphasis on "bio" for the Brazilian synchrotron.

Rather than involvement in global initiatives to solve grand challenges, RIs collaborate in international organisations and forums, often with the aim of developing future facilities in their scientific/technical field. Examples include international collaborations to develop future (SR) light sources or future XFEL facilities and International and Asian HMF forums. As interesting finding is that NP facilities responded that, they were not involved in such global initiatives or collaborations. PP RIs are in general global collaborations to solve a specific fundamental physics question.

5.4.8 Impact

Where metrics and indicators are concerned, unsurprisingly the majority of RIs (SR, FEL, NP, NS, PP and HMF) follow their scientific output (publications (including high impact publications), theses, patents, etc.). Usually this is carried out within their organisation, but occasionally a third party (external organisation) is involved (e.g. the Department of Energy in the USA or the Helmholtz Gemeinschaft in Germany). Bibliometric or citation data is tracked by some SR facilities (Australia and the USA) while an Asian (Thailand) SR facility reports annual economic impact studies carried out by third parties. A USA SR RI mentioned that citation impact was available via commercial databases. A USA FEL reported that an independent assessment team carried out regular impact reviews. Academic awards are included, for an Asian (Chinese) NP RI. Other indicators include numbers of academic users, industrial users, and students trained. Reports on scientific and societal impact are available publicly for some RIs, but not for all. For example, for 12 international SR facilities polled, five reported that such reports are available, while five reported that they were not, and two did not reply or answered "unsure". The impact reports take several forms, including research highlights and annual reports.

There were several interesting examples of "other means" to demonstrate impact. FEL sources in Japan and the USA cited studies by social scientists and focused reviews, respectively. Asian HMF facilities replied that patents, educational output and government grants were included as indicators of impact. The Australian SR source added media coverage and case studies, while an Asian (Thailand) SR facility included social impact (such as cultural heritage studies) but pointed out that such indicators were difficult to quantify. A USA SR facility responded that Impact statements on proprietary research were another useful indicator of impact.

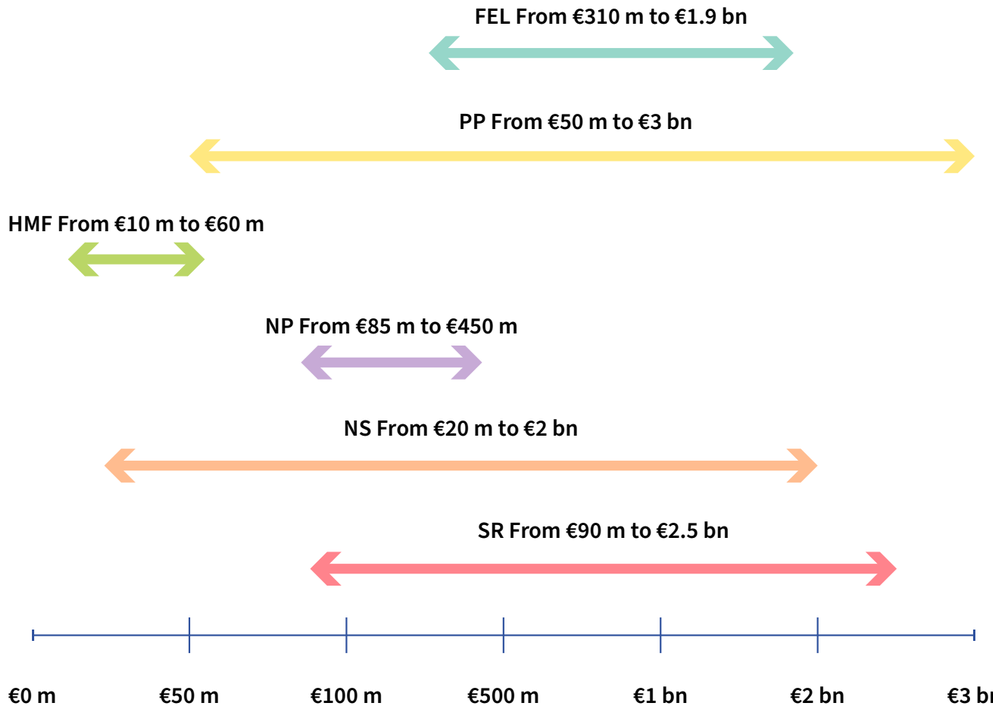


Figure 5.3 *"If you were building your organisation today, what would be the approximate construction costs?"- Scale of the organisations.*

6. ENERGY RESEARCH INFRASTRUCTURES

Main contributors
Mikkel Knudsen (University of Turku)
Marianna Ferreira-Aulu (University of Turku)
Elizaveta Shabanova-Danielyan (University of Turku)
Weiqing Wang (University of Turku)
Jyrki Luukkanen (University of Turku)
Jari Kaivo-oja (University of Turku)

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6.1 Domain overview

In this domain report, Energy Research Infrastructures is the research object. Energy research infrastructures (RI) are the performer and supporter of top-level academic and industrial energy research activities. Throughout the successive framework programmes of the EU, such as the current framework programme Horizon 2020, various actions have been developed to support researchers to access top-level European Energy RIs located outside their own countries, moreover, to improve the coordination and integration of these infrastructures Europe-wide, enabling better research services. Energy RIs pave the way for the development of scientific and technological advances in energy industries and markets. The energy sector is key to social and economic development, however, it is also one of the main contributors to global CO_2 emissions. For the EU, the goal of reducing CO_2 emissions in a sustainable framework is a major driver of its energy policy, with the objective of creating a secure, sustainable, competitive and affordable energy system. Energy Research Infrastructures play a major role in achieving this objective, through driving forward testing, demonstrating technologies and their interplay in the future energy system (ESFRI Roadmap 2018: 49).

The ESFRI Strategy Report and Roadmap (2018) for the energy domain divides the energy domain into five main areas, which themselves comprise several specific fields[1]. The five subdomains are:

6.1.1 Energy Systems Integration

– including networks, transport, storage and smart cities/districts. The focus is on the design, operation, and integration of all parts of the energy system of the future in a safe and secure manner. It is also important to point out that the socio-economic and human behaviour aspects are essential for energy transformation processes. Achieving more efficient ways of transporting, distributing and, perhaps most importantly, storing energy in addition to a sustainable transformation of the mobility sector are important elements of the research agenda globally as well as in Europe. Most RIs covered by RISCAPE touch upon elements of this subdomain, e.g. renewables research also tackling issues of grid integration.

6.1.2 Renewable Energy

– including solar energy, renewable fuels, wind energy, geothermal energy, and ocean energy. The last couple of years have witnessed a considerable drop in levelized cost of energy for renewable energy, and further massive cost reductions can be achieved through the development of new concepts. They require long-term research and state-of-the-art Research Infrastructures. Advancing clean, sustainable energy sources for the global energy transition is a challenge at the top of the European research and societal agenda. In terms of Research Infrastructures, renewable energy is still an emerging field of science, as there is still no European ESFRI Landmarks in renewable energy. However, for Europe as well as internationally, it is a rapidly advancing field. It must be noted that almost all identified RIs, in addition to the wealth of non-RISCAPE RIs in the field, except for dedicated nuclear RIs, do work related to renewable energy research.

6.1.3 Efficient Energy Conversion and Use

– seeking enhanced efficiency in energy production, conversion and use is an important and viable aim. It is vital for the future system of energy efficiency that it will supply the necessary base-load power in a reliable and secure way, always and at a reasonable cost. Energy efficiency in buildings and in the industry are important means of achieving a cheaper, more efficient, and more sustainable energy system. Similarly, the ability to transform intermittent power from renewables into other sources of energy – Power-to-X (-to-Power) – is considered essential for the future needs of international energy systems. While these subfields all attract significant energy research, the only existing RI in Europe (ECCSEL ERIC) is in another field within this subdomain concerned with carbon dioxide capture, storage and utilisation.

6.1.4 Nuclear Energy

– including fusion and fission. Nuclear power plays an important role in providing stable, base-load electricity. The main strategic objectives are the safety aspects and the long-term waste disposal. In many countries, the issue of prolonging the life of existing Nuclear Power Plants (NPPs) leads to the development of materials research under nuclear irradiation. In some countries, which have aging NPPs or decide to step out of nuclear energy, the issue of the dismantling of NPPs is an important one. Some RIs also take the responsibility

[1] http://roadmap2018.esfri.eu/landscape-analysis/section-1/energy/

for providing governments and the public with technical support in the event of a nuclear or radiological incident. The nuclear energy subdomain can be split further into two main elements: nuclear fission and nuclear fusion. Research in nuclear fission often leads to prolonging the life of existing nuclear power plants, maximising efficiency and enhancing the utilisation of materials. Research in nuclear fusion advances the development of a possibly very important future energy source. As nuclear facilities tend to require large investments, as well as very long timeframes for planning, construction, operation and post-operation phases, nuclear energy research is more inherently linked with Research Infrastructures than other subdomains in this analysis. This is true for both Europe and globally.

6.1.5 Cross-sectional Energy RIs

– exploiting synergies across different technologies will benefit the energy research community, and in return, the energy research community can further advance the cross-cutting methodological development. Energy technology-oriented roadmaps have prioritised the need for cross-sectional energy RIs in Europe. Cross-sectional RIs also include infrastructures focused on energy materials and infrastructures focused on data, simulation and modelling, usually featuring high-performance computing (HPC). Cross-cutting Research Infrastructures in the energy sector advance simulation and modelling, as well as new energy materials. These are integral issues in order to stimulate and optimise future international energy systems. ESFRI (2018) notes that more emphasis should be put on developing European research infrastructures within this subdomain. In practice, marking differences between Energy RIs and infrastructures promoting High-Performance Computing (HPC) or materials research is difficult. Again, the global list of potential partners for cooperation is much more extensive than this analysis will indicate.

The Energy domain differs from many other research areas since there is no cluster project for the Energy RIs.

6.1.6 Energy research overlap

Our analysis shows that energy research commonly overlaps with (or borders) a number of research fields and other science domains. Figure 6.1 illustrates some of the borders often encountered during the analysis. As an example, nuclear research facilities and synchrotrons clearly share characteristics with physics research, and they are often also active in facilitating biomedical and research (nuclear medicine). These research synergies are to be applauded, but they make it difficult to clearly define the boundaries of Energy Research Infrastructures.

The first phase of the RISCAPE project was concerned with the interaction with the European Energy RI by contacting each identified RI directly. The purpose of this interaction was both to provide an overview of the European landscape, and to use the European organisations as a valuable source of information for the subsequent mapping of the international landscape. The initial analysis used the 2016 ESFRI Roadmap as a starting point. The 2018 ESFRI Roadmap features two ESFRI Landmarks and four ESFRI projects. In the nuclear research subdomain, ESFRI Landmark Jules Horowitz Reactor (JHR) is an experimental reactor facility intended to provide scientific breakthroughs on nuclear fuel and materials. European Carbon Dioxide Capture and Storage Laboratory Infrastructure (ECCSEL) was officially recognised as an ERIC in 2017 and operates a distributed RI on Carbon Capture and Storage (CCS) in the efficient energy conversion and use subdomain. ECCSEL participated in the previously mentioned RISCAPE workshop. In the renewable energy subdomain, two projects exist on the latest ESFRI Roadmap. European Solar Research Infrastructure for Concentrated Solar Power (EU-SOLARIS) advances thermal solar power research, while European WindScanner Facility (WindScanner) is a distributed RI focused on the characterisation of wind fields. In the nuclear energy subdomain, there are also two projects on the 2018 ESFRI Roadmap. Multi-purpose hYbrid Research Reactor for High-tech Applications (MYRRHA) is a unique first prototype of a multi-purpose hybrid reactor for high-tech applications. Finally, The International Fusion Materials Irradiation Facility-DEMO Oriented NEutron Source (IFMIF-DONES) entered the roadmap as a new entry. It gained recognition from ESFRI for its strategic role in the implementation of nuclear fusion solutions to the massive production of energy, and for its role as an active actor in the development of nuclear fusion technologies (ESFRI Strategy Report and Roadmap 2018: 14). This nuclear fusion project has not been activated as a participant in the RISCAPE project, but it serves as an important comparison for the international RIs.

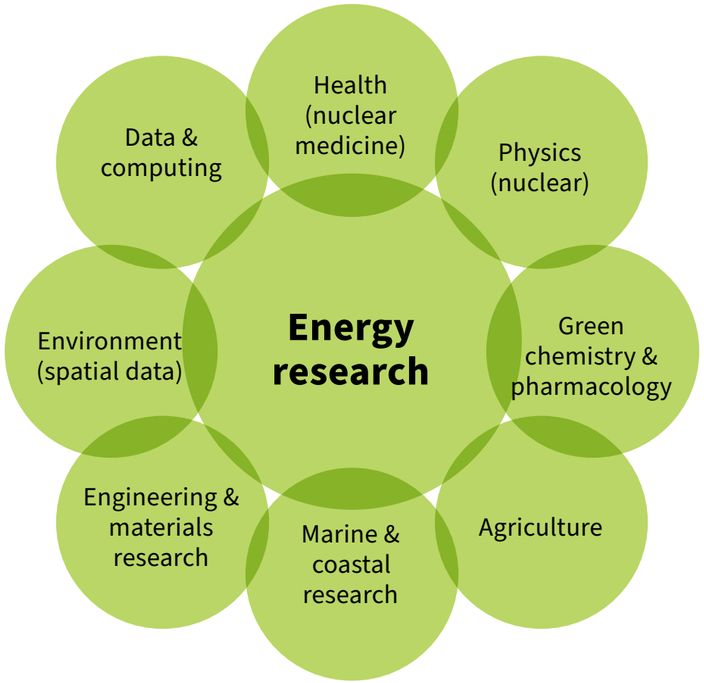

Figure 6.1 *Selected overlaps of energy domain with other scientific domains*

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6.2 The methodological approach

The methodology used to acquire information for the domain is explained in chapter 2. The flow chart in chapter 2 describes the steps taken to gather relevant information about the RIs in question. For the global landscape analysis, the common methodology of the RISCAPE project was used with some slight modifications. Similarly, the project definition of Research Infrastructures was used. The first stage of the project briefly assessed the European landscape, as described below. A list of non-EU Energy RIs was then drafted on the basis of desk research and the comments from European stakeholders. It was extended and adapted during the more detailed research phase through snowball sampling, with some RIs added and some deleted according to the common RI definitions. The final contact list includes 37 organisational structures outside Europe. Six additional possible RIs were examined in detail but left off the final contact list due to the RISCAPE criteria of RIs[2].

A dedicated RISCAPE workshop was arranged in Brussels in July 2017 with invitations for the main European Energy RI stakeholders. The workshop included participants involved in key research projects of geothermal energy, fuel cells and hydrogen research, biofuels, bioeconomy research, and smart energy and transport solutions. Several participants represented projects funded under e.g. Horizon 2020 with the aim to build RIs appearing in future ESFRI roadmaps.

Some of these organisational structures focus exclusively on energy research, while others are multi-programme organisations, having energy research as a part of their research portfolio. Energy-related RIs are found in all continents except Africa (as noted in box 6.1, one possible RI in South Africa was recognised as mainly commercially-oriented and thus excluded from this domain report). Some RIs are parallel programmes organised under the same organisation. This made it difficult to assess – also from the point of view of our interviewees – what constituted the boundaries of the RI organisation and who the relevant interviewee would be. This also affected questions regarding e.g. operating costs, missions and visions, as the entire organisation may span significantly more parts than our main object of analysis, the Research Infrastructure element. The list of RIs includes also two university initiatives (Stanford University's Precourt Institute for Energy and MIT Energy Initiative in the USA), which are organisational structures providing support (organisational and financial support in the communication) for energy research inside the university. These organisations themselves do not own any research facilities for shared use. However, the research facilities and services are available at the university and may serve as contact points for establishing collaborations with energy research teams inside the university.

[2] For the purpose of clarity these organisations are also listed at the end of Appendix 6.

JHR	Jules Horowitz Reactor	ESFRI Landmark
ECCSEL	European Carbon Dioxide Capture and Storage Laboratory Infrastructure	ESFRI Landmark (Roadmap 2018)
EU-SOLARIS	European SOLAR Research Infrastructure for Concentrated Solar Grid	ESFRI Project
MYRHHA	Multi-purpose hybrid Reactor for High-Tech Applications	ESFRI Project
WindScanner	European WindScanner Facility	ESFRI Project
MARINERG-I	Marine Renewable Energy Research Infrastructure	Funded by Horizon 2020.
MaRINET2	Marine Renewables Infrastructure Network	Funded by Horizon 2020.
ITER		ITER agreement signed by EU, China, India, USA, Russia, South Korea and Japan.
JET	Joint European Torus	RI in operation, supported by EU (EURATOM).
DEMO	Demonstration Fusion Power Reactor	
ERIGrid	European Research Infrastructure supporting Smart Grid Systems Technology, Validation and Rollout.	Integrating Activity funded by Horizon 2020
BRISK-2	Biofuels Research Infrastructure for Sharing Knowledge	Integrating activity funded by Horizon 2020
H2FC		Project funded by Horizon 2020.

Figure 6.1 *European research infrastructures identified and contacted*

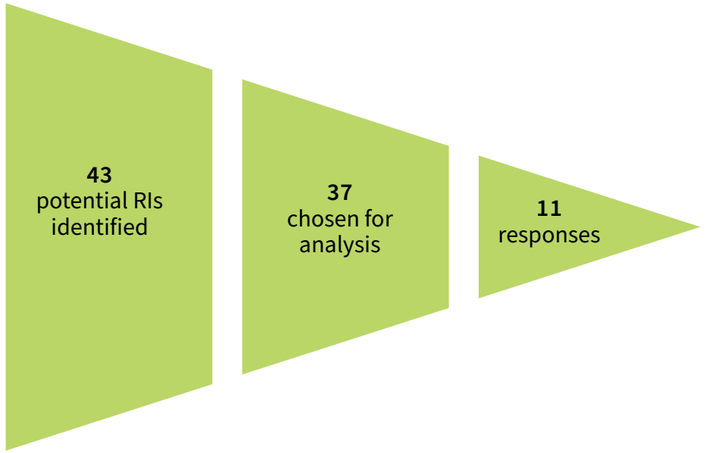
6.3 The international landscape

North America and Asia stand out in the international landscape with 15 organisations located in North America and 13 organisations in Asia. The USA clearly dominates the energy research landscape with 11 organisations located in the USA versus four organisations in Canada, and none in Mexico. In Asia, energy research organisations are more equally distributed with five in Japan, four in China, three in India and one in South Korea. In South America, three organisations – all from Brazil – were identified as qualifying for the RI definition of the project. In Australia, three organisations were identified. Russia is a significant actor in nuclear energy research. For all the countries above, at least one of their RIs is a nuclear research organisation.

The subdomains with the most RIs are Renewables (17 RIs) and Nuclear Energy (19 RIs). In the renewables subdomain the important actors are the USA (six RIs), Japan (five RIs), Canada (three RIs), Brazil (two RIs), India (two RIs) and China (one RI). Materials research conducts studies at 11 international RIs within the Cross-sectional Energy subdomain. The majority of these RIs are in Asia (six RIs) and North America (four RIs, all in the USA) and one RI is in Australia. Six RIs are active in studies of Energy Systems Integration (four RIs is the USA, one RI in Canada and one RI in Australia). Finally, four RIs pursue studies in the field of Efficient Energy Conversion and Use (three RIs in the USA and one RI in Japan). USA has the most RIs in energy research subdomains.

6.3.1 Energy Systems Integration

In Canada, National Research Council Canada Energy, Mining and Environment Research Centre (**NRC EME**) is one of 14 research centres within National Research Council (NRC) Canada, uniting R&D capabilities and facilities in energy, mining and environment research. In energy research, **EME** focuses on bioenergy systems, energy storage and novel material for clean energy and aims to support Canadian industry in bringing the latest science and technology achievements to the market. EME has facilities to conduct bioenergy research and energy storage research.



In the United States, Stanford University Precourt Institute for Energy (**Stanford Energy**) is a focal point for Energy Research across various academic departments, labs and research programmes of Stanford University, while MIT Energy Initiative (**MITEI**) is an institute-wide initiative that brings together energy researchers within MIT and promotes collaboration with industry and governmental partners. These university-based RIs are important players in fields under the energy systems integration subdomain. Pacific Northwest National Laboratory (**PNNL**) is included in the list of national laboratories under the US Department of Energy (US DOE). While the laboratory covers several science disciplines, in energy research the core problem that PNNL aims to address is the creation of energy resilient systems. Oak Ridge National Laboratory (**ORNL**) is another relevant multi-programme national laboratory under the US DOE. The scientific portfolio in energy research includes nuclear energy technologies, fusion science and technologies, energy efficiency and renewable energy. Argonne National Laboratory (**ANL**), also under US DOE, is a multidisciplinary research centre with relevant facilities such as Advanced Mobility Technology Laboratory, Distributed Energy Research Centre, Engine Research Facility, Virtual Engine Research Institute and Fuels Initiative and others.

Definitional challenges in RISCAPE

The methodology used in the RISCAPE project excludes a number of organisations which could be natural partners for European Energy RIs.

First, the identified RIs do not include energy research infrastructures that works project-based on research questions that EFRIS scale research infrastructures normally cannot address.

Second, it excludes commercial actors for whom research may not be the most important goal of the organisation. However, in energy research, private and commercial actors make for a large share of total R&D spending. The line between commercial unit and 'real' research entity also proves challenging in practice. As an example, nuclear facilities surveyed in RISCAPE also enable the pharmaceutical industry with industrial and medical radioisotopes. The South African SAFARI-1 research reactor listed by GSO (2017) was, after careful consideration, left off the list due to being now primarily commercial with the aforementioned aim, while others with dual purposes form part of the final list.

Third, energy research – especially, but not only in the nuclear energy subdomain – overlaps with issues of critical national security interests. Constructing a list of RIs based on principles of accessibility and possibilities of cooperation for European Research Infrastructures may, therefore, leave certain e.g. military facilities off the list, even if those facilities themselves are high-quality Research Infrastructures.

Institute of Electrical Engineering, Chinese Academy of Sciences (**IEE, CAS**) in China and research institutes under Advanced Industrial Science and Technology (**AIST**) in Japan are also mentioned here.

Do we have representative responses?

The initial response rate from Energy RIs to our contacts was low. In addition, several RIs only had little information available on their websites in English, limiting our ability to collect sufficient information by other means. For this reason, the RISCAPE WP6 team was consciously extended with native speakers of Russian, Chinese, and Portuguese (Brazil). This proved more successful in inspiring dialogue with RIs and allowed for stronger independent research on the respective regions. However, the process reflects our priority on achieving representative geographical coverage rather than a representative snapshot of each subdomain or in getting as many total answers as possible. This risks some bias in our replies, although we believe that avoiding strong geographical and linguistic bias is a more important strength of the analysis. Furthermore, the interviews included several cases from all subdomains.

6.3.2 Renewable Energy

In China, **IEE**, **CAS** is a national research institution oriented to the development of electrical science and engineering, and it represents some of the most important energy research of the **IEE**, **CAS** research fields include renewable energy technologies.

The New Energy and Industrial Technology Development Organisation (**NEDO**) is one of the largest public research and development management organisations in Japan. **NEDO** has two missions, namely addressing energy and global environmental problems, and enhancing industrial technology. Its large-scale facilities include demonstration facilities for offshore wind. **AIST** includes Research Centre for Photovoltaics and Fukushima Renewable Energy Institute, established in Fukushima in 2014, three years after the 2011 earthquake.

In India, DBT-ICGEB Centre for Advanced Bioenergy (**DBT-ICGEB**) was established in order to strengthen existing capacity in synthetic biology and to promote the cutting-edge research in advanced biofuels. There are currently 41 facilities in **DBT-ICGEB**. As the only bi-national RI identified by RISCAPE, Solar Energy Research Centre for India and the United States (**SERIIUS**) facilitates joint R&D and related activities on clean energy by teams from India and the United States. SERIIUS's three research thrusts are Sustainable Photovoltaics, Multiscale Concentrated Solar Power, and Solar Energy Integration.

The leading South American Research Infrastructure in renewable energy is the Brazilian Centre for Research in Energy and Materials (**CNPEM**) in Brazil. **CNPEM** is a private non-profit Social Organization supervised by the Ministry of Science, Technology, Innovation and Communications (MCTIC). Located in Campinas, São Paulo State, it consists of four National Laboratories open to the scientific and technological communities, with competencies in biosciences, materials, renewable energies, and advanced instrumentation.

In North America, there is a plethora of renewable energy RIs. In Canada, NRC EME focuses, in addition to energy systems integration, on bioenergy systems and has facilities to conduct bioenergy research. Wind Engineering, Energy and Environment Research Institute (**WIndEEE**) was established in 2011 to "advance the development of wind energy, wind engineering, and wind environment through research, education, innovation and collaboration". In 2014, the **WindEEE** Dome 3D wind chamber was commissioned in order to accommodate multi-scale, three-dimensional and time-dependent wind testing. Canada also has an important RI for ocean energy: Fundy Ocean Research Centre for Energy (**FORCE**). **FORCE** is a private, non-profit institute, supported by the Governments of Canada and Nova Scotia and participating developers. It is Canada's lead demonstration facility for tidal in-stream energy conversion (TISEC) technology.

In the United States, many of the most prominent identified RIs are organised as parts of the National Renewable Energy Laboratory (**NREL**) under the US Department of Energy. **NREL** includes several laboratories, research centres and research programmes: National Bioenergy, National Centre for Photovoltaics, Concentrating Solar Power Research, National Wind Technology Centre, Geothermal Program. In addition, a number of other laboratories under US DOE have important renewable elements. Sandia National Laboratory (**SNL**) has several user facilities, most importantly here National Solar Thermal Test Facility (concentrated solar power) and Photovoltaic Laboratories (photovoltaics). Savannah River National Laboratory (**SRNL**) has research programmes and facilities related to hydrogen, bioenergy and energy materials. Argonne National Laboratory (**ANL**) has research and facilities related to hydropower. The multi-programme **ORNL** also covers renewable energy, as do MIT Energy Initiative (**MITEI**) and **Stanford Energy**.

6.3.3 Efficient Energy Conversion and Use

In Australia, Centre of Excellence in Exciton Science, Australian Research Council (**ACEX**) researches better ways to manipulate the way light energy is absorbed, transported and transformed in advanced molecular materials. The Centre has an extensive infrastructure for device fabrication including complete solar cell characterisation systems, a wide range of printing and deposition technologies, clean room access, a wide range of deposition methods and roll-to-roll printing and slot die coating facilities at CSIRO.

Research Institute for Energy Conservation **AIST** (**iECO**) in Japan is one of the research institutes of the Department of Energy and Environment, AIST. It conducts R&D on energy technologies to improve the efficiency of utilisation and conversion. The organisation includes eight research groups and three laboratories: Collaborative Engine Research Laboratory for Next Generation Vehicles, Energy Nano-Engineering Research Laboratory and Advanced Technology Laboratory for Solid State Energy Conversion (**ALSEC**).

In the United States, National Energy Technology Laboratory (**NETL**) is owned by US DOE as the only laboratory from the US Department of Energy National Laboratory that specialises in fossil energy studies. While it might be hard to imagine a future establishment of a fossil fuel-focused European RI, as much as increased energy efficiency also of existing energy sources would be a preferable outcome, **NETL**'s significant attention to carbon capture and storage complements **ECCSEL ERIC**. Other US DOE-laboratories with important infrastructures related to this subdomain are **SRNL**, **MITEI** and **Stanford Energy**.

6.3.4 Nuclear Energy

In Australia, Australian Nuclear Science and Technology Organization (**ANSTO**) operates much of Australia's landmark research infrastructures in nuclear research. This includes one of the world's most modern nuclear research reactors, OPAL; a comprehensive suite of neutron beam instruments; the Australian Synchrotron; the National Imaging Facility Research Cyclotron, and the Centre for Accelerator Science.

Joint Stock Company "State Scientific Research Center of Atomic Reactors" (**JSC "SSC RIAR"**) is a single-sited research and development centre located in Dmitrovgrad (Ulyanovsk region) in Russia. It was founded in 1956 as a nuclear testing centre, granted the status of State Scientific Centre in 1994, and became a joint-stock company in 2008. Facilities include six test reactors, post-irradiation examination facilities, and a radiochemical facility to perform NFC-related research activities. The new multipurpose fast reactor MBIR is currently under construction.

In India, Bhabha Atomic Research Centre (**BARC**) was established in 1954 as a multidisciplinary research programme essential for the ambitious nuclear programme of India. It is the parent body of several R&D institutions and has active groups for R&D in, among other things, reactor technologies, fuel reprocessing and waste management, isotope applications, and radiation technologies.

As Japan's sole comprehensive nuclear research and development institution, Japan Atomic Energy Agency (**JAEA**) officially aims to contribute to the welfare and prosperity of human society through nuclear science and technology. Its priorities are the research into improving nuclear power safety, basic and fundamental research of nuclear power, and R&D on nuclear fuel cycle. In response to the accident at Fukushima Daiichi Nuclear Power Plant, it has been conducting the R&D for decommissioning and environmental restoration.

National Fusion Energy Institute (**NFRI**) is the national institute in South Korea dedicated to conducting research and development of fusion energy. It has constructed the world's highest-ranking fusion research device named Korea Superconducting Tokamak Advanced Research (**KSTAR**) and has been actively involved in **ITER**.

In China, Institute of Plasma Physics, Chinese Academy of Science (**ASIPP**) was founded in September 1978 for the peaceful utilisation of fusion energy through the tokamak approach. As one of the most important laboratories in China, **ASIPP** has been conducting research in high temperature plasma physics and magnetically confined fusion engineering, and it has built the world's first non-circle cross-section full superconducting tokamak, namely Experimental Advanced Superconducting Tokamak (EAST). ASIPP is also a major contributor in China for **ITER**, having undertaken up to 73% of China's **ITER** Procurement Packages. Nuclear Power Institute of China (**NPIC**) is the only large-scale comprehensive R&D base in China incorporating reactor engineering research, design, test, operation and small batch production. It has established 90 laboratories, including two national key laboratories and two national energy R&D centres. It has designed seven nuclear facilities on self-reliance such as the first High Flux Engineering Test Reactor in China. There are 18 large-scale test installations for R&D of reactor engineering. Shanghai Synchrotron Radiation Facility (**SSRF**) is the largest synchrotron research facility to date in China, and it is one of the most advanced third generation light sources in the world, supporting and pushing cutting-edge scientific research and innovation.

In Brazil, Instituto de Pesquisas Energéticas e Nucleares (**IPEN**) (Nuclear and Energy Research Institute) is an autarchy of the São Paulo State, associated with the University of São Paulo for educational purposes, and supported and operated technically and administratively by the National Nuclear Energy Commission (CNEN). It is recognised as a national leader in research, development and applications in the areas of radiopharmacy, radiation technology, nuclear physics, materials, lasers, biotechnology, environment and clean energy, and also in design and operation of nuclear reactors and radioactive facilities. Centro de Desenvolvimento da Tecnologia Nuclear (**CDTN**) is a nuclear institute that conducts research on radiochemistry, radioprotection, radiological metrology and dosimetry, nuclear/radiological safety, radioactive waste management, and nuclear technology (thermodynamics and neutronics). The main nuclear/radioactive facilities of CDTN are Nuclear Research Reactor TRIGA IPR-R1, Unit for Research and Production of Radiopharmaceuticals –UPPR, and Laboratory of Gamma Irradiation. CDTN also plays a significant role in the technological development and the provision of specialised services for the mineral and metallurgical sectors.

Established in the middle of the 20th century, Canadian Nuclear Laboratories (**CNL**) has been a primary national nuclear research laboratory in Canada. For decades until its shutdown in 2018, the National Research Universal reactor was one of the world's most versatile high-flux research reactors. Currently CNL has a ZED-2 research reactor and several research facilities for materials research, fuel testing etc. The modern strategy for the years 2016–2026 has a special focus on the revitalisation of the Chalk River Laboratories site.

In the United States, many of the significant laboratories of US DOE have significant interest in nuclear research, both historically and currently. While several laboratories originally opened as single-mission organisations focusing on nuclear-related issues have since branched out, nuclear energy research remains the forte for several RIs. DIII-D National Fusion Facility (**DIII-D NFF**) is a laboratory operated by General Atomics for the U.S. Department of Energy. The laboratory investigates a broad range of fusion energy research topics from fundamental plasma science to the work of fusion power plants. DIII-D tokamak has operated since the mid-1980s. **SNL** has facilities available for the general scientific community under the Nuclear Energy and Fuel Cycle Programs and Nuclear Facilities Resource Centre. Idaho National Laboratory (**INL**) is one of the US DOE laboratories focused on nuclear energy studies. **INL** offers numerous user facilities for researchers, such as beamline, ion irradiation, post-irradiation examination and gamma-irradiation facilities. The laboratory also offers access to 10 nuclear reactors, each of those offering different capabilities for nuclear research. **SRNL** has concentrated its nuclear-related research facilities on its main campus, and regards environmental remediation and risk reduction, nuclear materials processing and disposition, nuclear detection, characterisation and assessments

among its core capabilities. **ORNL** has a scientific portfolio in energy research that includes nuclear energy technologies, fusion science and technologies, energy efficiency and renewable energy. ORNL is a member of the **ITER** project. Furthermore, **Stanford Energy** also works within nuclear energy.

6.3.5 Cross-sectional Energy RIs

In Australia, Australian National Fabrication Facility (**ANFF**) links eight university-based nodes to provide researchers and industry with access to state-of-the-art fabrication facilities. The nodes, located across Australia, draw on existing infrastructure and expertise. Each offers a specific area of expertise including advanced materials, nanoelectronics & photonics and bio nano applications. Its facility portfolio consists of over 500 instruments with projects valued over $200 million.

In China **IEE**, **CAS** has an interdisciplinary research centre as well as six laboratories, including Laboratory of Bio-electromagnetics and Electromagnetic Detection Technology, Laboratory of Superconductors and New Materials, and Laboratory of New Technology for Power Conversion. Institute of Plasma Physics, **ASIPP** is developing superconductors for **ITER**.

In India, Bhabha Atomic Research Centre (**BARC**) is active in energy materials research related to nuclear energy.

Global Research Centre for Environment and Energy Based on Nanomaterials Science (**GREEN**) in Japan was established in October 2009. It builds upon Japan's strength in the field of nanotechnology and materials science and aims to contribute to the creation of new materials for solving environmental and energy problems. **AIST** has a Research Institute on Electrochemical Energy and an Advanced Power Electronics Research Centre. In addition, **AIST** has a Department of Materials and Chemistry in parallel with the Department of Energy and Environment.

Brazilian Centre for Research in Energy and Materials (**CNPEM**) in Brazil is a private non-profit Social Organization supervised by the Ministry of Science, Technology, Innovation and Communications (**MCTIC**). It consists of four National Laboratories open to the scientific and technological communities, with competencies in biosciences, materials, renewable energies, and advanced instrumentation.

In the United States, **LBNL** positions itself as a leading basic sciences national laboratory. It is under the US DOE and its Energy Science activities encompass multiple scientific disciplines with major activities concentrated in Materials Sciences Division and Chemical Sciences Division. **ORNL** includes relevant and accessible scientific facilities in its Building Technologies Research and Integrated Centre and Carbon Fiber Technology Facility. At **SRNL** there is an Energy Materials Research Laboratory, while one of eight focus areas of **MITEI** is materials in energy and extreme environments.

6.4 General Features of the Energy sector

This chapter analyses findings from the responses for topics of common interest to the energy domain in the RISCAPE project, and which have been covered by the common methodology and questionnaire.

6.4.1 Type of organisation, financial aspects and time-horizon

The majority of interviewed RIs (nine RIs) receive funding (total or a major part) from the federal government. Some of them have a mixed funding scheme when the government (usually there are several governmental agencies or funding programmes) provides a major part of funding supplemented by the revenue from commercial contracts, industry, user fees or other foundations. The two RIs that stand out from this model are **JSC RIAR** and **Stanford Energy**. Though **JSC RIAR** is a state-owned company, it does not receive funding from governmental agencies, but finances its activities by getting revenue from commercial contracts for Russian and international clients (contracts on scientific research and development as well as production of radionuclides). At the same time, RIAR conducts its own research and acts as a scientific organisation (publishes its scientific articles, participates and organises conferences etc.). **Stanford Energy** receives funding for its activities mainly through donations and sponsorship.

Among the interviewed RIs, the lowest construction costs (€30 million) indicated were from **WindEEE**. For reference, the two ESFRI Projects on the current roadmap (2018) have indicated capital values of €7 and €20.5 million respectively. Centro de Desenvolvimento da Tecnologia Nuclear (**CDTN**) in Brazil and OPAL reactor at Australian Nuclear Science and Technology Organization (**OPAL**), both related to particular elements of the nuclear subdomain, have a similar order of magnitude in terms of construction costs (€300–€350 million). Including its nuclear research facilities, Brazilian Centre for Research in Energy and Materials would have construction costs in the order of €800 million. For comparison, **IMFIF-DONES, MYRHHA** and **JHR** in Europe have estimated construction costs from €700 to €1800 million. According to expert estimation, Japan Atomic Energy Agency (**JAEA**) has the highest both construction and operation costs among interviewed RIs with a possible construction cost (for the entire organisation) of a total of €100 billion.

All RI representatives (except **Stanford Energy**) mentioned that their organisation has either statutes or a business plan. The operational time horizon goes beyond a typical science project for most of RIs, except for **IPEN**, Brazil (the operational planning is done annually while a typical project lasts for 3–5 years) and **JAEA** (Japan). Only four RIs (**EME, PNNL, CNPM, OPAL ANSTO**) stated clearly that they receive multi-annual funding for their activities, though the time period varies depending on the organisation. **RIAR** also receives multi-annual funding (commercial contracts can run for a period of up to 10 years), but it does not have secured state funding. However, according to RIAR's expert "The functioning of JSC "**SSC RIAR**" as the main industrial centre of ROSATOM for conducting scientific research is guaranteed". **OPAL** reactor at Australian Nuclear Science and Technology Organization seems to be the most stable research infrastructure in terms of funding.

Construction costs

An indicator of construction costs for RIs in different subdomains, as suggested by our research:

- Renewables: €5–€50 million
- Specific nuclear facilities (e.g. synchrotrons): €300m–€1800 million
- Carbon Capture, Storage and Utilization: €1 billion
- Nuclear, large-scale: €5–€100 billion

Surprisingly, some of nationally important RIs do not receive multi-annual funding. For example, for **CDTN** and **IPEN** (both from Brazil), although these are strategic infrastructures, there is no existing long-term financial commitment from the government. Funding decisions are negotiated yearly and depend on government approval.

> **At the time of building the Australian government committed to funding the RI during the entire lifetime of the research reactor.**

6.4.2 Mission statement, focus goals and challenges

Experts from all organisations within the nuclear energy subdomain mentioned that their organisations exist on the national or international roadmap. Thus, JSC State Scientific Centre Research Institute of Atomic Reactors (**RIAR**) belongs to **ROSATOM** state corporation, therefore **RIAR** should follow all strategic goals identified by the mother organisation[3]. In Brazil, all three organisations contacted are included in Federal Government Plan[4]. Japan Atomic Energy Agency (**JAEA**) is incorporated into the Strategic Energy Plan of Japan and also in a Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1–4[5]. Australian Nuclear Science and Technology Organization (**ANSTO**), with its major facility – **OPAL** reactor – is mentioned in Australian National Research Infrastructure Roadmap 2016[6]. On this roadmap **OPAL** is given Landmark Infrastructure status.

On the contrary, organisations related to renewables, energy systems integration and efficient energy conversion and use subdomains, according to experts' responses, were not mentioned in any national or international roadmap. Most organisations' representatives were able to provide mission statements for their organisations (with the exception of the Research Institute for Energy Conservation, The National Institute of Advanced Industrial Science and Technology in Japan).

Some international RIs have a mixed research portfolio, therefore they may conduct research in various areas of energy research simultaneously. Therefore, respondents found it difficult to make comparisons on complementarities with European RIs, which have more focus on a single subdomain. For example, experts from **PNNL** (USA), **CDTN** (Brazil) had difficulties to describe how their organisation differs from European RIs, due to the diversity of research programmes. The expert from **EME** (Canada) compared the organisation with similar European organisations. This may also help to explain why some organisations may find it difficult to fit into a research infrastructure roadmap.

For some nuclear facilities (**RIAR** and **ANSTO**), the use of reactor facilities and laboratory equipment is, to varying degrees, limited to internal personnel. In practice, this blurs the lines between physical access and remote access, and perhaps falls somewhere in between.

The share of usage available for external RIs vary. **RIAR**, **Wind EEE** and **OPAL** (**ANSTO**) mentioned that 95%–100% of their services are available to external parties and that actual usage also is very high (about 100%). Respondents from AIST, EME and PNNL state that less than 25% of services are available to external parties. EME also notes that actual usage is very low, but that collaborative arrangements are under development. About half of the RIs find it hard to define the current level of usage of their services, because it varies from service to service and from laboratory to laboratory. One organisation (**CDTN**) also noted that facilities are open for access from European researchers, but that usage would be higher if the demand was also higher. RIs grant access to services on both peer-reviewed and commercial bases. Respondents from **PNNL**, **CNPEM**, **JAEA** and **OPAL** RIs note that the access to their services and facilities is determined by a peer review process. At **OPAL**, access on a commercial basis is also possible. That requires fee for access, and involves a different procedure for granting access, compared to a peer-reviewed process. **RIAR** and **IPEN** also grant access on a commercial basis, albeit with certain quality-control procedures.

Best-case examples of public information on services and access

Though most websites of RIs contain comprehensive information, relevant information is often scattered. However, some good examples are found among our respondents.

- *Service catalogue*: **EME, Canada** presents the service catalogue of the organisation in a structured way, encouraging researchers who are looking for collaboration possibilities: https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/energy-mining-environment-research-centre
- *Access*: **JAEA, Japan** has a clear and publicly available detailed explanation of the procedure for getting access to shared facilities https://tenkai.jaea.go.jp/facility/3-facility/05-support/jaea-facilities-eng.html

[3] ROSATOM "Strategic goals 2030. Corporation of knowledge. Corporation of the future" (in Russian) http://niiar.ru/sites/default/files/rosatom_strategy_17-08-17_1.pdf

[4] CNEN "PROGRAMA POLÍTICA NUCLEAR PPA 2016–2019 E LOA 2016" www.cnen.gov.br/images/cnen/documentos/planejamento/ProgramaPoliticaNuclear-PPA-2016-2019.pdf

[5] Ministry of Economy, Trade and Industry "Cabinet Decision on the New Strategic Energy Plan" http://www.meti.go.jp/english/press/2018/0703_002.html; Ministry of Economy, Trade and Industry "Mid-and-Long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 14" http://www.meti.go.jp/english/earthquake/nuclear/decommissioning/index.html

[6] Australian Government "2016 National Research Infrastructure Roadmap" https://docs.education.gov.au/system/files/doc/other/ed16-0269_national_research_infrastructure_roadmap_report_internals_acc.pdf

6.4.3 Data policies

Among respondents, the number of RIs claiming that they have an existing data policy is almost equal to the number of those claiming the absence of data policy. In some RIs, data regulations may differ from project to project, while one RI responded that they have different approaches to data licensing for external and internal researchers. It was a general experience from the research phase of this chapter that questions about (formal) data policies did not receive the same attention as they might receive from European RIs at this point in time.

6.4.4 Scientific and socio-economic impact,

The majority of respondents note that scientific impact is followed either by the research infrastructure itself or by third parties (an almost even split in the energy domain). Many RIs also publish annual reports on their scientific achievements on-line.

While scientific impact appears regularly followed, generally RIs provide very little information on how they follow the socio-economic impact. The experience of **RIAR** (Russia) showcases an example of how a research infrastructure may see its socio-economic impact. The expert from **RIAR** explains that the organisation attaches high importance to the development of Dimitrovgrad city and Ulianovsk region (the city and the region where the RI is located). For RIAR it is important that the city would attract talented scientists. Indicators are, for example, health of citizens, average salary etc. The institute implements programmes to support social initiatives, sport events etc. Also, there is work under way with the city's authorities and regional professional associations. However, **RIAR** does not conduct systematic work to develop and monitor socio-economic impact indicators[7].

Another interesting example is **EME**, Canada, which claims that some of its programmes have certain targeted parameters set on the planning state of the programme. Apart from scientific impact (such as the number of publications), those targets may be related to socio-economic impact (for example, possible reduction of GHG emissions).

[7] This response from RIAR was somewhat surprising, as the publicly available annual report provides a very impressive framework of measurements which can be considered parts of socio-economic impacts. See e.g. the 2018 version: http://www.niiar.ru/sites/default/files/annual_report_riar_2018_pdf_0.pdf

It was clear from the research that many RIs attach great importance to the application of their researches to practice, benefiting the public through product updates, training programmes, and industrial upgrading. Among them, Hainan New Energy Research Centre, as part of the Institute of Plasma Physics, Chinese Academy of Science (**ASIPP**), is one example which forms a complete chain from basic researches to industrialisation. **NEDO** in Japan has been offering support for practical application in renewable energy and welfare equipment fields. **DBT-ICGEB** in India organises various workshops and training programmes. Centre of Excellence in Exciton Science, Australian Research Council recognises translating research into commercially viable products and services as one of its core drivers.

In addition to the regular services provided by most of the RIs, such as the access to the facilities and technological applications, some RIs also provide the government and the public with specific services in accordance with their missions and organisational structures.

6.4.5 International collaboration and partnerships with European organisations

Surveyed RIs already partake in collaborations with European researchers and organisations. Some respondents noted international organisations, such as ***EUREKA*** and ***IAEA***, as important for developing international partnerships. During the research phase on European RIs, the international alliance on Mission Innovation was also stressed as a key opportunity for strengthened research collaborations in the energy field.

OPAL stressed the well-established international research community in nuclear energy research, which allows researchers to more easily find and access necessary user facilities for their research purposes. The "international neutron community" is a well-functioning network in which researchers can e.g. temporarily relocate when facilities have planned downtimes. Researchers have previously relocated from OPAL to the UK, and in 2019 relocation of researchers from Paul Scherrer Institute in Switzerland was expected.

It was clear from interviews and research that many Energy RIs outside Europe are proud of their self-developed facilities (for example, in nuclear energy research), which can be served as complementary to the EU facilities. At the same time, they are happy to use technologies from the EU countries while improving their own facilities, and some of the non-EU RIs also attach great importance to the cooperation with the EU RIs. This was, for example, noted by highlighting their cooperative relationship with **ITER**.

For example, China has become largely self-sufficient in reactor design and construction, and relative to the rest of the world, one of its major strengths is the nuclear supply chain[8]. In South Korea, National Fusion Research Institute has constructed the world-class fusion research device named KSTAR with domestic technology. It also gets involved in the **ITER** Korea Project, which has a long timeline until 2042 and beyond. In Russia, **RIAR** cooperates with the EU by carrying out research for individual enterprises and scientific organisations in Europe on the basis of commercial contracts.

6.4.6 Plans to develop facilities

Among RIs, the following projects for the development of facilities were explicitly mentioned by respondents. At **RIAR**, Russia, several projects for upgrading research facilities are ongoing. (1) The first project aims to refurbish the fast test reactor BOR-60 that was commissioned in 1969. The lifetime of the test reactor is scheduled to extend until 2025. Plans also include improving safety and expansion of experimental capabilities, "to ensure the experimental substantiation of the main parameters of the IV Generation reactors". (2) The second project, planned for the years 2017–2020, aims to modernise the high-flux research reactor SM-3 and extend its lifetime until 2030 and beyond. As a project outcome, the reactor should improve its operational reliability and expand its experimental characteristics (in particular, to increase the number of high-flux cells for irradiation). (3) Finally, the third project is related to the construction of the new multipurpose fast test reactor **MBIR** and polyfunctional radiochemical research complex.

At **IPEN**, Brazil, the ongoing project is the construction of Brazilian Multipurpose Reactor. As mentioned in the progress report published on IPEN's website: "The Nuclear Reactor RMB will be an open pool type reactor with maximum power of 30 MW having the OPAL nuclear reactor of 20 MW, built in Australia, as a reference"[9].

[8] https://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

[9] IPEN "Brazilian Multipurpose Reactor. Progress report", p.373 https://www.ipen.br/portal_por/portal/interna.php?secao_id=2520&campo=10370

As explained by the representative of Australian Nuclear Science and Technology Organization, operating **OPAL** research reactor is currently in the "scoping stage" of planning upgrades to the facility. The planning stage is expected to last two years more and will be followed by eight years of building up to final commissioning in 2029.

According to the expert from **CNPEM, Brazil**, the project of Sirius, a synchrotron light source, is planned to be completed in 2020. Also, cryo-microscopy facilities were launched in 2018 at **CNPEM**.

A new facility related to energy material development is under construction at **EME, Canada**, according to experts. An expert from **PNNL, USA** has also mentioned that the laboratory plans to add new facilities, geographically extend facilities or do major upgrades in the organisation but did not give any specific information on which developments are planned.

6.4.7 Energy RIs: Reflecting changing societal needs

In Russia, **JSC "SSC RIAR"** was founded in 1956 as a nuclear testing centre, with facilities commissioned during the 1960s and 1980s. Currently, following the Strategy for the Scientific Development and Technological Development adopted by the Russian Federation, **JSC "SSC RIAR"** has a long-term horizon of planning, at least until 2035. It conducts nuclear research for the peaceful utilisation of atomic energy and the nuclear fuel cycle. Countries in Asia followed suit, building their own energy RIs in the 1950s and 1960s, coinciding with the important historical moments of the history of the region, including national independencies, the recovery of economy, the establishment of the national industrial systems and the beginning of modern scientific research in the countries included in this landscape analysis.

In Latin America, the investment in energy infrastructures also coincides with the important historical events of the region. Most energy infrastructures in Brazil, for example, were built between the 1960s and 1980s during the military dictatorship period. Although this period in Brazilian history was marked by high political instability and declining economic growth, it was a moment when Brazil heavily invested in urbanisation, transport and energy infrastructures.

Today many Energy RIs reflect the evolvement of research objectives from peaceful utilisation of nuclear energy to energy efficiency, energy storage and renewable energy technologies. Combating climate change and promoting a sustainable transformation of the energy systems have risen to the 'mission forefront', next to developing an abundance of energy and enabling economic prosperity of nations. Looking forward, we expect Energy Research Infrastructures to reflect this new reality. Priorities in the European Union from the SET-PLAN (Strategic Energy Technologies) roadmap for low carbon technologies to the ESFRI are already moving towards this. In terms of already established global Research Infrastructures, expected emphasises on renewable energy, smart energy distribution, sustainable mobility etc. cannot really be deducted yet, however. This could suggest major changes to the RI landscape in the coming decades. Another possibility is that Research Infrastructures – outside the nuclear energy domain – may not be as important an enabler of critical research in the energy domain as they may be in other domains.

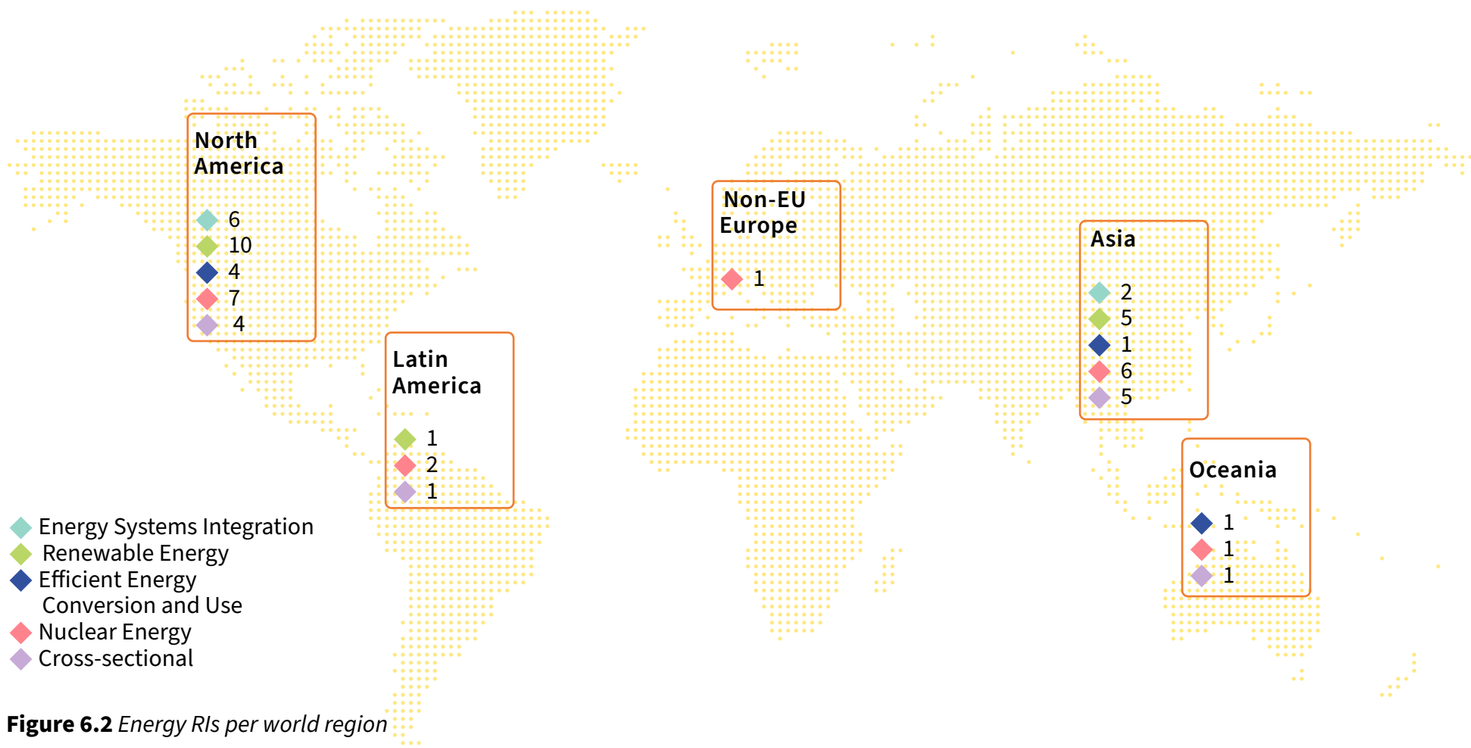


Figure 6.2 *Energy RIs per world region*

7. ASTRONOMY AND ASTROPARTICLE RESEARCH INFRASTRUCTURES

Main contributors
Carla Baldovin (ASTRON)
Marjan Timmer (ASTRON)
Rob van der Meer (ASTRON)
Rene Vermeulen (ASTRON)

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7.1 Domain overview

Astronomy has triggered human curiosity since ancient times. We have all stared at the night sky wondering "what is the extent of the universe?", or "are there other forms of life on distant planets?". Astronomical research pushes technological developments that help improve our daily lives: solar panels, magnetic resonance imaging scanners, global positioning satellites, just to name a few. Astroparticle physics is the "study of particles and radiation from outer space, and of rare, cosmologically significant elementary particle reactions" (OECD Report of the Working Group on Astroparticle Physics). This field is where astronomy, particle physics, and cosmology meet.

We are living in an exciting era for research in astronomy and astroparticle physics with hundreds of planetary systems discovered over the last 20 years, the exploration of our Solar System, the detection of gravitational waves, and the observation of the most energetic phenomena in the universe. In the 2010s, this field experienced a shift to multi-messenger astronomy; which is the observation of a single event almost simultaneously with different types of signals: neutrinos, charged particles, gravitational waves, and photons. This change has brought the astronomy and astroparticle physics communities closer together.

Astronomy and astroparticle physics belong to the physical sciences and engineering field as defined by ESFRI. These two fields are distinguished by the following of the natural classification by wavelength for astronomy, and the ASPERA (Astroparticle Physics Roadmap Phase I) classification for astroparticle physics.

Astroparticle physics is an interdisciplinary field between particle physics and cosmology. It attempts to reveal the nature and structure of matter in the universe. Astroparticle physics has evolved very quickly from an (almost) purely theoretical to an experimental science. Over the last three decades technological development has made it possible to observe these phenomena, opening a new window into the cosmos. The astroparticle physics address science questions as dark matter, neutrinos, high-energy universe, and gravitational waves.

The division in astronomy comes from the very different technical requirements of observations done at different wavelength regimes. The atmosphere is completely opaque at short wavelengths (X-rays, UV), visible light and near-infrared provide a window of transparency, allowing observations from the ground. Towards longer wavelengths the atmosphere becomes again almost completely opaque with some small windows of semi transparency between the mid-infrared and mm regime. At cm and m wavelengths it becomes again completely transparent. This intrinsic characteristic of the atmosphere makes the detectors, technology and methods used in the different wavelength regimes completely different. On the other hand, the science questions studied by astronomers can be tackled using a multi-wavelength approach, meaning using signal at different wavelengths.

Gravitational waves

Gravitational waves is a relatively new experimental field. The first-generation large gravitational-wave detectors started operations in mid-2000. The technology is currently in its second-generation. Both, the European **VIRGO** and the US-based **LIGO** are now operating with new technology and **KAGRA** is under construction in Japan and will soon become operational (2019). The new era of gravitational-wave astronomy will be characterised by the observation of gravitational-wave events using the global network of detectors. International collaboration will become intrinsic to gravitational waves research. In fact, there are standing collaborations between the three main facilities: **KAGRA**, **LIGO** and **VIRGO**.

7.2 The methodological approach

The analysis of the landscape of Research Infrastructures (RIs) in astronomy and Particle Physics, start from the European Landscape as mentioned in the RISCAPE methodology chapter 2.

The astroparticle physics community tends to follow a model where facilities are exploited by the consortium that built them. This means that the access to the experiments and - in many cases - also to the data, is restricted to researchers inside the collaboration. Astronomy on the other hand, has a longer tradition of facilities being open to the scientific community. A facility might be built by a restricted consortium but there are opportunities for scientists outside the consortium to request observing time, and the data becomes public after an embargo time (typically one-year). The engaged European RIs include key facilities that have a limited access for outsiders.

A further domain-specific constraint is to exclude space missions. The large scale of funding required for any space mission would make it very difficult to compare with ground-based facilities and are outside of the ESFRI framework in Europe. Additionally, the RISCAPE RIs must be valid beyond the duration of the project. RIs that are not yet in operation but that are in construction or in an advanced preparation stage are included in the landscape analysis. This choice is consistent with the ESFRI landscape.

The list of European RIs engaged is based on several resources. The starting point was the ESFRI Roadmap 2016, where we also included the major RIs featured in the "Astroparticle Physics European Consortium (APPEC) Roadmap" (update 2016) and in the "ASTRONET Infrastructure Roadmap Update 2014". To complete the list, the Mapping the European Research Infrastructure Landscape (MERIL) database and the available European National Roadmaps were used, keeping in mind that the definition of RI used by the different countries does not necessarily correspond to the RISCAPE definition. For this analysis, large structures like ESO as organisations and its sub-structures, for example the Very Large Telescope (VLT), were considered.

Next to large RIs, a mature research community needs small RIs, since they are the basis upon which larger infrastructures develop. There is a significant number of them in Europe, in particular in the optical and infrared spectrum, and to consider all of them would make the sample too large for a landscape analysis in this framework. Therefore, smaller structures were grouped within larger RIs when possible. As an example, the National Laboratory of Gran Sasso (IT) hosts several experiments. For this analysis the Laboratory was considered to be an RI.

The facilities listed in the report by the European Strategic Review Committee (ETSRC) on Europe's 2-4 m telescopes over the decade to 2020 were not included. We also consulted the report by the European Radio Telescope Review Committee (ERTRC) and selected only the large pan-European facilities. Both the ETSRC and ERTRC committees were appointed by ASTRONET.

The ESO

The European Organisation for Astronomical Research in the Southern Hemisphere (**ESO**) is an intergovernmental organisation with 16-member states. **ESO** provides research facilities to astronomers with Headquarters in Germany and observing sites in Chile. **ESO** is a member of EIROforum, the European Intergovernmental Research Organisation forum that brings together some of the largest research organisations in Europe. In the context of RISCAPE, we considered the **ESO** facilities to be the Research Infrastructures.

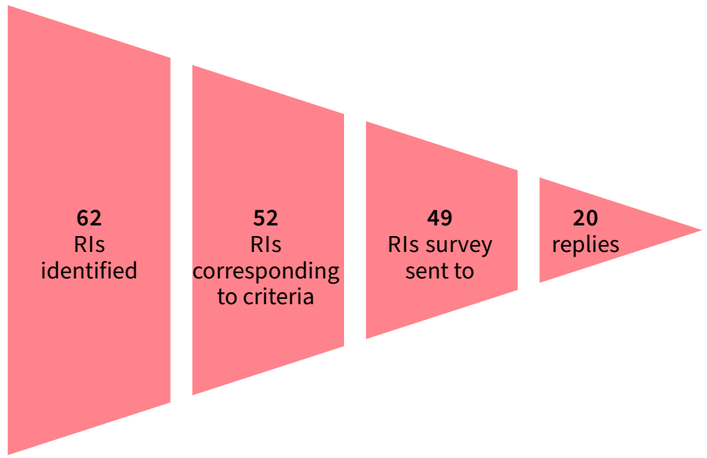
The aim of RISCAPE is to understand the international landscape in the individual disciplines covered by the project. Once the list of European RIs in astronomy and astroparticle physics was compiled, they were contacted to provide us with a list of non-European RIs that have similar technical capabilities and/or scientific goals. This initial list of international RIs was completed with a detailed research of science policy documents. Some of the documents consulted include the OECD Global Science Forum Report of Roadmapping of Large Research Infrastructures (2008), OECD Global Science Forum Report of the Working Group on Astroparticle Physics (2011), the OECD report on International Distributed Research Infrastructures: Issues and Options(2014) and national roadmaps such as the Report of the Working Group on Large Scientific Research Projects, Council for Science and Technology, Ministry of Education, Culture, Sports, Science and Technology-JAPAN (2017).

Each discovered facility received, to the contact person identified (spoke persons, directors, telescope scientist), an invitation e-mail to participate in the survey, explaining the scope of the study, the mechanism, and an estimate of the amount of time required to complete the survey and interview. Three contact attempts were done for each RI. In some cases, an alternative person was identified, thanks to the contacts already existing in the European network. A much higher probability of success in establishing contact was encountered when introduced by someone known by the contacted person.

Small-scale facilities

RISCAPE focuses on Research Infrastructures of pan-European scale. However, in this domain, small-scale facilities are crucial for the development of experimental or higher risk research programmes. They enable innovation and allow to perform science programmes that is complementary to the science offered by larger infrastructures.

The initial list of international RIs selected had 62 facilities. Among those, 10 were considered either not eligible for this study, for example because they were decommissioned/obsolete, or declined to participate. The main challenge faced during this study was to get the people in the targeted RIs interested in participating. In many cases, after an initial positive reply, it was extremely difficult to obtain a complete questionnaire or to schedule an interview.



Finally, the sample was reduced to 20 RIs for which we had a full questionnaire, validated either through an interview, or by e-mail exchange with the contact person. It is clear that this represents a limited sample of the global landscape of RIs in the field. Given the low number of completed questionnaires a complete statistical analysis of the results cannot be considered. However, we are confident that this sample is still representative of the current global landscape; since the sample has representation from a range of wavelength regimes and a good geographical coverage.

Geographically bound RIs

Astronomy is a field driven by the technical progress that allows us to have a larger collecting area (which means more light and therefore allow the detection of fainter and/or far away sources), and the capacity to process, store and distribute an ever-growing amount of data. The field is entering an era where the economic and technical effort required to build the new-generation facilities is too big for only one country. Facilities in astronomy and astroparticle physics are built in places chosen based on the natural conditions they offer, in order to optimise the performance of the instruments. The geographical distribution of RIs is therefore complex: the facilities and headquarters may be located in opposite sides of the world, often several countries are involved in one single Research Infrastructure.

7.3 Overview of the International landscape

Figure 7.1 shows the geographical distribution of the RIs considered in the study, specifying only the location of the headquarters. Astronomy and astroparticle facilities need to be in geographical locations with very specific conditions, such as a dry atmosphere, low interference from human activity, low background emission for neutrino studies, etc. In some cases, the RI headquarters are located in a different country from the location of the RI operational centre. For example, the Giant Magellanic Telescope (**GMT**) which is a collaboration between the US, Australia, Brazil, and Korea has its head office in Pasadena, US but the telescope will be located in Las Campanas, Chile. On the other side of the spectrum, we find clustered/grouped RIs. An example of this case is found in radio astronomy with the Very Long Baseline Interferometry technique. This technique uses the combination of multiple antennas separated by long distances, in order to act as a single and much larger telescope. As a result, the spatial resolution is enhanced and therefore the images obtained are much sharper.

In North America, there is a good representation of RIs. Sudbury Neutrino Observatory Laboratory (**SNOLAB**) is an underground science laboratory specialising in neutrino and dark matter physics. It's located two km below the surface in the Vale Creighton Mine near Sudbury Ontario, in Canada. The science programme of **SNOLAB** is focused on sub-atomic physics, and largely neutrino and dark matter research. The laboratory hosts experimental projects that are externally funded and provides the required services and scientific support for the successful completion of the projects. The Very Energetic Radiation Imaging Telescope Array System (**VERITAS**) is a ground-based facility for gamma-ray research, in the range between 50 GeV and 50 TeV. It is supported by funding from the US and Canada.

Laser Interferometer Gravitational-Wave Detector (**LIGO**) has two sites operated as a coherent pair, in the states of Louisiana (**LIGO Hanford**) and Washington (**LIGO Livingstone**). A third instrument is currently under construction in India (**LIGO-India**) with observations planned to start around 2025. LIGO is funded by the US National Science Foundation, and the detectors have also received financial support from Australia, Germany, and the UK.

The Thirty Metre Telescope (**TMT**) is projected to be located in the summit of Mauna Kea, Hawaii. The project is led by the US and has contributions from Canada, China, India and Japan. The Giant Magellan Telescope (**GMT**) is an RI currently in the construction phase by a consortium led by the US with participation from Australia, Brazil, and Korea. It will be one of the telescopes located in the Atacama Desert in Chile. TMT and GMT are RIs that belong to the optical-infrared astronomy sub-domain; they are new-generation telescopes with mirrors in sizes of 30 and 24.5 m each.

The Daniel K. Inouye Solar Telescope (**DKIST**) is a telescope with a 4-metre mirror telescope on the island of Maui, Hawaii, it is currently the largest telescope in the world dedicated to observing the Sun. **DKIST** operates in the optical and infrared domain and is part of the US National Solar Observatory.

The International VLBI Service for Geodesy and Astrometry (**IVS**) is a global collaboration to provide a service to support geodetic,

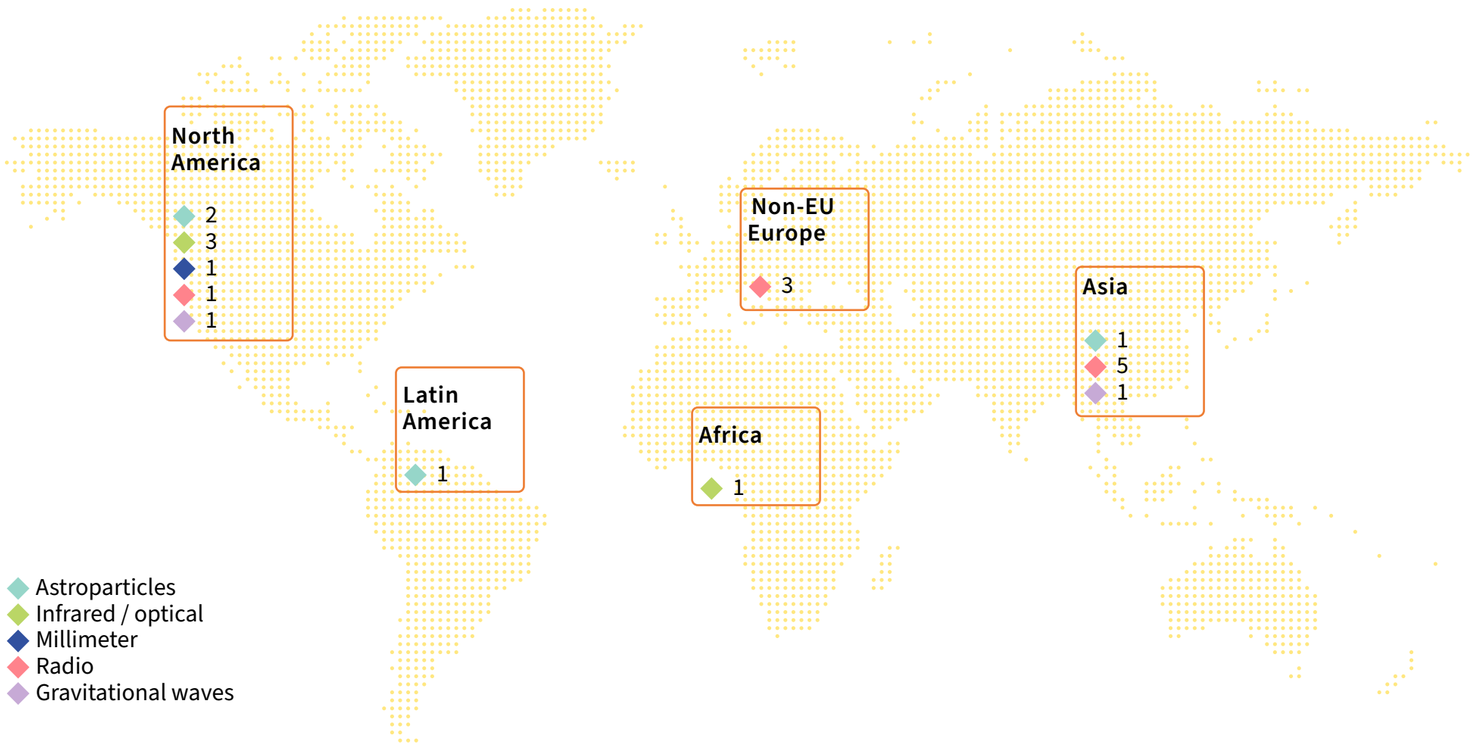


Figure 1.2 *Head office location of the responding Ris to the RISCAPE survey*

geophysical and astrometric research and operational activities. It is composed of about 40 institutions in 20 different countries and belongs to the radio astronomy sub-domain.

The Event Horizon Telescope (**EHT**) is a global enterprise that combines different telescopes around the world to create a virtual Earth-sized telescope in order to capture images of black holes. For this purpose, EHT uses telescopes operating in the mm and sub-mm wavelength domain. In 2019, the EHT revealed the breakthrough result of producing a direct image of a black hole by observing the centre of a massive galaxy (M87).

Africa is now gaining interest from the international community; South Africa will be one of the locations of the **SKA**, and there are efforts to bring the community up-to speed in preparation for this global facility. Collaborations with European countries are established, for example via training activities. The African VLBI Network is an example of community effort, which unfortunately did not respond to the survey. This initiative, led by South Africa, is looking to convert large dishes used for satellite telecommunications into radio telescopes. The countries in which upgrades are currently taking place or are planned are: Ghana, Zambia, Kenya, Mauritius, Botswana, and South Africa[1]. The Southern African Large Telescope (**SALT**) located in South Africa, is an optical telescope with a hexagonal primary mirror array 11 metres across, the largest single optical telescope in the Southern Hemisphere. **SALT** is owned by a consortium of international partners including South Africa (with approximately 30% of share), the US, New Zealand, Germany, Poland, the United Kingdom and India. The operations of **SALT** are contracted to the South African Astronomical Observatory (**SAAO**), the national centre for optical and infrared astronomy in South Africa.

Australia is well organised and there is a mature community. There are several facilities for radio astronomy operated by the Commonwealth Scientific and Industrial Research Organisation (**CSIRO**).

South America is another case with low representation in the survey. However, the high quality of its skies due to its very dry atmosphere and the low light pollution, make the Atacama Desert in Chile one of the preferred locations to install telescopes; for example, **VLT**, **Gemini South**, **LSST**, **ALMA**, and in the near future **ELT** and **CTA**, which are both ESFRIs. The western part of Argentina hosts the Pierre Auger Observatory aimed at the detection of cosmic rays. Auger is a collaboration of multiple countries with a strong involvement from Europe, receiving funding from the EU, the Czech Republic, France, Germany, Italy, the Netherlands, Poland, Portugal, Romania, Slovenia and Spain. The collaboration is also funded by Argentina, Australia, Brazil, Mexico, and the US. Given the important involvement of Europe in this RI, this was considered to be a European RI, although with strong international character. The only Research Infrastructure considered in our study that is both located in Latin America and funded by Latin American institutions is the Agua Negra Deep Experiment Site (**ANDES**), currently under construction in the Agua Negra tunnel between Argentina and Chile. This Research Infrastructure, when operational, will be the only deep experiment, not only in Latin America, but also in the Southern Hemisphere. It will be dedicated to the study of neutrinos, dark matter search, nuclear astrophysics, but also studies in biology and geology. The collaboration includes Argentina, Chile and Brazil; Mexico is also expected to join.

The VLBI Exploration of Radio Astronomy (**VERA**) in Japan is a network of radio telescopes that use the technique known as interferometry, where multiple single-dish telescopes are operated in coordination to observe the same astrophysical object. By combining the signals received by each individual telescope, astronomers can produce a virtual telescope which aperture is equal to the distance between the components. Thanks to this technique, scientists can obtain sharper images and observe fainter objects.

[8] https://www.ska.ac.za/science-engineering/avn/

The **KVN** and **VERA** Array (**KaVa**) is a RI that brings together the Japanese **VERA** and its South Korean counterpart. The countries have an agreement to develop projects using jointly both networks. At the same time, the network participates in the East-Asian VLBI network, a collaborative effort in the East-Asian region, currently consisting of 21 telescopes in the region. This is an example of how RIs from individual countries work together to boost their technical capabilities, this initiative also motivates scientific collaboration. The Kamioka Gravitational Wave Detector (**KAGRA**) in Japan, finalised its construction in October 2019. When operational, it will work in close collaboration with **VIRGO** and **LIGO**, the two major gravitational-wave detectors in Europe and the US. A memorandum of understanding between the three facilities has been signed.

The Five-hundred-metre Aperture Spherical radio Telescope (**FAST**) in China and the Giant Metrewave Radio Telescope (**GMRT**) in India are two RIs in radio astronomy. **FAST** is the largest single-dish telescope in the world with an aperture of 500 m. **FAST** is a facility of the National Astronomical Observatories, Chinese Academy of Sciences. The Large High-Altitude Air Shower Observatory (**LHAASO**) located in China, is an RI that belongs to the high-energy universe sub-domain. **LHAASO** has recently started operations as one of the most sensitive cosmic-ray facilities. The experiment consists of a multiple type of detectors; scintillator and underground muon detectors within an area of 1 km2 to detect TeV gamma-rays, and PeV cosmic rays. A large Cherenkov detector responsible for the TeV energy gamma and cosmic rays. In addition, 18 wide field of view telescopes to detect cosmic rays between sub-PeV to EeV energies.

GMRT is a network composed by 30 dishes of 45m diameter. **GMRT** belongs to the Indian National Centre for Radio Astrophysics (NCRA), that also operates a smaller facility. Approximately 70% of the annual budget of NCRA is dedicated to operations and maintenance of **GMRT**.

The Giant Ukrainian Radio Telescope (**GURT**), the Ukrainian T-shape Telescope (**UTR2**), and the Ukrainian Radio Interferometer (**URAN**), are three RI in radio astronomy from the Ukrainian Academy of Sciences.

7.4 Findings

Astronomy and astroparticle physics are collaborative fields. Large projects in astronomy require an effort beyond what a single country can afford. For example, projects that have similar scale than the European ELT, (e.g., **GMT, TMT**) are carried out through a collaboration between multiple countries.

7.4.1 Characteristics of the domain landscape

ESFRIs in Europe are divided into three different categories: single-sited, distributed and virtual. A single-sited RI is, as defined by the OECD, a unified body of equipment at one physical location, whereas a distributed RI is a network of distributed instrumentation or collections, archives and scientific libraries. The international RIs included in this domain were almost equally distributed over single-sited and distributed RIs. None of the international RIs were virtual.

One of the key parameters for RIs is to have a science orientation. However, many facilities also mentioned secondary or associated activities that come hand by hand with the main scientific activities. Research constantly pushes the boundaries of knowledge, and by doing so it unravels new questions that require, in many cases, new methods and techniques to be developed. In this way science helps to push further the technological development. Training, education, and outreach are very important aspects of the scientific activity and one of the main, and maybe the most straightforward contribution to society, but it is not the only one. In fact, there are many examples of scientific discoveries that have found application in our daily lives, the Charge Coupled Device (CCD) sensors used in astronomical instrumentation and now broadly used in (almost) every photographic camera, webcam, and smartphone is just one of multiple examples.

The longevity of the RIs give information about their maturity and long-term perspective, in terms of operations and funding and 14 out of 20 RIs indicated the expected lifetime of at least 5 years. It is important to remark that across all sub-domains and geographic distribution; funding decisions follow a cycle much shorter than the expected operational lifetime of the RIs. In most cases, funding is received on a 5-year basis, but the infrastructure expected operational lifetimes are longer than 10 years. In six cases, a lifetime longer than 45 years was reported.

The large majority of the RIs in the study receive public funding; only three of them, all in the US, mentioned to receive private funding in addition to public funding. Construction and operations budgets widely vary between RIs. Larger construction budget typically is typically connected with higher annual operation budgets. The operations costs cover a wide range of categories and cannot be easily compared between different RIs. In addition, many RIs received in-kind contributions, for example in some cases universities associated to a collaboration provide staff to support the operations of a RI, and these figures are not always reported as operational costs. In seven cases the RIs declared to belong to a larger organisation, in those cases the operation costs are included in the budget of the parent organisation. In the US a mix between private and public funding seems to be more common than in the rest of the world. The US National Science Foundation (NSF) has recently announced the creation of the Optical-Infrared Astronomy Research Laboratory (**OIR Lab**). This new structure will manage all of NSF's ground-based facilities operating in the optical-infrared domain, similar to the European **ESO**.

In the analysis, 14 RIs indicated having plans to add new facilities, geographically extend facilities or to do major upgrades in their organisation. This includes the facilities that are still under construction. Out of 14 RIs that are currently operational, 12 are planning upgrades or extensions. Five of these have already started or have secured funding. Another five RIs are planning to extend by adding new telescopes to their array.

Most RIs offer physical, virtual and/or remote access to the provided services. Peer review access is common practice in astronomy; scientist interested in using a facility write projects that are reviewed by an independent panel of experts. After projects are carried out, researchers can benefit from the exclusive rights to exploit the data during a certain period of time the embargo period. This time ranges usually from 12 to 18 months. At the end of the embargo period, the data become public to all the scientific community through a public database. Over half of the RIs surveyed provide access to services based on a peer review process. In other cases, access is determined by the advice from a committee of experts. In one case the RI was declared to be for exclusive service of the collaboration, but in that case access to the collaboration is open to any scientist willing to make a commitment, even if not financial contribution is done. RIs that have an open access policy have to provide a minimum level of

services to the users, and therefore need to have staff dedicated to these activities. These include daily operations of the experiment/observatory; developing tools and methods that allow users to exploit the scientific potential of the data (for example software), data processing (calibration, correcting for instrumental and natural effects, etc.), data curation and distribution, and user support. We find that 16 out of 20 RIs already have a publicly available data policy or are planning to have one once the RI is operational.

Eight RIs indicated that 95-100% of the RI's services are available to external parties. An additional five RIs have 25-95% available for external parties. Two RIs mentioned that they are not yet operational and therefore cannot provide the numbers. One RI (**EHT**) only provides access by special arrangement. Nine RIs estimated the percentage of services that are actually used by external parties. In six cases, the percentage actually used by external parties matched the proportion of RI's services that are available to external parties. In three cases, the percentage used was estimated at 30%, whereas the percentage available was 95-100%. European researchers can currently access the international RI's facilities by submitting a proposal, by joining an existing collaboration, by data access, by joining a working group, partnership or foundation or through another RI. Dependency on external service providers related to data transfer and storage was reported by 7 out of 16 RIs, and six RIs indicated providing key services to other facilities or RIs.

Five RIs indicated having additional quotas or limitations for external user access, these are: Open laboratory grants from CAS or National Resources (**FAST**); usage of facility limited to researchers affiliated or collaboration with TIO partner institutes (**TMT**); LSC membership required for data access (**LIGO**); number of experiments (but not users) is limited due to the available underground space (**SNOLAB**); the joining process requires approval from the collaboration meeting. This process is documented and open to the public (**KAGRA**).

7.4.2 Collaboration

A majority of the RIs included in the survey have existing collaborations with EU-based research organisations (17 out of 20). The Thirty Meter Telescope (**TMT**) is a large research infrastructure in astronomy (optical-infrared) that will soon start its construction phase. The project is led by the US and includes Canada, China, Japan, and India. There is no European involvement in **TMT**, in fact the **ELT** is an RI with similar technology and characteristics currently under construction by Europe (**ESO**) in Chile. However, there are informal contacts and collaboration between the EU and the US facilities, mainly regarding exchange of know-how and technology development solutions.

Another example is the Event Horizon Telescope (**EHT**).

> "The **EHT** is an international collaboration that has formed to continue the steady long-term progress on improving the capability of Very Long Baseline Interferometry (VLBI) at short wavelengths in pursuit of the goal to directly observe the immediate environment of a black hole with angular resolution comparable to the event horizon."

This RI includes 11 facilities worldwide, including telescopes and data correlation centres.

7.4.3 Scientific impact

Scientific impact is one of the criteria typically used to evaluate scientific activities; from individual researchers being evaluated based on their publication record, to accessing new working opportunities, to RIs being assessed by funding agencies. Scientific impact is an abstract construct and it can mean prestige but also popularity. RISCAPE attempted to understand impact in a broad sense, including scientific and socio-economic impact. For some of the RIs it is not possible to provide evidence of impact at this stage, because they are very new or not operational yet. Being present in a roadmap or strategic document is a clear sign of recognition for an RI; 11 RIs participating in the survey are present in a roadmap or strategic document in their country or at the international level. In a majority of cases, impact is an important aspect followed by funding agencies and also by the RIs themselves. This is done typically via the number of publications based on data from the RIs and by the number of citations that those publications get. In some cases, for example **VERA, KAGRA, LIGO**, it was specifically mentioned that external reviews are organised to assess the performance and quality of research done at the RIs. It was mentioned that the contribution to scientific publications is a measure of success for the funding agencies. RIs can use different means to demonstrate their impact (scientific and socio-economic), for example, by monitoring the work opportunities that are brought by the construction and operation of a facility, the number of projects submitted to the RI or, similarly, by the number of hours requested per semester/year, patents, participation of researchers at international meetings.

In general, RIs in this study pay a great deal of attention to measure their impact in their scientific domain, and to some extent, also to society. Monitoring of the RIs' activities is done internally, for example by collecting the number of users, proposed projects, web counters, number of publications, statistics on user distribution, etc. Only the RIs in Ukraine that are mentioned do not collect users' statistics because this is not requested or not considered necessary at the moment. Funding bodies usually consider societal impact in their evaluation.

7.4.4 Reflections

There is a great deal of similarity in how the RIs work within the different domains; astronomy, astroparticles, gravitational waves. Underground laboratories in astroparticle physics are usually providing the infrastructure, the scientific and technical support for science collaborations to perform their experiments. These are usually externally funded and are hosted for a definite period of time. There are no fundamental differences between the functioning of RIs in different geographical regions and domains.

Experimental gravitational waves research is a relatively new field. The first-generation detectors and experiments were typically run by closed collaborations and data remained private. But this practice has changed since the detection of gravitational waves, first recorded in 2015. New facilities are already working closely together through collaboration agreements and joint observing campaigns. The data are initially reserved to the collaboration but open to the broad scientific community within a short period. The first detection of an electromagnetic counterpart of a gravitational-wave event in 2017 supports the need for collaborative research. In fact, during this event, immediate observations were triggered at different telescopes around the world, confirming the need for an approach that uses information from different messengers, including electromagnetic radiation, neutrinos and gravitational waves, now known as multi-messenger astronomy.

8. SOCIAL SCIENCES RESEARCH INFRASTRUCTURES

Main contributors
Lorna Ryan (ESS ERIC)
Peter Elias (ESS ERIC, consultant)
Ivana Versic (CESSDA ERIC)

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8.1 Domain overview

The importance of the social sciences domain in the European research ecosystem is recognised, as is their international relevance:

> *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. 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 (ESFRI, 2018 Roadmap, p107,110)*

The social sciences domain in RISCAPE specifically focuses on social surveys and social science data archive Research Infrastructures. Currently, key pan-European RIs are **ESS ERIC** (social attitudes and behaviours); **SHARE ERIC** (health, aging and retirement); **CESSDA ERIC** (the consortium of social science data archives); and an emerging RI, Generations and Gender Project (family dynamics and relationships). Specific issues in the social sciences domain include data capture (response rates), data quality (methodological), data curation (technical) and data linkage (technical and methodological)[1].

Main characteristics of the social science (surveys and data archives):

- **Size**: The size of the social science domain is large and amorphous; the boundaries of the domain are relatively porous, a characteristic linked to the increasing availability of a range of data types (from administrative records to social media data).
- **Access**: The access arrangements of European based social science RIs are generally free of charge. ESS ERIC and CESSDA ERIC have data access policies that restrict access for commercial use but are otherwise free.
- **Integration with other RIs**: The social science RI domain has the potential to be related to other domains such as environment (for example, ESS ERIC carried questions about climate change in its survey round 8); SHARE ERIC collects biomaterial (blood spots). CESSDA ERIC deals with archiving and data services provided not only to social sciences, but to humanities and health sciences as well, with experimental dealing with geospatial or social media data.

	Full name	ESFRI status
ESS ERIC	European Social Survey	Landmark
SHARE ERIC	The Survey of Health, Ageing and Retirement in Europe	Landmark
CESSDA ERIC	Consortium of European Social Science Data Archives	Landmark
E-RIHS	European Research Infrastructure for Heritage Science	Project
GGP	The Generations and Gender Programme	Emerging

Table 8.1 *ESFRI Landmarks and Projects relevant to the domain, all are distributed RIs.*

The European landscape of RIs and key initiatives presented in Table 1 is tightly defined in respect of key pan-European surveys. EU funded studies, such as the European Quality of Life Survey and the EU Statistics on Income and Living Conditions are carried out by European agencies. **SHARE ERIC** and **ESS ERIC** have links with such agencies. Such links are ongoing and formalised in respect of specific initiatives; for example the Board of Strategic

[1] A technical issue is not simply about dataset access but is about data linkage. The Australian Public Health Research Network, for example facilitates cross-jurisdiction data linkage in Australia. Some data linkage for global projects may be subject to differing national laws.

Advice for the INFRA-DEV 3 Cluster Project, Synergies for Europe's Research Infrastructures in the Social Sciences (SERISS[2]) included representatives from the EU's European Agency for Fundamental Rights and European Foundation for the Improvement of Living and Working Conditions,[3] The landscape surveyed is a subset of the social sciences data landscape, in particular, quantitative social surveys and social science data archives.

A project focused on the sustainability of the European Social Survey ERIC, the **ESS SUSTAIN** project, had been undertaken with a view to identifying key initiatives. Similarly, **CESSA ERIC** undertook a project, CESSDA SAW (GA 674939), that involved a detailed mapping of existing data archives in the European Research Area as potential **CESSDA ERIC** Service Providers and key initiatives in the social science data archive domain. Since 2016, CESSDA has regular bi-annual widening events to monitor developments in non-member countries across Europe.

Five of the six ESFRI listed social sciences and humanities RIs progressed to achieve ERIC status (**ESS, SHARE, CESSDA, DARIAH** and **CLARIN**). Additional emerging RIs, such as **ERHOS**, described as a "central and distributed facility to promote and ensure cooperation and integration of data, technologies and policies", represent an emerging Research Infrastructure INGRID in 2019, but is not yet on the ESFRI Roadmap. **E-RIHS**, is the European Research Infrastructure for Heritage Science, that supports research on heritage interpretation, preservation, documentation and management (described in chapter 9). Another emerging infrastructure is the Gender and Generations Programme RI (**GGP**).

8.2 The methodological approach

A review of the MERIL database and of the RICH database enabled the discovery of RIs. The H2020 INFRA-DEV 4 funding supported both CESSDA SAW and ESS SUSTAIN (2015-2017). In both of these projects, systematic mapping of relevant initiatives, on an international scale, was undertaken. Where relevant, data gathered as part of the INFRA-DEV 4 projects are referenced in this RISCAPE domain report. Exploration of the international landscape was undertaken by reference to world regions. Documentary reviews of academic and "grey" literature, with follow-up internet searches and academic article checking activities were undertaken to identify key initiatives globally. Documentary review, for example of the publications arising from the work of the Group of Senior Officials (GSO) in respect of global Research Infrastructures, was undertaken. At the same time, policy review exercises were ongoing with particular reference to the European Union. A project focused on the sustainability of the European Social Survey ERIC, the **ESS SUSTAIN** project, had been undertaken with a view to identifying key initiatives. Similarly, **CESSA ERIC** undertook a project, CESSDA SAW, that involved a detailed mapping of existing data archives in the European Research Area as potential **CESSDA ERIC** Service Providers and key initiatives in the social science data archive domain. Since 2016, CESSDA has regular bi-annual widening events to monitor developments in non-member countries across Europe.

Some identified entities were contacted via their web-enabled contact email, others were emailed with a view to wider discussions about social science Research Infrastructures in their country, as well as to seek to engage them as respondents in the RISCAPE survey. This held for initiatives in China, in Japan and in India. In addition, contact was made with national research funding bodies and relevant "desks" of the EU External Action Service (e.g. EU-China Delegation) for background reference purposes. The non-response from contacts in Japan, China, India and from some of the key global initiatives suggests that the designation of the entities as Research Infrastructures was not appropriate, and language may have played a substantial role as the RISCAPE request was in English. Unlike the situation within most European countries, which cooperate voluntarily with the ESFRI to promote RIs in the social sciences, most of the three countries reviewed in this report do not provide a mechanism to list such RIs. In the absence of any definitive lists, the approach was adopted to search for relevant RIs and contact those operating such facilities to obtain information about their structure, funding, user base and sustainability. Internet and documentary review contact with coordinating organisations and reference to completed mapping exercises enabled the creation of the listing.

[2] www.seriss.eu
[3] https://seriss.eu/who-is-involved/board-of-strategic-advice/

8.3 The International landscape

Within Europe, and within regions across the world, there is a large number of social surveys. Similarly, in respect of cross-national surveys, there is an ever-increasing number; the International Social Science Council lists 81 cross-national surveys[4] in its "survey of international surveys". These surveys are classified by their empirical and substantive foci (attitudes and values; elections; living conditions; literacy and skills; elite studies; and crime). These are then subdivided into studies which are ongoing and those which have ceased. For each one of the 81 cross-national surveys there is a three to four-page synopsis and a link to the project website. The characteristics of the individual social surveys (within country) vary. Bilateral type arrangements between the European RIs and individual surveys/initiatives exist, for example, for **ESS ERIC**, the ESS Related Studies approach is in place. Similarly, the Generations and Gender Project has "related studies", and **SHARE ERIC** has a set of "sister studies." As noted above, the focus of the activity project has been on the social surveys and social science data archives. Due to the challenges of Research Infrastructure definition in this field, listings in this section includes organisations that are government bodies and other organisations and so not usually identified as a Research Infrastructure; however, its inclusion points to how such entities share characteristics with RIs, providing facilities for the scientific community. The international landscape of social surveys and social science data archives includes pan-national initiatives that would not accept categorisation as Research Infrastructures.

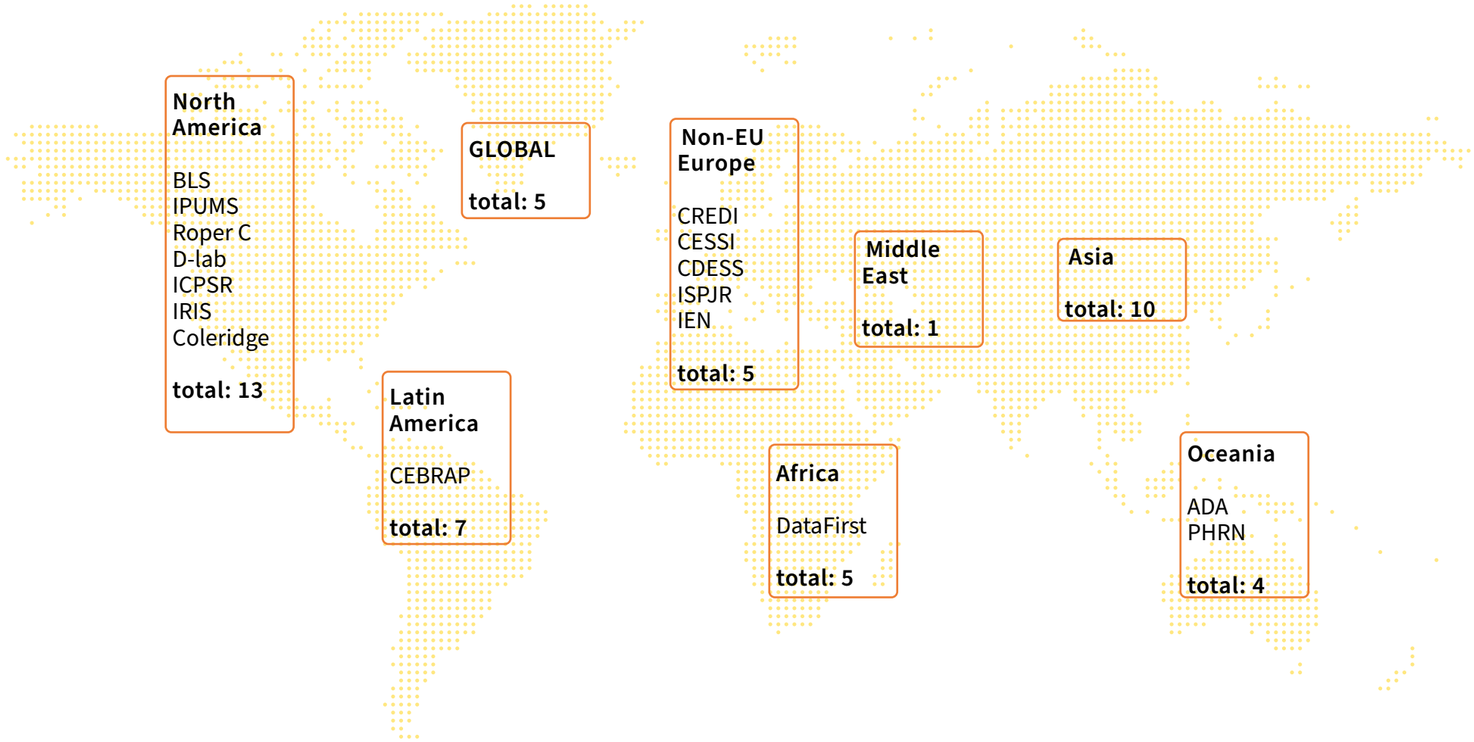

Figure 8.1 *Social Science infrastructures and initiatives interviewed and total number of found SS initiatives in the area*

[4] http://www.worldsocialscience.org/resources/survey-surveys/

The Group of Senior Officials assessment of global Research Infrastructures recognises the existence of a range of RIs that exist within the international landscape:

- global single-sited: In the social sciences, there are no comparable global single-sited Research Infrastructures.

- globally distributed: In the social sciences, these include international surveys, for example the International Social Survey Programme (**ISSP**).

- national with internationalisation potential: National facilities of global interest are national facilities with unique capabilities that attract wide interest from researchers outside of the host nation. In the social sciences, there are a huge number of national initiatives with potential for internationalisation; the challenge is identifying particular complementarities.

Only 15 actual surveys were made, since most of the listed initiatives did not match the definition of a Research Infrastructure, and because of low response rate. Of the previously listed initiatives, the surveys were completed for Australian Data Archive (**ADA**), Population Health Research Network (**PHRN**), Institute of Economic Sciences Belgrade (**IEN**), Ss. Cyril and Methodius University in Skopje, Institute for sociological, political and juridical research (Macedonian social science data archive) (**ISPJR**), Center for Development Evaluation and Social Science Research (**CDESS**), DataFirst, Institute for comparative social research (**CESSI**), Coleridge Initiative at New York University (**Coleridge Initiative**), University of Michigan, Institute for Research on Innovation & Science (**IRIS**), Inter-university Consortium for Political and Social Research(**ICPSR**), University of California Berkeley Social Science Data Lab (**Berkeley D-Lab**), Roper Center for Public Opinion Research, Centro Brasileiro de Analise e Planejamento – CEBRAP, IPUMS University of Minnesota (**IPUMS**), and the US Bureau of Labor Statistics (**BLS**).The RIs and key initiatives responding to the RISCAPE survey were a mix of distributed, single-sited and virtual entities, for example, the US IPUMS is a single-sited RI; the Australian Population Health Research Network is a distributed RI, with supported facilities distributed across Australia; the Australian Data Archive (**ADA**) is a digital data archive, as is the US Roper Centre for Public Opinion Research (a web-based, digital service provider). Even a government organisation, the US Bureau of Labor statistics, was included to show how such entities share characteristics with RIs, providing facilities for the scientific community. Of these 15 initiatives, 2 are listed on existing national Research Infrastructure roadmaps, both in Australia's National Collaborative Research Infrastructure Strategy.

Global initiatives, such as the Cross–national equivalent file (**CNEF**), exist, with a range of international partners and accessible via national nodes, which contains equivalently defined variables for the British Household Panel Study, the Household Income and Labour Dynamics in Australia, the Korea Labor and Income Panel Study, (new this year), the Panel Study of Income Dynamics, the Russia Longitudinal Monitoring Survey, the Swiss Household Panel, the Canadian Survey of Labour and Income Dynamics, and the German Socio-Economic Panel.

Global surveys initiatives cover a significant part of the global population. The World Values Survey (**WVS**), is a global network of social scientists studying changing values and their impact on social and political life. Its secretariat is based in Vienna. The survey seeks to use the most rigorous, high-quality research designs in each country. The WVS consists of nationally representative surveys conducted in almost 100 countries which contain almost 90% of the world's population, using a common questionnaire. The WVS is the largest non-commercial, cross-national, time series investigation of human beliefs and values ever executed, currently including interviews with almost 400,000 respondents. Gallup World Poll (**GWP**) tracks the most important issues worldwide, such as food access, employment, leadership performance, and wellbeing. With some exceptions, all samples are probability-based and nationally representative of the resident population aged 15 and older. International Social Survey Programme **ISSP** is a cross-national collaboration programme conducting annual surveys on diverse topics relevant to social sciences, with members covering various cultures around the globe. Its institutional members, each of them representing one nation, consist of academic organisations, universities, or survey agencies. Global Barometer Surveys (**GBS**) is a collaborative research project consisting of six regional barometers. It is the first comprehensive effort to measure, at a mass level, the current social, political, and economic climate around the world. It provides an independent, non-partisan, scientific and multidisciplinary view of public opinion on a range of policy-relevant issues. Currently, the **GBS** network covers 70% of the world's population and is still expanding.

A number of regional survey initiatives exists. **Afro-barometer** is a survey research project that measures citizens' attitudes on democracy and governance, the economy, civil society, to give the public a voice in policy making. Surveys and other activities are carried out by a network of national partners in over 30 countries. There are four core partners – Ghana Centre for Democratic Development; Institute for Development Studies, University of Nairobi; Institute for Justice and Reconciliation; and Institute for Empirical Research in Political Economy, with two support units (Michigan State University, US, University of Cape Town, SA). **Latinobarómetro** conducts an annual survey in 18 Spanish and Portuguese speaking countries, using representative samples. **Arab Barometer** is a regional public opinion survey established in 2005 and conducted in the 12 Middle Eastern countries Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Palestine, Qatar, Saudi Arabia, Sudan, Tunisia, and Yemen. The first wave was conducted from 2006-2008. **Asian Barometer** includes 14 countries and territories in East and South East Asia. It uses the Global Barometer Survey as the model and is administered by country teams. East Asian Social Survey (**EEAS**) is a biennial social survey that aims to produce and disseminate academic survey datasets in East.

In North America, a number of significant national surveys, centres, and services are found. The Labor and Work-life Program (**LWP**) is Harvard University's (US) centre for research, teaching and creative problem solving related to the world of work and its implications for society. **LWP** organises projects and programs that (1) examine critical changes in labour markets, labour law, and the experiences of working people and (2) analyse the role of advocates, unions, worker organisations, business, and government in improving the quality of life. The **Health and Retirement Study** is a longitudinal is a longitudinal panel study that surveys a representative sample of approximately 20,000 people in America, sponsored by the National Institute on Aging and the Social Security Administration. It is undertaken by the Survey Research Centre at the University of Michigan's Institute for Social Research. National Opinion Research Center (**NORC**), at University of Chicago conducts research in five main areas: Economics, Markets, and the Workforce; Education, Training, and Learning; Global Development; Health and Well-Being; and Society, Media, and Public Affairs. University of Minnesota, **IPUMS**-International (**IPUMSi**) is dedicated project to collecting and distributing individual and household level census data from around the world. The goals are to collect and preserve

data and documentation, harmonise data, and disseminate the harmonised data free of charge. Currently, census data from 94 countries, with 365 censuses and over one billion person records are available. **ICPSR** (International Consortium for Political and Social Research) is the one of the leading data archives in the USA for access to social and economic data. Currently there are nearly 800 institutions and approximately 30 US agencies contributing data. The Institute houses over 11,000 separate studies with 5.3 million variables. ICPSR is a trusted digital repository, having gained CoreTrustSeal accreditation. The **Center for Open Science**, based in Charlottesville, Virginia, aims to provide researchers with shared tools, space to deposit projects (source code, working papers, interim results, etc.). The **Coleridge Initiative** is aiming to use data to transform the way governments access and use data for the social good. The infrastructure itself is a secure remote access facility, which provides access to and use of confidential microdata, and associated training programs Coleridge has partnered with a variety of universities. The Institute for Quantitative Social Science (**IQSS**) in Harvard, works to transform social science research from the art of studying the greatest problems that affect human societies to the science of understanding and solving these problems. Institute for Research on Innovation and Science (**IRIS**) is a consortium of universities, and a data repository hosted at the University of Michigan. It collects record level administrative data from its members to produce a de-identified dataset for research and reporting. The National Bureau of Economic Research (**NBER**) is a private, non-profit, non-partisan membership organisation dedicated to conducting economic research and to disseminating research findings among academics, public policy makers, and business professionals. Their focus areas include developing new statistical measurements, estimating quantitative models of economic behaviour, and analysing the effects of public policies. Access to research resources via the NBER requires the applicant to have a research link with the NBER, usually via research cooperation with a member. The **Bureau of Labor Statistics** houses the largest collection of data relating to the labour market in the US, most which can be accessed via the Datafinder crosstabulation device. Access to person and household level data is possible but under restricted access conditions. The **Roper Center** states in its mission to collect, preserve, and disseminate public opinion data; to serve as a resource to help improve the practice of survey research; and to broaden the understanding of public opinion through the use of survey data in the United States and around the world. UC Berkeley **D-Lab** promotes research links with the global social science research community, but its primary focus is on building research capacity within the Berkeley science community. D-Lab provides cross-disciplinary resources for in-depth consulting and advising, access to staff support, and training and provisioning for software and other infrastructure needs.

The Brazilian **CEBRAP** (Centro Brasileiro de Analise e Planejamento) is an independent research institute based in Sao Paulo, with links to researchers in universities across Brazil. It provides access and research support to many of the key datasets held at the IBGE (Brazilian Statistical Institute) and by other departments of state and national government. The Brazilian Institute of Geography and Statistics - **IBGE** is the provider of data and information, which meets the needs of the most diverse segments of civil society, as well as federal, state and municipal government agencies. IBGE offers a complete and current view of the country through the performance of its main functions, including statistical, geographic and environmental information, and dissemination and mapping services. **DIEESE**, Inter-Union Department of Statistics and Socio-Economic Studies was born from struggles led by Brazilian trade unions. Most national workers confederations and federations as well as main trade unions are affiliated to **DIEESE**, being at the top of it and contributing to its support, taking profit of its services and scientific production. Currently there are more than 700 entities affiliated to DIEESE. **ELSI-Brazil** (The Brazilian Longitudinal Study of Aging) is a longitudinal, home-based survey, conducted in a nationally representative sample of older adults. The research aims to examine the social and biological determinants of aging and its consequences for the individual and for the society.

The National Institute of Statistics and Censuses (**INDEC**, in its Spanish acronym) is a public deconcentrated body of a technical nature in Argentina, and which runs all the official statistical activities carried out throughout the country. Its responsibilities are to apply the statistical policy of the government; organise and run the National Statistical System, design the methodology, organise and run the national operations to gather and collect information through censuses and statistics, and to produce basic indicators and social and economic data.

The China Health and Retirement Longitudinal Study (**CHARLS**) aims to collect a high-quality nationally representative sample of Chinese residents ages 45 and older to serve the needs of scientific research on the elderly. The baseline national wave of **CHARLS** is being fielded in 2011 and includes about 10,000 households and 17,500 individuals in 150 counties/districts and 450 villages/resident committees. The individuals will be followed up every two years. All data will be made public one year after the end of data collection. China Family Panel Studies (**CFPS**) is a nationally representative, annual longitudinal survey of Chinese communities, families, and individuals launched in 2010 by the Institute of Social Science Survey (ISSS) of Peking University, China. The purpose of the Chinese Household Income Project was to measure and estimate the distribution of personal income in both rural and urban areas of the People's Republic of China. Data were collected through a series of questionnaire-based interviews conducted in rural and urban areas in 1988, 1995, 2002, and 2007. Chinese National Survey Data Archive, Renmin University of China (**CHSDA**) hosts data sets from major longitudinal and cross-sectional studies in mainland China on social, economic and political topics, such as the Chinese General Social Survey.

The Japanese General Social Surveys (**JGSS**) Project is a Japanese version of the General Social Survey project closely replicating the original GSS. Japanese Study of Aging and Retirement (**JSTAR**), a panel survey of elderly people aged 50 or older conducted by the Research Institute of Economy, Trade and Industry, Hitotsubashi University, and the University of Tokyo. Detailed survey results as well as information regarding the use of the microdata collected in the survey are made available to researchers belonging to universities and/or research institutes. The Social Science Japan Data Archive (**SSJDA**) is located in "Information Centre for Social Science Research on Japan". It collects, maintains, and provides access to the academic community, a vast archive of social science data (quantitative data obtained from social surveys) for secondary analyses.

The Australian Data Archive (**ADA**) is a Core Trust Seal certified repository, based in the ANU Centre for Social Research and Methods at the Australian National University (ANU). **ADA** was established in 1981 with a brief to provide a national service for the collection and preservation of digital data relating to social, political and economic affairs and to make these data available for further analysis. The National e-Research Collaboration Tools and Resources project (**Nectar**) provides an online general infrastructure (see also chapter 10 e-infrastructures) that supports researchers to connect, collaborate and share ideas and research outcomes.

Lately, Nectar was merged with RDS (see Australian Research Data Commons - ARDC). Population Health Research Network (**PHRN**) is a national network of data linkage units, a secure data laboratory and e-research services which support researchers access to linked population data, included on the Australian Government's National Research Infrastructure Roadmap (2016). National Research Data Storage Infrastructure is a cost-effective, scaled up, shared research data storage services provided through Research Data Services (RDS) that are aimed at improving research collaboration through the storage and provision of access to research data collections of national significance The Research Data Services (RDS) project is a continuation of foundations project the Research Data Storage Infrastructure. **Life in Australia**, a project of the Social Research Centre of Australian National University exclusively uses random probability-based sampling methods and covers both online and offline population. Results from surveys are generalisable to the Australian population and the sampling approach ensures that sampling errors and confidence intervals can be calculated. Panel members are randomly recruited via their landline or mobile phone and provide their contact details so that they can take part in surveys on a regular basis. Life in Australia hosts standalone and omnibus surveys.

DataFirst is a research data service dedicated to giving open access to data from South Africa and other African countries. They provide the essential Open Research Data infrastructure for discovering and accessing data and by developing skills among prospective users, particularly in South Africa. The South African Data Archive at the National Research Foundation serves as a broker between a range of data providers (for example, statistical agencies, government departments, opinion and market research companies and academic institutions) and the research community. Additional RI like services can be considered from **Statistics South Africa** statistical systems for evidence-based decisions. The South African Social Attitudes Survey (**SASAS**) is a nationally representative, repeated cross-sectional survey that has been conducted annually by the Human Sciences Research Council since 2003. The survey series charts and explains the interaction between the country's changing institutions, its political and economic structures, and the attitudes, beliefs and behaviour patterns of its diverse populations. Designed as a time series, SASAS is increasingly providing a unique, long-term account of the speed and direction of change in underlying public values and the social fabric of modern South Africa. The African Population and Health Research Center, with an office in Nairobi, Kenya, is generating evidence to drive policy action to improve the health and wellbeing of African people. It is African-led global research centre concentrated on research on Aging and Development; Education and Youth Empowerment; Health and Systems for Health; Maternal and Child Wellbeing; Population Dynamics and Sexual Reproductive Health and; Urbanization and Wellbeing in Africa. They also provide data, measurement and evaluation systems and capacity.

Based on the activities of the Data Center Serbia for Social Sciences (**DCS**), the Institute of Economic Sciences of Belgrade became a service provider for CESSDA ERIC. By supporting the development of the Center, researchers in social sciences have been given the opportunity to store and download microdata collected in primary research, in accordance with the provisions of the Platform for Open Science. The Institute for Sociological, Political and Juridical Research (**ISPJR**) in Skopje, North Macedonia, was founded in 1965 with the decision of the Council of the University "St. Cyril and Methodius". Since then, the **ISPJR** is devoted to scientifically examine the sociological, political and legal phenomena in the country, to encourage and to organise appropriate researches for social development, to educate young scientist and to develop scientific staff.

The Centre for Development Evaluation and Social Science Research (**CREDI**) in Sarajevo, Bosnia and Herzegovina, is an independent, non-profit and non-partisan think tank. They act in policy evaluations, as well as research in social sciences and host **Analitika** a non-profit, non-governmental organisation, established in July 2009. The mission of **Analitika** is to enhance the public policy process by conducting socially relevant, high-quality research. In its research, the organisation places great importance on the application of contemporary research methods, analytical capacities, competence and experience of its researchers, as well as rigorous external peer review procedures for its publications. **Analitika's** areas of research include rule of law, public administration reform with a focus on local self-government, and media and communication.

CESSI (Institute for comparative social research) is a marketing, public opinion and survey research organization in post Soviet region. They work in Russia, Ukraine, Belarus, Moldova, Kazakhstan, other Central Asia and Transcaucasian countries. CESSI offers field services in different survey modes and different samples (general population - national, regional, municipal samples, special groups of population – customers, stakeholders, government, media, business clients and providers, in hall testing).

European **SHARE ERIC** has connections with **LASI**, the Longitudinal Aging Study in India, a US supported he nationally representative, longitudinal survey to examine aging and retirement among India's 45+ population, **KLoSA** -The Korean Longitudinal Study of Aging survey subjects of appx. 10,000 middle/old-age population (45 or older) nationwide. Basic survey for **KLoSA** will be conducted every even-numbered year, mostly using the same survey categories. Topics under **KLoSA** include those that are deemed to have an impact on the economic and social activities of the middle/old-age population. The Mexican Health and Aging Study (**MHAS**) is a national longitudinal study of adults 50 years and older in Mexico. The baseline survey was conducted in 2001 with follow-up interviews in 2003, 2012, 2015, and 2018. A new sample of adults born between 1952-1962 was added in 2012. Similarly, in 2018 a new cohort of adults born between 1963 and 1968 was added to refresh the sample.

8.4 Discussion

8.4.1 Robustness of data analysis

Declining response rates is a phenomenon affecting the robustness of data analysis and affects all social surveys and has relevance not only for academic surveys but also for commercial entities. Monitoring and ensuring data quality is an ongoing methodological challenge. The data curation and data linkage issues are both technical and methodological and, in addition, raise complex legal challenges, particularly in relation to data protection arrangements. Social surveys lack harmonisation and operationalisation of concepts to enable comparison between surveys. This is a both a methodological and a substantive challenge in terms of complementarity. The main area of change, of potential gaps and challenges relate to "big data". In addition to technical challenges, the ESFRI Roadmap considers that "The use of Big Data also bears new methodological challenges with implementation for empirical research: the implementation of surveys on emerging social trends in longitudinal perspectives can lead to important advances in epistemological and methodological fields". Beyond big data and

inter-disciplinarily, the direct needs of social survey and social science data archives identified by ESFRI include the need to address, as noted, the globally reported phenomenon of falling response rates; the need to maintain data quality and, in the context of data availability, the ability to link data from different sources and to make these available in a way that is consistent (such as in accordance with FAIR principles). European Research Infrastructures, such as **GGP, SHARE ERIC** and **ESS ERIC**, allow access to their datasets free of charge. Data Research Infrastructures in, for example, Australia, have a variable charging rate, depending on the access requested.

8.4.2 Compliance to FAIR principles

In terms of social science data archives, critical gaps and associated challenges relate to ensuring that data (and datasets) are FAIR and the technical challenges associated with each of the principles. Core challenges relate to existing human resources, technological infrastructures and support services (libraries, research institutes, and research information services). The Comprehensive Research Data Archive Mandate arises from a shared common interest of a variety of communities, including academic researchers, policy analysts, archivists, librarians, and producers of data; including a legislative framework to articulate the interests of these communities. Furthermore, development of data archiving services (DAS) in each country depend on the wider ecosystem of data sharing culture, organisational settings and service operational profile. Where the research data infrastructure is only emerging, it identifies promising candidate services[5].

8.4.3 Cost of operation and investments

The initiatives that responded ranged in size and level of funding. An outlier is the US Bureau of Labor Statistics that reported USD $615 m as the annual (financial year 2019) funding level. Research initiatives reported a range of funding levels – for operating costs the figure ranges from €30,000 to €13,5 m (this list excludes the US BLS). In social science terms, and in comparison, with the European RIs, the available data suggest that there is a higher level of funding allocated to the Australian and US initiatives than is the case in Europe. Construction costs – essentially, a question that aimed to assess the replacement (or replication) costs of the infrastructures identified.

The answers indicate the significant investment to date - the construction is at least the actual annual running/implementation cost, and the **IPUMS** estimated that while its annual costs were $12 m, construction costs were €200 m. In general, constructions costs were at least twice the annual costs. Significantly, respondents noted as an additive, “archive materials are invaluable” and that the reported costs for an infrastructure that is based in a university excluded the costs of use of “part of the university infrastructure”

Funding sources are various as well. From hosting universities (**ADA**) to project-based funding with a range of funding sources (national government, membership fees). The picture of funding sources contrasts with the European experience in which funding is largely public and relates, to philanthropic activities in the US. However, some commercial activity also takes place in some of the organisations. A critical issue is the funding timeline – All but one reported that it has a funding time horizon well beyond a typical science projects, however a range of modalities, from annual funding to 1-5 years of funding periods were identified. One infrastructure reported that each year, the replacement of ongoing research projects, meant that at least five new projects had to be brought in. In addition, especially a feature of US funding arrangements, private and federal funding had to be sought. The funding lifetimes are thus generally comparable to that in Europe. The implications of these relatively short period of agreed funding are of relevance to the sustainability of RIs internationally.

8.4.4 Data access and policies

A myriad of access arrangements exists, particularly relating to restricted datasets; some training is carried out in the physical building in which the initiative is based otherwise access arrangements to datasets are via the web. Commonly data access requires mediated processes, ethics and data custodial approval, however many of the organisations have completely open access to non-sensitive data. Only one initiative, the Institute of Economic Sciences, Belgrade reported that access is mainly determined using an independent peer review process that is excellent based. The rarity of this access arrangement is similar in European RIs. 9 of the 15 respondents reported that their access by external parties amounted to 75%+; five reported that access was under 75% and one reported that this question was not applicable (3 reported less than 25% access, one reported 25-50% and one reported 50 to 75%.) One respondent clarified that “we do make our services available to researchers outside our university on a fee for service basis” and so the access that the question captured is “free of charge access”. Of the respondents, 9 of the 15 reported that a data policy was in place, others noted the development of a policy. Around 40% reported they did not use open licenses for data produced in their organisation. Others reported the use of creative commons licenses for some outputs. Others reported that the IP was owned by the researcher: “We generally do not produce data. Data produced with the assistance of our staff is generally the property of the researcher.”

8.4.5 International collaboration

The opportunities for collaborative work were appreciated by respondents. **PHRN** (AUS) commented that there are a number of areas for possible collaboration between Australia and the EU on data linkage and we would be interested in any suggestions re suitable contacts or mechanisms to explore the possibilities. Most of the entities were national entities; only one, **IPUMS** (US) identified a global reach of its services, however most reported openness to European researchers access to services. The similarity or difference to European Research Infrastructures and similar initiatives was explicitly probed: Some responses indicated clear alignment to European RIs (especially CESSDA). Other respondents reported a lack of familiarity with European RIs or reported that there were no similar initiatives in Europe. Whether collaboration is possible was considered and respondents indicated their interested and provided specific instances of collaborations. There are also related possible collaborations with the ESS and SHARE infrastructures in the social sciences, and the recently announced Social Science and Humanities Open Cloud as well as more broad areas of collaboration

The international initiatives reported a number of partnerships with European bodies; for example, with CESSDA and with ESS ERIC; with national research bodies such as the UK Economic and Social Research Council. Others had arrangements with individual universities in different European countries. **IPUMS** (US) reported that the great majority of European national statistical agencies participate in IPUMS.

[5] CESSDA SAW D Deliverable 3.2 Country report on development potentials

8.4.6 Access policies

ICPSR (USA) noted: "Many European universities and research organisations are members of **ICPSR**, either directly or through a consortium, Researchers associated with member institutions can access our services. A large fraction of our data is available to non-member researchers at no charge. Non-member researchers can also participate in training and access data for additional fees". Similarly, **ADA** (AUS): "European users are welcome to, and regularly do, use data from **ADA**. There are some restrictions on a small number of datasets in our collection, but the large majority (>95% of the collection) is available to European researchers". Only one organisation reported the use of quotas/limitations for external users use of the RI.

8.4.7 Societal impact

Some initiatives note their general support for social scientific research which in turn address grand challenge, i.e. indirect impact. The impacts are thus expected to come via use the e.g. data to impact domestic and global policy decisions. The interviews suggested that long-term preservation of research outputs can contain important information about various aspects of societies and none of the grand challenges, including international development plans like the SDGs, can be met without the free flow of reliable data for planning and monitoring development progress. Additionally, empirical foundation of social science, statistical and public agencies working to transform understanding of how our society works is seemed important. The direct and indirect impact of research initiatives can be discerned in the responses provided. The coherence or alignment with the European-agreed grand challenges in the Lund Declaration is noted. Many of the respondents try to follow the impact of their facilities, e.g. **PHRN** (AUS) has completed an external Return on Investment evaluation. A recently published study has also demonstrated the proportion of Australian research using linked data that has used PHRN-supported facilities. Figures of users' access to and use of the RI are routinely recorded by respondents, either as a routine part of their business operations or as part of annual reporting activities. Capturing user activities includes web searches as well as data downloads. This focus on user statistics is consistent with the European RIs attention to this dimension of infrastructure operations. Some respondents indicated that they also track citation data.

8.5 Conclusions

The reference points for the landscape analysis of initiatives in the global research ecosystem included the European Commission's Communication "Enhancing and focusing EU international cooperation in research and innovation: A strategic approach" (COM (2012) 497). In 2019, the European Parliament reviewed the implementation of the EU's international cooperation strategy. It concluded:

> *"The EU cooperates with third countries and international organisations to promote a high level of research and innovation. In 2012, the Commission structured this cooperation within a new strategy. That strategy pointed to the Horizon 2020 programme and 'science diplomacy' as the two main tools for its implementation."*

The experience undertaking the landscape analysis of the social science RIs and initiative supports the veracity of such statements. Even in those countries for which national science and technology funding plans/roadmaps were available, social science RIs were marginal. This was a consistent finding.

The possibilities for international engagement, the logical endpoint of a landscape analysis, are numerous. This engagement, for the social sciences Research Infrastructures, can build on the existing arrangements; for example, the EU's bilateral agreements in science and technology[6] can be explored for the purpose of identifying funding opportunities. It is notable however, in considering collaboration actions that the "quality'" of the data must be assessed as a precondition; there is, for example, little exploration of survey quality between infrastructures.

A final key issue is the fact that initiatives may not identify as a Research Infrastructure relates to the opportunities for collaboration to harness/exploit complementarities. These may not be affected by the organisational structure. However, the durability of collaboration may indeed be affected; first by eligibility requirements if funding is available for Research Infrastructures and not projects; second, by duration if core funding for the collaborating entity is limited to project-lifetime funding of 2-3 years; third, by expertise as Research Infrastructures contain expertise beyond the immediate science – reaching to include considerations of impact, of sustainability, communication and dissemination and wider data curation issues. Those Social science RIs that have grown in importance and have acquired a sustainable position are usually driven by an individual who has the vision and enthusiasm to promote the RI. Generating global outreach for an RI is time-consuming and may not attract national or international funding until the impact of the RI is well-established. Unsurprisingly therefore, the most successful RIs tend to be driven by academics who see the long-term benefits in terms of the research community they serve and wish to develop. Identifying such leadership potential is clearly an important factor in the long-term development of national and international Research Infrastructures.

[6] https://ec.europa.eu/research/iscp/index.cfm?pg=countries

9. CULTURAL HERITAGE, DIGITAL HUMANITIES AND LANGUAGES RESEARCH INFRASTRUCTURES

Main contributors
Franco Niccolucci (PIN)

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9.1 Domain overview

This report presents the key European Research Infrastructure initiatives and a first list of identified non-European RI centres and resources of the research sector cultural heritage (CH), digital humanities (DH), and languages (L). The results take account of the ESFRI Roadmap 2016 report, consultations with RI experts of the sector, analyses of RI and research data registries, and information collected from other relevant sources. We considered that digitised, web-enabled and aggregated collections of CH institutions are essential resources for research in the digital humanities. Since about 15-20 years ago, CH institutions in European and some countries in other world regions have digitised increasingly large volumes of cultural history and heritage content. Without this massive digitisation and building of CH RIs, the development of the digital humanities in these countries would hardly have been possible.

Cultural heritage, digital humanities and language research combined is a very large and diverse scientific sector. The addressed three fields of research within this sector have two main commonalities, which are a) that they address cultural materials and content, and b) that these are increasingly represented in digital formats to allow enhanced and new ways of research. Beyond these commonalities the three fields present considerable differences with regard to their research foci and methods.

This RISCAPE landscape report, based on survey and analysis, covers the development of significant RIs in the following sub-domains:

Cultural Heritage (CH)

In this survey, under cultural heritage (CH) we mainly address heritage sciences which focus on material CH. Material CH includes archaeological remains, historic environment and buildings, and artefacts held by museum collections. Heritage Sciences employ natural sciences methods and techniques to analyse, document and preserve the material objects. For example, this includes archaeometrical research and research aimed to improve the preservation of historical buildings and museum objects as well materials held by archives and special collections of libraries (i.e. papyri, historical manuscripts, photographs, etc.). The research supports heritage documentation and interpretation in fields such as archaeology and art & architecture as well as heritage conservation and management.

Digital Humanities (DH)

The humanities mainly study cultural works (i.e. literature, sculpture, painting, photography, film) and performances (i.e. music, theatre, dance). Here the historical, literary and other humanities research focuses not on the physical material in which the works or performances are captured but on the cultural content or expressions. The physical material is largely held and increasingly digitised by archives, libraries and museums. Digital Humanities (DH) research use digital content, methods and tools for their studies. Without the massive digitisation of cultural/CH material since about 15-20 years ago, the development of the DH would not have been possible. In addition, there is some DH research which focuses on born-digital content, for example within the field of media studies.

Languages (L)

In our survey, this field concerns research on written and spoken languages which employs language technologies for linguistic and text analyses. The survey focuses mainly on the application of natural language processing methods and techniques on digitised or born-digital cultural content (not, e.g., content of fields such as political and social studies). This can be subsumed under the digital humanities, but as a distinct area of research. The researchers of this area employ methods (i.e. corpus analytics) different than those of other textual studies, such as scholarly editions of ancient and historical texts, for instance.

ESFRI Landmarks, Projects and Preparatory phase		
Short name	**Name**	**ESFRI status**
E-RIHS	European Research Infrastructure for Heritage Science	Preparatory phase
DARIAH	European infrastructure for arts and humanities	Landmark + ERIC
CLARIN	The Common Language Resources and Technology Infrastructure	Landmark + ERIC
ERIH	European Holocaust Research Infrastructure	Preparatory phase

Table 9.1 *Overview of the ESFRI landmarks, projects and preparatory phase*

In Europe there are four RISCAPE-type ESFRI RIs. A cluster project titled **PARTHENOS** has just ended, and, outcomes of the cluster project are a summary and an online wizard of policies for the sector, a list of a set of standards, a semantic model called PEM (Parthenos Entity Model) to describe institutions, digital objects such as datasets, software and procedures. The PEM has been used to create a VRE (Virtual Research Environment) enabling advanced search tools. Finally, **PARTHENOS** has developed a large number of online tutorials and webinars addressing various issues related to the sector. Most of **PARTNEOS** are continued in the ESFRI RIs listed below. Another cluster called SHHOC that will merge this sector with social sciences has just started.

E-RIHS is a distributed RI on the ESFRI Roadmap currently in the preparatory phase (2/2017-1/2020), and an RI for heritage science research including material analysis, documentation, interpretation and preservation of both cultural and natural heritage. E-RIHS has been noted by the Group of Senior Officials (GSO) on Global Research Infrastructures as an international RI initiative of global interest; it is the only heritage or humanities RI recognised by this high-level group.

DARIAH is an ESFRI Landmark RI. It has been developed for over 10 years as a distributed RI, and was still in its implementation phase during 2014-2018, with the start of full operation expected in 2019 (ESFRI Roadmap 2018c: 2014). **DARIAH** aims to support and enhance digitally enabled research in the arts & humanities, including the teaching and take-up of digital research methods in these fields. **DARIAH** is being supported by 17 EU member states and involves dozens of domain institutions/centres and several hundred scholars, including from other European countries and beyond.

CLARIN: is a distributed RI focused on e-infrastructure for language research. **CLARIN** was an ESFRI Roadmap initiative from 2006, became a legal entity (ERIC) in 2012, and has been recognised as a fully operative ESFRI Landmark RI since 2016. The RI supports the development, sharing and sustainability of language data and tools for research in the humanities and social sciences. **CLARIN** is supported mainly by national contributions to the **CLARIN**-ERIC and centres in the member countries, and additional income from EU-funded and other projects. **CLARIN** hubs are still being constructed in some European countries, and research centres outside of Europe are interested to learn from and possibly join the **CLARIN** network.

ERIH has been a distributed RI on the ESFRI Roadmap since 2018. It builds on the FP7 and H2020 **EHRI** projects (2010-2019) and its preparation and implementation phases in the ESFRI framework are set up to 2019-2022 (ESFRI 2018c: 178). The main aim of **EHRI** is to develop enduring possibilities for international networking of Holocaust documentation and research based on common guidelines, methods and tools. The **ERIH** initiative on the ESFRI Roadmap is being led by the Netherlands and coordinated by the Institute for War, Holocaust and Genocide Studies (Amsterdam). The initiative is supported by six other EU countries (Austria, Czech Republic, Germany, Romania, Slovakia, United Kingdom) and Israel. The core group of the **EHRI** initiative comprises over 20 memory and research institutions, but the initiative facilitates an extensive network of archives and researchers in Europe and beyond.

Services from the research infrastructures vary but can be characterised as follows.

Cultural Heritage. Collection, curation and preservation of CH objects, incl. conservation, documentation of CH objects and (in-field) monuments and sites, digitisation and online access to collections, presentation & communication.

Digital humanities. Important role of digitised ancient material (e.g. papyri) and historic manuscripts, transcription and annotation tools, scholarly digital editions of literary works, geo-mapping of information (GIS) in Ancient World and Historical Studies.

Language Research. Quantitative analysis of corpora, natural language processing, text mining & analysis of large corpora, topic modelling of textual content, stilometry, attribution, network analysis of relations (e.g. authors, places, etc.)

9.2 The methodological approach

The methodology used to acquire information for the domain is explained in chapter 2. The flow chart in chapter 2 describes the steps taken to gather relevant information about the RIs in question. For this domain there is no specific sub-domain partitioning, but the analysis and discussion is based on the four RIs listed in table 9.1. The results presented in this chapter are based on the following methodology.

First, we identified the key European RIs (ESFRI) and other initiatives that integrate resources of the CH-DH-L domain. This identification supported the RISCAPE mapping work with regard to the comparison of non-European RI initiatives to European ESFRI RIs and other RIs of the domain. For this task we consulted the following:

- the ESRFI Roadmap 2016 – for the key sector RIs,
- the Roadmap's Landscape Analysis section "Social and Cultural Innovation" – concerning recognised other major initiatives,
- presentations of the ESFRI Social and Cultural Innovation SWG summarising the view of the strategy working group concerning the humanities RI landscape,
- furthermore, we mined the Mapping of the European Research Infrastructure Landscape (**MERIL**) registry, established under the lead of the European Science Foundation, for its coverage of RIs of "more-than-national relevance" (ESF Forum on RIs).

Second, we prepared an initial list of RIs outside of Europe, with the following actions:

- consultations with experts of European CH-DH-L RIs (i.e. **IPERION-CH** and DH RIs participating in the **PARTHENOS** cluster) allowed receiving suggestions of RIs outside of Europe to consider as well as opinions concerning the RI landscape in general,
- mining of the international re3data Registry of Research Data Repositories surfaced some relevant non-European research data resources that could be relevant for international collaboration on RIs in the field of CH-DH-L,
- furthermore, other sources were consulted to extend the first list of RI initiatives and resources, i.e. available RI Roadmaps, the international **ICCROM** Forum on Conservation Science, and others.

The ESFRI Roadmap landscape analyses of 2016 and 2018 characterise **EUROPEANA** as an "integrating Research Infrastructure" (e.g. ESFRI 2018b: 112). **EUROPEANA** is the EU gateway to digitised content of archives, libraries and museum across European countries, about 54 million items from over 3,700 providers of 44 countries. **EUROPEANA** has not been built as a research e-infrastructure but since about five years ago the **EUROPEANA** for Research initiative has been promoting and supporting the use of the accessible cultural history and heritage content by researchers. **EUROPEANA** also collaborates with **CLARIN** to make its textual resources accessible for language processing and data mining applications.

Some initiatives have been completed recently while others are outdated:

ARIADNE - Advanced Research Infrastructure for Archaeological Dataset Networking in Europe (EU, FP7-Infrastructure, Integrating Activity, 2/2013-1/2017)3. **ARIADNE** is being continued by **ARIADNE**-plus (2019-2022). It created a searchable registry of archaeological datasets, currently cataloguing about 2 million of them, with search functionalities, and several tools to post-process the data, currently improved within **ARIADNE-plus**.

ECHO - European Cultural Heritage Online (Max Planck Institute for the History of Science, Germany)4; the digital library is accessible but apparently not in active development, last update: June 2015 (in the ESFRI landscape analysis **ECHO** is mentioned as an "integrating Research Infrastructure").

EHRI - European Holocaust Research Infrastructure (EU, H2020, Integrating Activity, 5/2015-4/2019)5. **EHRI** has been included in the most recent ESFRI Roadmap and is currently in the preparatory phase.

TextGrid: Was a 10-year project funded by the German Federal Ministry of Education and Research until May 2015)7; the project website states that the **TextGrid** Laboratory and **TextGrid** Repository will be maintained, and several technical components moved to the e-infrastructure of **DARIAH-DE**.

Of the above mentioned initiatives only, **ARIADNE** is still fully functional, while **EHRI** has very recently been upgraded to the status of an ESFRI project.

9.3 The International landscape

The first and most important result of the landscape study is that **nothing similar to European Research Infrastructures exists outside Europe in the fields of research surveyed**. In all fields no research infrastructures comparable to the collaborative ESFRI RIs (CLARIN, DARIAH, ERIH, E-RIHS) could be found. In the area of Digital Cultural Heritage some countries have comparable e-Infrastructures (e.g. Canada, USA, Australia and New Zealand) that support finding and accessing digital research resources. These are national systems, not gateways to CH resources of many countries like **EUROPEANA** in Europe. However, all these systems are not research-oriented, hence there is a lack of collaborative research e-Infrastructures dedicated to Digital Cultural Heritage. The tentative repurposing of **EUROPEANA** for researchers is promising but at present only partially a success, as **EUROPEANA** would still not be the first place where CH researchers look for information. Thematic domain infrastructures better meet the needs of researchers, as demonstrated by the success of the **ARIADNE** RI for archaeology in Europe and its attraction of non-European research centres, which is completely absent as regards **EUROPEANA**. This situation is common worldwide: digitised CH resources have little attraction to research if they are not accompanied by rich domain-relevant metadata and services and tools for researchers.

9.3.1 Cultural Heritage (CH)

There exists no distributed RI for heritage science comparable to the **E-RIHS** initiative, only single-sited centres with a focus on heritage conservation. A number of such centres in different world regions have expressed interest in cooperating with **E-RIHS**. Also missing are large-scale e-infrastructure that provides online services based on aggregated digital resources of different centres.

Heritage science centres: These are typically single-sited centres with a national or regional focus, for example conservation departments of CH institutions. Worldwide there could be some 350 significant centres with a focus on heritage conservation; 100 in Europe, 100 in the United States, 150 in other countries (estimate based on **ICCROM** survey figures 2016 and additional information). As significant we consider medium to large size centres with staff specialised in different objects and materials, state-of-the-art laboratory equipment, and measurement and analysis methods.

Selection of heritage science centres: The domain survey identified a number of non-European heritage science centres that are relevant in the context of E-RIHS. The centres have been selected based on information provided by the E-RIHS scientific coordinator Luca Pezzati (CNR, Italy), identified networks of centres, documentation of the **ICCROM** forum on heritage science (Heritage & Golfomitsou 2015), and other sources consulted.

9.3.1.1 Holocaust research

*RI comparable to **ERIH***: **ERIH** is the only initiative worldwide for a distributed RI supporting archives and research centres in different countries. The leading institutions in Holocaust research outside Europe, Yad Vashem (Israel) and the United States Holocaust Memorial Museum, participate in **ERIH**. The **ERIH** initiative includes, as a core element, an e-infrastructure providing access to a catalogue

and portal for searching archival institutions and collections currently in 53 countries around the world. Of the currently 2056 archives and other institutions, 1708 (83%) are located in 38 EU and other European countries; 348 (17%) in 15 non-European countries. Among the latter institutions most are located in the United States (82), Russia (55), Israel (52), Ukraine (52) and Belarus (27).

Holocaust research centres (single-sited): These centres are memory institutions which regularly conduct, and support Holocaust research based on collections of primary sources. Such archives or museums either curate mainly collections of Holocaust-related material or, more often, hold such collections among others. These are the core centres of Holocaust research precisely because they hold such collections, the archival and research work is closely intertwined, and other functions (documentation, education, exhibitions) are based on this work. Worldwide there are hundreds of Holocaust memorial sites and study and education centres but arguably only around 100 Holocaust research centres which build on their significant own archival collections.

9.3.1.2 Digital Cultural Heritage

Centres of CH digitisation: Such centres can be found in many countries around the world, however there are huge differences regarding the volume of web-accessible resources. In most cases there is a clear correspondence between the level of accessible digitised cultural heritage and history resources and the development of the digital humanities in the country. There are no CH e-infrastructures for multi-country aggregation of digital CH resources like **EUROPEANA**, but major aggregators at the national level. Closest to the aggregation of CH content records by **EUROPEANA** (records of 54 million items) come the Digital Public Library of America (33.7 million) and Trove in Australia (22 million).

The leading countries are the United States, Canada, Taiwan, South Korea, Japan, Australia and New Zealand. These countries also stand out as international or regional promoters of DH research. South Korea and Taiwan first have run programmes of mass-digitisation of CH collections and, in the current second phase, extend this to DH research based on the digitised resources. In the process, they became centres leading in digital CH and DH in the region.

In Central and South America only **MEXICANA**, developed in the

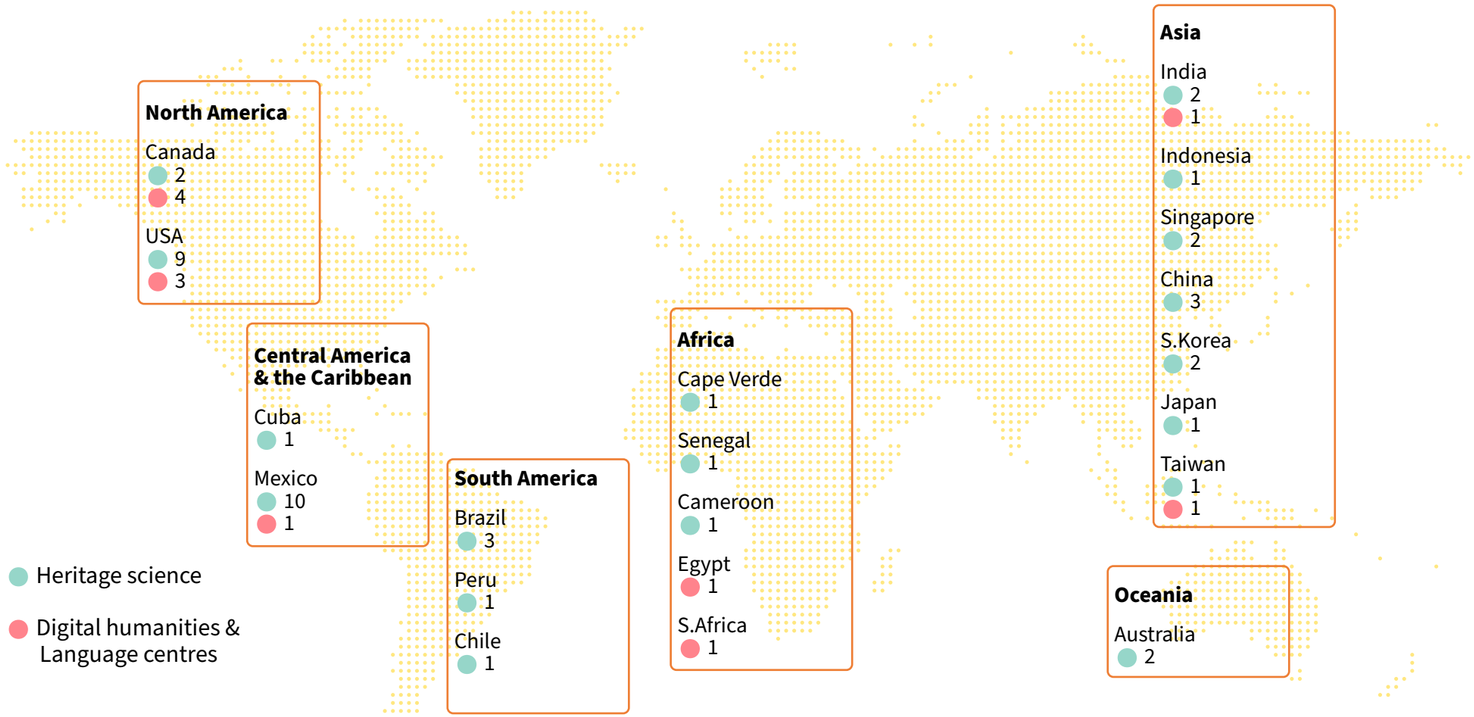

Image 1. *Distribution of selected Heritage science and Digital humanities & Language centres*

digitisation programme of the Ministry of Culture of Mexico, is a large digital resource (530,000 items). In other countries the largest digital libraries provide access to far fewer items, e.g. Memoria Chilena (National Library of Chile) 33,000 items or the Biblioteca Virtual del Banco de la República en Colombia (national bank of Colombia) 8,000 items. Consequently, there is a gap between the recent DH movement in South America and the available digitised CH resources.

In the Middle East and North Africa, only Israel and Egypt stand out. In Israel the National Library and other institutions have digitised several million cultural history and heritage items, e.g. the Historical Jewish Press database (2.3 million pages) or the A-Z Archives Network Israel Project (over 1 million items). In Egypt, the Bibliotheca Alexandrina and the Centre for Documentation of Cultural and Natural Heritage (CULTNAT) must be noted. They have developed digital collections as well as special systems, e.g. the Global Egyptian Museum, a virtual museum of ancient objects. Digitised collections of other institutions in North Africa are often not web-based or become inaccessible due to technical issues.

For Sub-Saharan Africa, South Africa stands out regarding both digitisation and DH activity, however, it is not yet on a par with comparable international leaders such as Australia or Canada, for instance. A large resource here is South African History Online (**SAHO**, non-profit organisation), providing access to 50,000 documents and 20,000 images and videos, many are linked to about 7,000 online biographies. Digital Innovation South Africa (University of KwaZulu-Natal and other universities) provides access to 20,000 items of “struggle for freedom” material. South Africa has a striving DH community and the establishment of the South African Centre

for Digital Language Resources (**SADiLaR**) as part of the national RI roadmap has raised its profile significantly.

For South Asia, India could be a giant in digital CH and DH in South Asia, however there is a large gap between the capacity in information technology and humanities scholarship, and the digitisation of content relevant for DH research is rather low. For example, a significant regional resource for Digital History is the Panjab Digital Library of 14,345 accessible manuscripts, books, pamphlets and issues of magazines and newspapers. In Pakistan the Iqbal Cyber Library of Urdu classics, poetry, and studies provides access to 1,475 full-text e-books.

Japan, South Korea and Taiwan are leaders in CH digitisation in East Asia, however so far, the integration of the produced databases in central national search & access portals has only been partially successful. In Japan, the National Diet Library (**NDL**), the library of the National Congress, is developing such a portal. Its own digital collection comprises 2.7 million digitised or born-digital items but, due to copyright restrictions, only 530,000 items up to the 1960s are accessible online. South Korea has over 60 databases of materials from the national digitisation programme, but these are dispersed over a number of institutions (Cha 2015). In Taiwan, the Research Centre for Digital Humanities (National Taiwan University) alone has 33 databases that contain about 30 million items of digitised heritage and history material.

China could become a strong force in digital CH and humanities within ten years. The country has a broad and state-of-the-art digital library and information science capacity; there are large-scale digitisation efforts focused on historical materials, e.g. in the Quing History Project (currently 2 million digitised items of archival material), although with a sensitive political background (Crossley 2019); and participation in international projects, e.g. the International Dunhuang Project: The Silk Road Online (coordinated by the British Library), in which the National Library of China and the Dunhuang Academy take care of the Chinese version.

9.3.2 Digital Humanities

There exists no distributed RI for the humanities comparable to **DARIAH**; what exists are many DH centres, of which those with a larger number of staff, state-of-the-art research resources (equipment, tools, data) and projects are RIs. In some world regions and countries large-scale aggregated digital resources for cultural history and heritage research are available to DH scholars (e.g. Canada, USA, Taiwan, Australia, New Zealand). Their infrastructure and tools qualify as research e-infrastructure. These resources are described in the chapter on Digital Cultural Heritage. In addition, there are virtual research environments, often developed by scholars for scholars, which are addressed in the DH domain survey. Worldwide there are at least 300 significant DH centres, about a third in Europe, a third in the United States, and a third in other countries (estimated). A DH centre is often established at a research library, but can also be embedded in an institute, or be a university-wide programme to promote digital scholarship. The growth in DH centres in the last 10-15 years may be explained by the fact that such centres allowed universities to receive fresh funding for research facilities and projects. In an analysis of 785 DH projects (DH-Commons database) we found that most are in the fields of languages & literature (19.5%), history (18.5%), archaeology, classics and ancient world studies (14.6%), followed by the performing arts (7.6%). Others have a share of below 3% in the sample, e.g. visual arts (2.9%) or linguistics (2.7%).

9.3.3 Languages

Language research centres see CLARIN as the model for distributed RI in this field and are interested to participate. For example, the South African Centre for Digital Language Resources (**SADiLaR**), the only humanities RI on the national RI roadmap, has been inspired by CLARIN and represents the country with observer status in CLARIN. There are language Grid initiatives in East Asia, United States and Europe which have a more generic RI approach than CLARIN but could help expand its reach. The research community avails of numerous, text, speech and vocabulary resources (e.g. dictionaries, lexicons, thesauri, etc.) as well as technical LR systems and tools (software). Differences between these resources, especially between technical systems/tools, also characterise different groups among the research community. Most of the technical systems, tools and components covered by these catalogues require advanced software and computing skills. Therefore, some research groups provide toolkits for broader user groups, for example, the web-based Voyant Tools which are often used in training courses for novices in the digital humanities and other fields.

Language research centres comprise centres of basic research, which develop new or advanced LR technologies, and centres of applied research, which employ generic and specialised technology for processing and analysing data of different domains. The survey focused on centres of applied LR in domains such as culture, literature and history, in line with other focus areas of the survey. Indeed, LR in these domains could be subsumed under the digital humanities, but as a distinct field of computational humanities research. The number of significant LR centres or units (often of DH centres) with teams of developers and scholars focussing specifically on culture, literature or history, could be around 100. Such centres/units are mostly located in Europe, North America, Australia, Japan, Taiwan and some pockets of computational DH in other countries. In Central America & the Caribbean and South America the humanities do not have a strong tradition of humanities computing, hence only a small base for applying advanced LR technologies. Furthermore, there is a lack of large volumes of digitised content in most countries in these regions. Except for South Africa, this also applies to Africa as a whole.

Given the lack of RIs outside Europe that are comparable to the collaborative ESFRI RIs, the landscape survey has been developed by looking into significant research centres, which might act as catalysts for collaborative RI initiatives, and research trends and needs which might push towards integrating efforts.

9.3.4 Research centres as RIs

The rationale for the survey approach is that research centres are RIs in their own right. Research centres provide the institutional framework for building and sustaining research capacity and a regular stream of projects. They have a local physical and digital infrastructure with equipment, tools, data etc. as required for carrying out state-of-the-artwork in their fields of research. In the fields covered by the domain survey, for example, material analysis of heritage objects, cultural heritage 3D modelling, geographic mapping of historical information, text processing and analysis. Therefore, individual research centres, at least significant medium-size or large ones, must be recognised as domain research infrastructures.

With their local physical and digital RI and skilled workforce research centres can carry out projects rather autonomously but

are, of course, also often active in collaborative projects. Domain e-infrastructures and portals have been developed to allow research groups access to resources (content/data, tools, computing) which they do not have themselves or not in the volume or specialisation required for advanced research. Sharing through research e-Infrastructures available resources leverages the capacity of the research community as a whole. Their increasing role corresponds to the overall trends in scientific research, which are that the research is becoming increasingly collaborative, distributed and data intensive (Riding the Wave 2010).

9.4 Discussion

We consider the results of the first mapping round to be satisfactory and see potential and ways for improvements in several respects. The results of the first round of RI mapping for the CH-DH-L sector can be briefly summarised as follows.

Types of RI initiatives, institutions and resources covered in this mapping exercise.

- Most of the identified entities are local centres or national centres. These entities are single research centres and aggregated digital resources such as corpora, databases or repositories.
- Currently no ESFRI type of RIs are identified. Such entities would be RIs similar to ESFRI RIs of the CH-DH-L sector in Europe or other cross-national integrators of research centres and resources such as **ARIADNE** or **IPERION-CH**.
- However, some of the identified research centres could serve as nodes of such distributed, cross-national RIs or national RI networks such as the ones brought together by **DARIAH**.
- International relations and cooperation, the **E-RIHS** initiative for a global RI in the field of heritage sciences with **ICCROM**, as a strong promoter.

Regions / countries covered

- Several research centres or resources are present for most regions. The United States and Australia are already relatively well covered, there are a number of first entries for Asian countries, while in Africa at least one emerging major RI could be identified in South Africa.
- Colleagues from **DARIAH** noted that the uptake of DH practices in different world regions and countries is uneven, depending, among other factors, on access to digitised major heritage resources of the country as well as academic institutionalisation of DH (i.e. centres and courses). We assume that due to such requirements a large part of Africa will remain a “terra incognita” with regard to RI-based scholarship.

The CH-DH-L domains

- The domain so far covered best is CH/heritage sciences, including also a number of research centres in South America.
- For DH RI initiatives, in the next mapping round South America deserves more attention, starting from nodes of the Red de Humanidades Digitales (RedHD) and other, country-level networks and associations. This approach may also allow a better coverage of other countries.
- For the field of language technologies some significant RI centres and resources could be identified, but there certainly are more, especially in the Asian region.

10. E-INFRA-STRUCTURES

Main contributors
Gergely Sipos (EGI)
Roberta Piscitelli (EGI)

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10.1 Domain overview

This chapter provides a review of the global e-infrastructure landscape. Data for this report was gathered using online and face-to-face interviews with both international and European e-infrastructure representatives, harvested from presentations given at regional e-infrastructure events and from public websites and publicly available documents. Although the prime focus of the report is on infrastructures located outside of Europe, it was inevitable to include in our review also those projects that advance such infrastructures with respect to the offered services, and/or with the interconnection and alignment to the European ones. In some regions, and for certain types of e-infrastructures, the line between 'being an infrastructure or being a project' is blurry, as many e-infrastructures are funded through short-term project cycles (2-3 year long projects) without the long-term business and sustainability plans that RISCAPE has identified as an important characteristic of a "Research Infrastructure."

Today, almost all large-scale research activities include or are supported by several e-infrastructure components. Major scientific breakthroughs are increasingly achieved by an international and cross-disciplinary team transferring, storing and analysing vast data collections, and performing advanced simulations using different types of computing facilities. Understanding the global e-infrastructure landscape is therefore of upmost importance for Europe – for both researchers and for those funding, designing, implementing and operating e-infrastructures. Collaboration with e-infrastructures outside Europe can enable new modes of science where resources, in particular for the other Research Infrastructures, are shared and used remotely to overcome fragmentation and to cope with increasing costs and complexity.

The pan-European e-infrastructures for networking, high-performance computing (HPC) and high-throughput computing (HTC, clusters built from more commodity-type hardware) are already well established and provide services used by international research and Research Infrastructures. Also, data and cloud infrastructures are developing fast. It should be noted that the European-level e-infrastructure services are often provided by national e-infrastructures in a collaborative setting and that the pan-European initiatives are dependent on the existence of strong and coherent national e-infrastructure nodes and their cooperation and complementarity to enable cross-border services for scientific communities. Available e-infrastructures and their related services might not always fulfil the user's needs. But collaboration and coordination between e-infrastructures and between e-infrastructures and Research Infrastructures is ongoing. The main strategic body facilitating the overall integration of e-Infrastructures and connected services within and among European member states is e-IRG, the "e-Infrastructure Reflection Group". The following subsections present a brief introduction of the major pan-European e-infrastructure initiatives mostly reusing content from their Guide to e-infrastructure requirements for European Research Infrastructures[1].

The European landscape classification of sub-domains we use for e-infrastructure domain is used in this report and applied when describing e-infrastructure for the rest of the world. The sub-domains are:

- Network (Connectivity)
- High-Performance Computing (supercomputers)
- Grids and clouds (clusters, grids and IaaS-PaaS-SaaS compute services)
- Data (storage and data management infrastructures as well as the data they host)

10.1.1 Network

Connecting research communities across the globe is a prerequisite to stimulate exchange of ideas, data and results. Already since a few decades the National Research and Education Networks (NRENs) have been connecting universities, research institutes, and sometimes other public institutions in their country. The **GÉANT** Association provides interconnectivity between NRENs across 43 European countries, serving an estimated 50 million of users of practically all research disciplines and thematic domains. In addition to pan-European connectivity, the **GÉANT** network has international connections to a large set of partner networks (some 70 NRENs) worldwide, in particular through regional agreements – thereby enabling international collaboration for research and education.

[1] http://e-irg.eu/catalogue/eirg-1004

10.1.2 High-Performance Computing

The High-Performance Computing (HPC) national infrastructures are federated at the European level in the Partnership for Advanced Computing in Europe (**PRACE**). **PRACE** offers access to world-class high-performance capability computing facilities and services. For the national HPC infrastructure(s), the access modes are closely connected to the ruling national governance.

10.1.3 Grids and clouds

In this document we use the 'grids and clouds' category to refer to a number of different types of compute infrastructures: high-throughput compute infrastructures implemented in the form of institutional clusters and compute grids, cloud compute infrastructures implemented as Infrastructure as a Service, Platform as a Service or Software as a Service. A rich variety of such infrastructures exist within the academic sectors of European countries. On the national level these are often brought together using national infrastructures (NGIs), which are federated into the **EGI** pan-European computing infrastructure.

10.1.4 Data.

Data is a key component of Research Infrastructures, a fundamental scientific product offered for scientific and commercial exploitation. The storage, curation, archival and sharing of scientific data for download and for online analytics is a shared challenge of e-infrastructures and Research Infrastructures. Data has to be open (except for legitimate restrictions such as privacy), FAIR, "Findable, Accessible, Interoperable, Reusable" - and preserved on the long term. The users of the data infrastructures and services are the data providers and data consumers, who can belong to the scientific community, to industry, to the public sector or can be citizens.

Initiatives at the European level have been started to offer various services (e.g. storage, permanent identification, access, anonymisation, discovery, monitoring, semantic linking, validation, data management planning) for research data in general (e.g. **EUDAT** services) for publications and a growing range of other research outputs (**OpenAIRE** and its **Zenodo** repository), and for the caching and staging of research data to/from compute resources (e.g. **EGI** data services). Scientific communities and Research Infrastructures have been building frameworks for data sharing and in many cases building their own data infrastructures. National, regional and local authorities have also set up data infrastructures. All of them should be interconnected in a 'European Data Infrastructure', which should be an ecosystem able to include different components. Other initiatives contribute to this with for example: **EOSC** (see below) defining interoperability guidelines, **CoreTrustSeal** defining certification requirements that reflect the core characteristics of "trustworthiness" for data repositories (and recently adopted in the **FAIRsFAIR** project), and the **re3data.org** project providing a global registry of research.

The European e-infrastructure landscape with the four sub-domains for e-infrastructures, has the following ESFRI RIs:

GÉANT and its NRENs, **GÉANT** provides interconnectivity between NRENs across 43 European countries, serving an estimated 50 million of users of practically all research disciplines and thematic domains. In addition to pan-European connectivity, the **GÉANT** network has international connections to a large set of partner networks (some 70 NRENs) worldwide, in particular through regional agreements – thereby enabling international collaboration for 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 related NRENs and **GÉANT** for international point-to-point links to connect parts of the Research Infrastructure that are distributed over Europe or beyond.

PRACE offers access to world-class high-performance capability computing facilities and services. **PRACE** is managed by the **PRACE** AISBL organisation. **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 " Excellence of science" and supported by scientific peer-review. There are basically two forms of access: 1) Preparatory access, intended for short-term access to resources, for code-enabling and porting, required to prepare proposals in the category "project access" and to demonstrate the scalability of codes; 2) Project access, intended for individual researchers and research groups including multi-national research groups, which can be used for 1-year, 2-year or 3-year (Multi-Year Access) production runs. For the national HPC infrastructure(s), the access modes are closely connected to the ruling national governance.

A new legal and funding entity, the European High-Performance Computing Joint Undertaking (**EuroHPC JU**) will pool European and national resources to develop top-of-the-range exascale supercomputers for processing big data, based on competitive European technology. **EuroHPC JU** develops a pan-European supercomputing infrastructure and supports research and innovation activities during the development and later in the exploitation of the HPC infrastructure.

There are other types of pan-European initiatives that should be considered on the e-infrastructure landscape. The **EGI** Foundation and its NGI members provide solutions built through a service catalogue that has been evolving during many years. The **EGI** Federated Cloud Solution offers a standards-based and open infrastructure to deploy on-demand IT services that can host, process and serve datasets of public or commercial relevance and can be flexibly expanded in capacity and capability by integrating new providers. The European Cloud Initiative – which started implementation in 2017 under the name "European Open Science Cloud" (EOSC) – will provide European science, industry and public authorities with world-class data infrastructures, high-speed connectivity and increasingly powerful computers and networks of computers. The objective of **PLAN-E** is to bring together leading influential e-Science centres across Europe to help coordinate ongoing innovation in scientific methods and exploitation of infrastructure. The goals of **PLAN-E** cover all the topics that help promoting the e-Science approach and strengthening the groups and centres conducting e-Science. **OpenAIRE** supports Open Science and FAIR via its services and its network of 34 National Open Access Desks (NOADs), which comprises experts working on transferring and translating EU policies to a local level. NOADs and their organisations are the de-facto national nodes for Open Science in most of their countries.

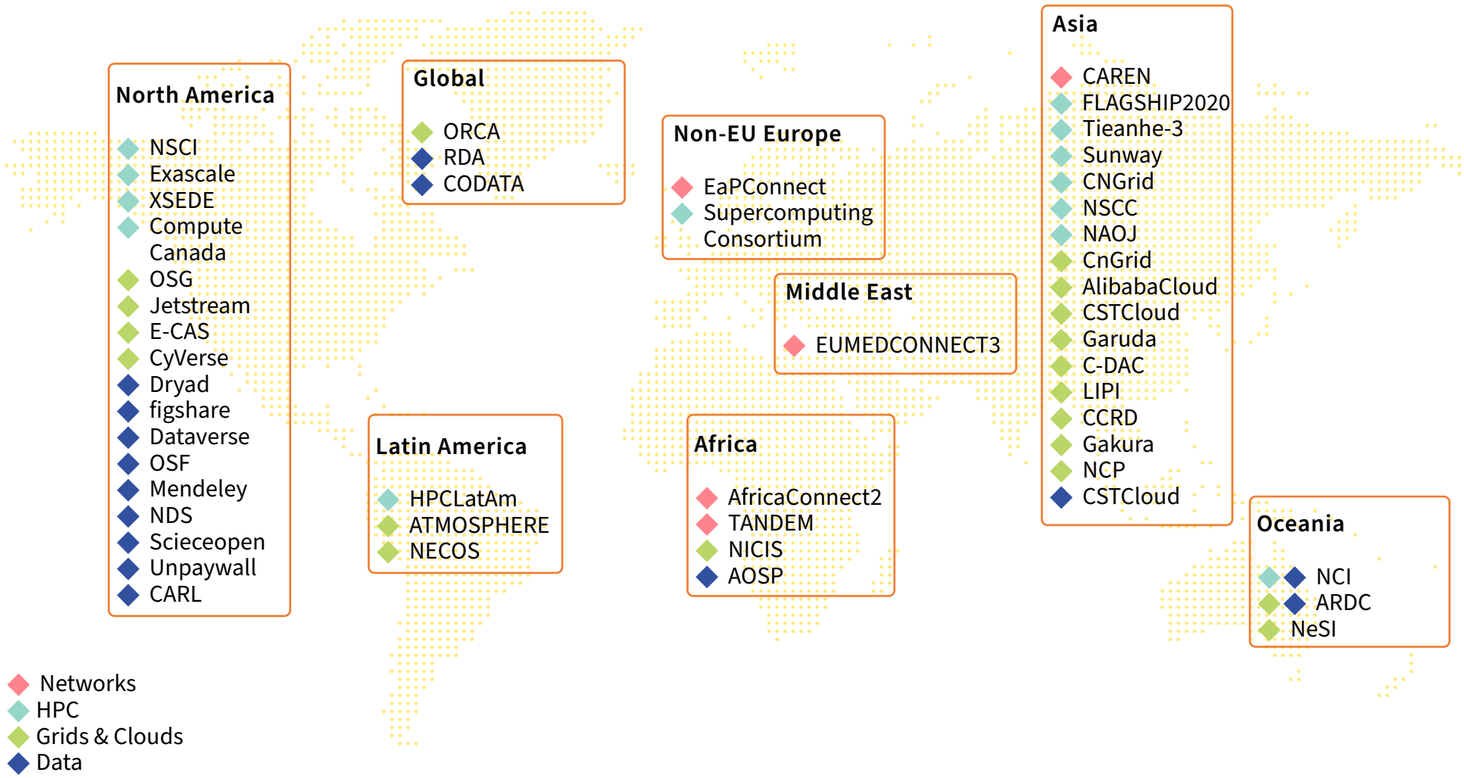

Figure 10.1 *Main facilities and initiatives discussed in this section*

10.2 The methodological approach

The international landscape of e-infrastructures was reviewed by **EGI** in collaboration with some of the key pan-European e-infrastructures that best know their peers worldwide (**PRACE**, **GÉANT**, **OpenAIRE**). The landscape was assembled by interviewing the European e-infrastructures about their understanding of the rest of the world, by collecting information about non-European e-infrastructures with online surveys, with teleconference interviews and through face-to-face meetings attended in various regions of the world. We complemented this data with harvested data from public websites and deliverables that are referenced in the report. We feel that, compared to other Research Infrastructure domains, the e-infrastructure landscape is rather well known by, and well connected to, the main players of the European landscape. Moreover, the e-infrastructures have informative and fairly up-to-date public websites both in Europe and worldwide.

The e-infrastructure websites are quite content-rich, and we managed to obtain or double-check most of the data for this report from there. Attending regional e-infrastructure conferences were also a big help to identify the key players of the field and to engage with them face-to-face. When we used interview, we did not receive significantly more data and knowledge than with the above-mentioned methods. Responses were often pointers to specific webpage sections or public documents.

10.3 The international e-infrastructure landscape

In subsection 10.3.1 Networks are presented with a description of current infrastructures, also ones that to some degree is in development. In subsections 10.3.2, 10.3.3 and 10.3.4 HPC, "Grids and Clouds" and Data infrastructures and projects are presented according to their geographic distribution. This approach was chosen because the distinction between infrastructures and projects is not so clear in these areas and the geographical location is felt to be a stronger distinguishing feature.

10.3.1. Networks

National Research and Education Networks (NRENs) are a large and diverse family. At the time of writing 122 NRENs exist around the globe: with 14 in East and Southern Africa , 5 in South Africa, 8 in West and Central Africa, 7 in the Indian subcontinent, 19 in Asia-Pacific, 16 in the US, 11 in Canada, 17 in Latin America, 4 in the Caribbean, 12 in Middle Asia, 9 in Central Asia and 46 in Europe (including the Nordics). Each NREN organisation reflects the specific environment in which it grew, with country-specific peculiarities such as the political situation, the history of the organisation and its relations with user groups, funding agencies, and the status of research and education in that country all woven into its fabric. Another important aspect is the difference between the leading communities that established the NRENs – each NREN was set up in a form that suited a country's needs and background. The development and support of an NREN infrastructure is often determined by the vision, resource and funding levels in a given country – and this differs between national authorities. Whether an NREN is or is not connecting a specific institution to the network is also dependent upon an acceptable use policy, which varies by NREN: some can connect primary and secondary schools, while others' mandates may extend also to private R&D firms.

The NRENs

Network provisioning to research and educational institutes happens similarly in both Europe and the rest of the world: by National Research and Education Networks (NRENs). Each NREN organisation reflects the specific environment in which it grew, with country-specific peculiarities such as the political situation, the history of the organisation and its relations with user groups, funding agencies, and the status of research and education in that country.

GÉANT has been a trusted partner of the European Commission for many years, as the coordinator of network projects co-funded by the European Union and NREN organisations in Europe, and by those in other world regions. **AfricaConnect2** supported the development of high-capacity Internet networks for research and education across Africa. It builds on existing networks in Eastern and Southern Africa and North Africa and will extend connectivity into West and Central Africa. With links to the **GÉANT** network **AfricaConnect2** established an African gateway for global collaborations. Launched in 2010, **CAREN**, interconnects researchers, academics and students at over 500 institutions in Kyrgyzstan, Tajikistan and Turkmenistan with Kazakhstan and Uzbekistan also candidate countries. Eastern Partnership Connect (**EaPConnect**) project sets out to create a regional high-speed Internet network dedicated to research and education across Armenia, Azerbaijan, Belarus, Georgia, Moldova and Ukraine. The network will interconnect the NRENs in these six countries and integrate them with the pan-European **GÉANT** network. **EUMEDCONNECT3** provides a high-capacity dedicated Internet network for the research and education communities across the southern and eastern Mediterranean region. Trans-African Network Development, **TANDEM** supported dialogue between the EU and African research and education networks, with special attention to the Western and Central Africa region. Middleware for collaborative Applications and Global virtual Communities (**MAGIC**) aims to establish a set of agreements for Europe, Latin America and other participating world regions (North Africa and the Middle East, West and Central Africa, Eastern and Southern Africa, Central Asia and Asia-Pacific) to create a marketplace of services and real-time applications for international and inter-continental research communities.

Besides these focused projects, several European NRENs meet on a regular basis with Chief Executives of other NRENs in the 'International NREN CEO Forum'.

10.3.2 High-Performance Computing

The growing demand for High-Performance Computing (HPC) resources in scientific computing has triggered a number of initiatives globally. The National Strategic Computing Initiative (**NSCI**) and the Department of Energy's related **Exascale Computing Project** in the USA, the Japanese **FLAGSHIP 2020** project, the **Tianhe-3** and **Sunway** exascale projects and quantum computing initiatives in China, the **PRACE**, **ETP4HPC**, and **EuroHPC** projects in Europe are examples of such large-scale efforts.

For decades, the notion of "performance" has been synonymous with "speed" (as measured in FLOPS, short for floating-point operations per second). This particular focus has led to the emergence of supercomputers that consume egregious amounts of electrical power and produce so much heat that extravagant cooling facilities must be constructed to ensure proper operation. In order to raise awareness to other performance metrics of interest (e.g., performance per watt and energy efficiency for improved reliability), the Green500 list was established in 2006.

TOP500 dominance

Throughout the years China's dominance in HPC significantly increased, while the USA's dominance decreased, and Japan's and Europe's have remained constant. Despite China's dominance in number of Top500 machines, it is the USA which dominates in terms of total computational capacity. Europe requires unified effort, such as the EuroHPC initiative, to be a considerable player in the race towards the exascale.

The National Science Foundation (NSF) in the US provides computing time to researchers in the US through the **XSEDE** program. In addition to having outreach programs, the **XSEDE** program also allocates free of charge computational resources to researchers. The effective review model of **XSEDE** evaluates the scientific merit of the projects only if the researchers do not already have any grant from independent funding agencies. The NSF has also funded a new system (Frontera at TACC) as the NSF's largest HPC system. In general, the NSF manages funding for specific HPC systems on a competitive project basis, awarding operators with funding based on the quality of new proposals and their historical performance record. The US government has also been investing in the next generation of supercomputers, which are basically quantum computers. In this area, the US might stay behind China for a while, however the recent investment of about $1.2 billion on the national quantum initiative might reduce the gap in quantum technology between these two countries.

China has had a wide variety of HPC investment programs active since 2002. Early supercomputers within the network of the China National Grid (**CNGrid**) have been replaced since 2010 by the world's most powerful supercomputers. **CNGrid** is supported by 17 national HPC centres, each of which has a system within the Top500. China is supporting more than 20 R&D projects towards exascale computing and is considered to be the world leader in quantum computing research with its $10 billion investment plan in the field.

While there is no machine on the Top500 list from Latin America, the High-Performance Computing Latin America Community (**HPCLatAm**) is a growing platform that brings together HPC actors such as researchers, developers and HPC users to discuss new ideas, experiences, and problems.

Saudi Arabia represents the Middle East with one machine around #85. Two machines represent Africa, both hosted in South Africa and around #350-400 on the list. Having five supercomputers for HPC research and industry, Australia provides computational power to its researchers through the National Computational Infrastructure (**NCI**) and Pawsey Supercomputing Centre. Singapore's National Super Computing Center (**NSCC**) was established in 2015 and provides HPC resources for academic and industrial needs in the field of science and engineering. It supports a 1 petaflop system, a 10 Petabyte data service coupled with dark fibre network to support the Singapore Advanced Research and Education Network.

The European Commission Directorate General for Research and Innovation (DG RTD) recently established the EU-ASEAN High Performing Computing (HPC) Coordination Group with the aim to support the establishment of the ASEAN-EU Research and Innovation Policy Exchange Platform. The Coordination Group brings together EU Member States' HPC policy experts and ASEAN HPC officials from policy and technical levels, enabling them to exchange HPC strategies and plans on regional aspects.

Even though several Russian systems are listed in the Top500 list each year, their standing in the list has been falling since 2011. Like **PRACE**, **The Supercomputing Consortium of Russian Universities** provides free of charge CPU cycles to researchers in the field of HPC. **PRACE** has initiated an action to setup a link to this only Russian organisation on supercomputer research and technologies.

Japan has recently started to develop the most powerful supercomputer in the field of computational astronomy. According to the National Astronomical Observatory of Japan's (**NAOJ**) announcement, the supercomputer with the nickname "**NS-05 ATERUI II**" provides 3.087 peak petaflops for astronomy related research. Japan is targeting to commission its first exascale machine by early 2022.

Compute Canada is a partnership of over 30 universities as well as the regional organisations providing advanced research computing systems, storage and software solutions to all Canadian researchers. Through **Compute Canada**, researchers can access four large HPC systems installed across the country. The Canadian government has committed C$572 million to digital research infrastructure, of which an estimated C$360 million will be managed by a new advanced research computing organisation being established in 2019, with the intent of ensuring continued computing access for Canadian researchers – either through additional investment at existing systems or the launch of new systems in the future.

10.3.3 Grids and clouds

A global alliance, called Open Research Cloud Alliance (**ORCA**) was initiated in 2017 to form a global community what would establish and promote research technology standards that foster interoperability between and among scientific research clouds. **ORCA** was initiated from the US but by now has attracted members from all over the world, including **EGI**, **GÉANT** and other stakeholders from Europe.

In the US the Open Science Grid (**OSG**) is the largest computing grid e-infrastructure. The OSG consists of computing and storage elements at over 100 individual sites spanning the United States. The setup is very similar to the High-Throughput Compute service of **EGI** in Europe, and **OSG** and **EGI** actually use common operational tools and practices and serve common user communities (primarily in High Energy Physics). The US NSF runs various types of projects to make cloud computing services more prominent on the US cyberinfrastructure landscape. **Jetstream** expands the **XSEDE** cyberinfrastructure with a Level-1 site using OpenStack cloud technology. The system provides more than a half petaflop and 2 petabytes of block and object storage. "Exploring Clouds for Acceleration of Science (**E-CAS**)" is a cooperative agreement between NSF and the Internet2 NREN to build partnerships with commercial cloud computing providers and science applications in ne uses of cloud computing capabilities. The approach is similar to the one the EOSCpilot took in Europe H2020, but the **E-CAS** project mobilises services from commercial providers instead of public ones. **CyVerse** provides life scientists with powerful computational infrastructure to handle huge datasets and complex analyses, thus enabling data-driven discovery. It provides data storage, bioinformatics tools, image analyses, cloud services, APIs, and more. The Internet2 NREN of the US runs the NET+ Cloud Services Program to support the adoption of cloud services within the academic and scientific sectors. The program is similar to the Cloud Framework of **GÉANT** in Europe and helps NREN members and other qualified institutions access cloud services through a variety of ways, including leveraging the Internet2 connection for delivery of cloud services, adoption of federated identity and access management, deployment and ease of integration of commercial cloud services, evaluation of key service components, facilitation community knowledge sharing, Influencing the industry to develop services, and encouraging a strategic relationship between the community and service providers.

A regional grid infrastructure was established in Asia-Pacific in the early 2000s to serve the Worldwide Large Hadron Collider Computing Grid. The infrastructure is still in use today and consists of a WLCG Tier-1 centre in Taipei and several, smaller Tier-2 sites. The infrastructure gradually opened up to other science disciplines and sites, thanks to various EC co-funded projects. As in the rest of the

world, cloud computing is becoming the dominant or desired type of infrastructure besides HPC in Asia-Pacific.

The Chinese grid infrastructure was deployed in alignment with and based on European grid infrastructures in the mid-2000s and resulted in the **CNGrid** infrastructure. Since 2007, there has been basically no exchange of e-infrastructure technology between Europe and China. **CNGrid** has evolved into an HPC infrastructure. The **AlibabaCloud** became one of the most significant global players, but its role in research use is not yet significant [36]. A recent cloud federation, **CSTCloud** is expected to bring an academia-led cloud infrastructure for the Chinese education, research, scientific and technical communities, government departments and hi-tech enterprises. This has recently started to exchange information with EGI on practices and tools for federating cloud sites.

Academia Sinica in Taiwan operates a distributed cloud environment for national researchers, based on OpenStackOpen. The system offers IaaS as well as higher level capabilities through a home-grown front-end, called DiCOS.

The Indian Grid, **Garuda**, is today India's national grid infrastructure of HPC systems, connecting 70 academic and research institutions across 17 cities. **C-DAC** has developed a complete open source based cloud software stack named "MEGHDOOT" for setting up a private cloud to offer basic cloud services such as Infrastructure, Platform, and Software services.

The National Institute of Science in Indonesia (**LIPI**=Lembaga Ilmu Pengetahuan Indonesia) operates a grid cluster, but also services other applications from weather forecast and molecule modelling. Insitut Teknologi Bandung runs two GPU clusters to support firewatch and other environmental science applications.

The Japanese National Institute of Informatics (NII) hosts a Centre for Cloud Research and Development (**CCRD**) as well as a **Gakunin** Cloud Adoption Support Service. The service provides a cloud testbed based on AWS and Google to run Proof of Concepts, and helps projects and institutes select and procure commercial cloud services for production runs.

The National Centre for Physics (**NCP**) in Pakistan supports physics and related applied disciplines in the country. One of the support activities is the operation of e-infrastructures for researchers in the field, and in this context the institute operates an OpenStack based private cloud. The cloud is hosting the national WLCG Tier-2 site and an HPC cluster for other communities.

The Advanced Science and Technology Institute (Philippines) provides NREN, HPC, science cloud infrastructures, as well as operates satellite ground stations to serve national research. The science cloud delivers cloud-based services to researchers and students and enables private sharing of data among specific groups. It provisions virtual machines and support projects and researchers.

The Australian research cloud, called **Nectar**, provides flexible scalable computing, with infrastructure, software and services that allow researchers store, access and run data, remotely, rapidly and autonomously. The architecture is similar to the **EGI** Cloud in Europe, the two infrastructures evolved in parallel and there are regular meetings between the two teams. Nectar also hosts online virtual research environments, called '**Nectar** Virtual Labs' for various disciplines. In 2017 **Nectar** was merged as a part of 'Australian Research Data Commons' (**ARDC**). Australia (and South Africa) will host one of the Square Kilometre Array astrophysics observatories and this instrument is expected to boost the national e-infrastructure landscape.

In New Zealand the New Zealand eScience Infrastructure (**NeSI**) has a service portfolio consisting of (1) HPC and analytics; (2) Consultancy; (3) Data transfer and share and (4) Training services.

South Africa supports e-Science with its National Integrated Cyber Infrastructure System (**NICIS**). **NICIS** promotes scientific and industrial development through the provision of HPC capability, high-speed network capacity and a national research data infrastructure, providing seamless access for the research and education communities of South Africa. It is a national initiative of the Department of Science and Technology and implemented by the **CSIR**. As mentioned above, South Africa will host one of the Square Kilometre Array astrophysics observatories and this instrument is expected to boost the national e-infrastructure landscape.

Cooperation in ICT between Brazil and European Union include coordinated calls between Brazil and EU). So far there have been four coordinated calls, with last round of projects to finish in 2019. Two of them relate to cloud application development (but not cloud infrastructure development): **ATMOSPHERE** aims to design and implement a framework and platform relying on lightweight virtualisation, hybrid resources and Europe and Brazil federated infrastructures to develop, build, deploy, measure and evolve trustworthy, cloud-enabled applications and **NECOS** addresses the limitations of current cloud computing infrastructures to respond to the demand of new services, as presented in two use-cases, that will drive the whole execution of the project.

Besides providing a Tier-1 and Tier-2 sites in WLCG, we could not find information about other grid or cloud e-infrastructures in Russia.

10.3.4 International Data infrastructures

Before going into regional infrastructures and projects, two global initiatives should be mentioned.

The Research Data Alliance (**RDA**) was already introduced in Section 2.5. **RDA** is not a technical infrastructure. It serves as a global platform for scientific communities and e-infrastructure communities to capture and share good practices and standards for data management, sharing and analysis, and to facilitate the uptake of those good practices within different disciplinary areas.

Generic e-infrastructure services

While some of the Research Infrastructures built their own services for the management of digital data, others rely on generic e-infrastructure services and expand those with science discipline-specific tools, data and support to achieve a customised setup for data depositing, short/mid-term storage, archival, processing, analysis and data dissemination. This work is supported by national, regional and continental e-infrastructures, and RDA and CODATA as global community platforms.

A similar global effort is **CODATA** [57], the Committee on Data of the International Science Council (ISC). **CODATA** exists to promote global collaboration to advance Open Science and to improve the availability and usability of data for all areas of research. **CODATA** also works to advance the interoperability and the usability of such data. Similarly, to **RDA**, **CODATA** also runs Task Groups and Working Groups but also supports the Data Science Journal and collaborates on major data conferences like SciDataCon and International Data Week.

The US nurtures a diverse and growing 'data services' landscape. Systems, such as **Dryad, figshare, Harvard Dataverse, Open Science Framework, Mendeley Data** are based in the US and offer data repository for researchers from any discipline to store and to share data. Although based in the US, these services attract an international user base. These repositories basically work with one of the following two business models, or a combination of those: 1) The repository is free for the users, but upload is subject to charge. In this case the cost of operation is covered by funders or from sponsors and donations; 2) The repository charges the users (e.g. **Dryad**). In this case the costs are recovered from the usage fees. Some of the repositories combine the two models and offer free services for users up to certain capacity limits, then introduce usage fees. Another, more complex generic data service in the US is the National Data Service (**NDS**). **NDS** is an emerging vision for how scientists and researchers across all disciplines can find, reuse, and publish data. It builds on the data archiving and sharing efforts already underway within specific communities and links them together with a common set of tools designed around the search, publishing, linking and reusing services. **NDS** shows remarkable similarities with the EOSC, with more focus on data and less on services and tools for data analysis. **ScienceOpen** is a discovery platform with interactive features for scholars to enhance their research in the open, make an impact, and receive credit for it. **ScienceOpen** offers services for three distinct user groups: Publishers are offered content hosting, context building and marketing services; Institutions are offered solutions and services to promote and share work, to build up branding for Open Access publications, to develop Open Access publishing paradigms, to create an independent Open Access publishing environment and; Researchers are offered search and discover of relevant research in over 56 million Open Access articles, sharing of expertise and receiving credits by publicly reviewing any article, promoting research and tracking readership with article- and author-level metrics, creation of topical collections. **Unpaywall** is an open database of more than 23 million free scholarly articles that the site harvested from over 50,000 publishers and repositories. The service comes with a Chrome browser extension that indicates during browsing that the user is reading an article record for which **Unpaywall** has the full text available. "**Dataset Search**", the service launched by Google in September 2018. It is, as the name clearly explains, a search tool to find datasets. Similar to the way Google Scholar works, Dataset Search lets users find datasets wherever they are hosted – a publisher's site, a digital library, or an author's personal Web page. Website owners shall enrich their site with metadata based on schema.org for **Dataset Search**. These metadata provide salient information about datasets: who created the dataset, when it was published, how the data was collected, what the terms are for using the data, etc. So opposite to the "push model" that data repositories typically use for gathering metadata from researchers' about datasets, Google Dataset Search applies a pull model reusing Google's Web crawler infrastructure.

Portage, Compute Canada (CC) and the Canadian Association of Research Libraries (**CARL**) are collaborating to provide a scalable federated platform for digital research data management and discovery Federated Research Data Repository (**FRDR**) service.

In Latin America we could find only the **LA Referencia** repository service, which gives visibility to the scientific production of higher education and research institutions in Latin America, promoting open and free access to full text, with special emphasis on publicly financed results. **LA Referencia** is a federated access layer to the Open Access repositories of 10 Latin American countries. **LA Referencia** has a strong partnership with the **OpenAIRE** repository services of Europe and facilitates the use of the **Zenodo** repository for Latin American researchers and institutions. **LA Referencia** stores scientific papers, articles, reports, doctoral and master theses, over 1.6m items in total.

10.3.4.1 Australia

The key data initiative in Australia is the Australian National Data Service (**ANDS**), now merged with **RDS** and **Nectar** in the Australian Research Data Commons (**ARDC**). **ANDS**' core purpose is to make Australia's research data assets more valuable for researchers, research institutions and the nation. **ANDS**' flagship service is the Research Data Australia discovery portal where one can find, access and reuse data for research from Australian research organisations, government agencies and cultural institutions. **ANDS** does not store the data itself here but displays descriptions of, and links to, the data held by their data publishing partners or contributors. In a simplistic sense **ANDS** is the Australian version of Google Dataset Search, using the RIF-CS schema. **NCI Australia** is the nation's most highly integrated high-performance research computing environment. **NCI** operates the National Research Data Collection, Australia's largest collection of research data, encompassing more than 10 PB of nationally and internationally significant datasets.

10.3.4.2 Africa

In Africa the most relevant generic data project we could find is the African Open Science Platform initiative (**AOSP**). **AOSP** is funded by the South African Department of Science and Technology (DST) through the National Research Foundation and implemented and managed by the Academy of Science of South Africa. **AOSP** is a pan-African project for Africa by Africa, with direction provided by **CODATA** (See Section 3.4 above). The 3-year project was launched in December 2016 and ended in October 2019, possibly with a second phase starting in 2020. Until now AOSP facilitated the exchange of good practices, tools, approaches for Open Science by organising schools and other events but sharing information has taken place through the Web and other channels.

10.3.4.3 China

China mandated data availability in national data centres after 2018 when the Chinese government decreed that all scientific data generated in China must be submitted to government-sanctioned data centres before appearing in publications. The Chinese government supports the implementation of both policies by developing 20 national data centres, covering all types of research data. These national data centres are planned to feed into an overarching cloud infrastructure called **CSTCloud**, similar to the European Commission's vision for the **EOSC**. While development of the **CSTCloud** and the 20 national data centres is ongoing, there are many Chinese repositories with a more focused scope making good progress in key aspects of open data. A notable example is the Fudan University Social Science Data Repository.

10.4 Findings

The e-infrastructure landscape is quite well connected between the EU and the rest of the world. **GÉANT, PRACE, EGI, OpenAIRE** have active collaborations worldwide. E-infrastructure facilities/ capabilities are well developed and organised in the US, Canada, Australia and Japan, but how they relate to one another is often in flux: From the high-middle income countries China and Russia were found hard to assess and we do not believe we could fully review their landscape. The main reasons are related to language issues, the size of countries and that the EU did not have joint e-infrastructure activities for some years with them. Joint EU-regional initiatives (such as calls for projects like in Brazil) could facilitate regional activities and/or more intense international exchange of information. Africa, India and the Middle East seem to be lagging in e-infrastructure availability, compared to the rest of the world.

The NREN concept is adopted worldwide, and collaborations between **GÉANT** and NRENs of other regions are in place. The EC runs initiatives to develop NRENs in regions where NRENs do not exist yet. **GÉANT** with its expertise is recognised and used in those projects.

The HPC topic is competitive in nature. Europe recognised that it can remain competitive with the US and China only if national fragmentation is eliminated from HPC development. The **EuroHPC** initiative therefore started, and it is on its way to help Europe enter the “Exascale club”. **PRACE** participates in joint initiatives with US, Japan and the ASEAN countries.

11. CONCLUSIONS AND GENERAL FINDINGS

Main contributors
Ari Asmi (University of Helsinki)
Jostein Sundet (Independent expert)

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11.1 Overview of the analysis and its goals

The RISCAPE project was supported by the European Commission (EC) Horizon 2020 programme to do a landscape analysis of major Research Infrastructures (RIs) globally (in this context – outside of Europe). The project lasted for three years (2017-2019) and was tasked with publishing a coherent and comprehensive landscape report. A landscape report is a consistent snapshot of RI organisations and their services in an area that can give insight into competition, coverage, overlaps and gaps of various kinds. For RIs, a landscape mapping will give insights into what is the current availability and types of support structures for research in a given geographical area and science field.

The motivation to make a global RI landscape report is partly based on the developments of the European RIs. ESFRI will soon have been active for 20 years and has, during this period, been instrumental in setting up and implementing a European strategy for building up critical RIs to meet the EC goals for an inclusive, expansive and leading region for science, innovation and sound societal development. Challenges scientists are trying to overcome are often global, with ever increasing need for integration, alignment, and co-operation. Therefore, there is a need for finding, understanding, and connecting Research Infrastructures globally – and in this context there is a need to better understand the global RI landscape.

11.1.1. The team

The European landscape of RIs are divided by ESFRI into domains. These domains have often self-organised (with the help of European Commission funding) into RI clusters, where RIs for similar user communities or communities with similar RI service needs, can coordinate and align their operations and strategies. An essential part of the RISCAPE data acquisition and analysis was to harness the disciplinary knowledge and networks RI clusters have gained during their development. For scientific domains without an RI cluster, either an RI or a research organisation was invited to join the consortium and suggest or appoint experts for RISCAPE. In addition to the RISCAPE project team, a stakeholder panel with representatives from international organisations, funders, international RI and ESFRI experts was established to oversee the development of the project and give advice on methodological and domain data and analysis questions.

11.1.2 Prioritisation, scoping and implications

A landscape analysis requires careful consideration of the scope of the analysis (what is included and what is not), as well as consideration of the information to be collected. The analysis is primarily intendended for European users, particularly funding agencies and European ESFRI RIs; they were also carefully considered in the overall design of the study. From this it follows that the analysis naturally has a European viewpoint on the landscape – which increases its applicability for these user groups but with some loss of generality. Overall the project aimed to find and analyse Research Infrastructures that resemble or could somehow complement the European ESFRI (and other major) RIs. Another consideration is the resources and time available, and expertise needed for the collection of information. An analysis of every facility which is used to support science (of any kind) anywhere in the world would be a truly Herculean task – with that perspective it is evident that some limitation of the scope was needed; there was a need to limit the study to only consider relatively large and critical RIs. There were also considerations of the types of RIs that we would not analyse, as they are already covered in other landscape analyses, not considered as European RIs, unlikely to provide information, or would be unlikely to be useful collaborators. These limitations reduced the RI landscape considerably, and satellite observations, many governmental monitoring systems (e.g. operational meteorology), military research, and facilities not (openly) available for the research communities were disregarded. In the end, a common RISCAPE definition of a Research Infrastructure was devised and used to choose objects for this study (see chapter 2 for details). This a priori definition of the RI was necessary to initiate the information collection but proved to be challenging for some domains.

The overall methodology is based on using existing ESFRI RI knowledge and networks, augmented by desk research, to find potential RIs. The RIs were contacted to do a structured interview with a person who represented the target RI, to collect a wide set of information about their organisation, its goals and operations. The number of questions was limited by time. Similar consideration was given to the content of the questions to avoid possible sensitive

topics. The interview process was generally a positive experience for the interviewers and the interviewees, and the open discussion was considered a good way to avoid misunderstandings and provide reliable data.

This report gives an overview of large RIs for the eight domains devised and is believed to be useful for funders and international organisations that want to understand the current landscape. We have also placed effort on making the report useful for RI managers, both within and outside Europe, to be useful as a directory to find other interesting RIs around the globe. Finally, we have documented all the steps we have taken in the methodology to be used as basis for future landscape exercises, whether global, regional or national.

11.2 Organisational perspectives

The analysis of the international Research Infrastructure landscape in this chapter is done in three parts. The first looks at more generic features of the organisation of the RIs that cover themes such as geographical cover, the outcomes and consequences of the methodology used, scale issues for the RIs and the funding and support both for establishing and for operating an RI. The second comments on more operational perspectives of international Research Infrastructures identified in this report. The last part shares some reflections on the landscape mapping exercise.

11.2.1 Where the RIs are located?

In this report it is consistently shown that the wealthiest regions have the most RIs. This is in itself not a surprise, but the data collected can shed some light on several reasons for this. Europe, the US and parts of Asia and Australia are well represented with a plethora of RIs for most of the domains studied. The most likely reason for this is the number of scientists and the presence of funding for a science area that support the need of RIs, although there may also be political, economic, security and sometimes prestige motivations for building up RIs. A dynamic combination of excellent science and funding pushes the need for more advanced tools and developments, leading to development of (local) RIs that is needed to do even better science. This structural condition appears to be of prime importance for the initiation and growth of RIs, that often later will, under the right conditions push development of global level Research Infrastructures.

There is a strikingly different view when we look at presence of RIs in Africa, the Middle East and, to some extent, South America. These regions seem to lack a critical mass of scientists and funding needed to motivate world class facilities. This lack of strong scientific communities can also be due to few RI facilities, creating a system where critical research needs are dependent on the use of non-local facilities. In many cases we find that the existence of RIs in these regions is fostered through collaborations with Europe, the US, China, Japan and/or Australia. This does not mean that there are no smaller-scale but important RIs in the regions, which by additional investments could become critical nuclei of scientific excellence. An important driver for establishing RIs in these areas is continued collaboration with Europe and other key countries. South Africa is an interesting exception and has RIs in several domains as explained in the different chapters of this report.

Another interesting result is the apparent lack of RIs in Russia and China, and to a lesser degree in South Korea and other Asian countries. These countries generally have high impact and investment in global research communities but have a surprisingly low number of RIs in this analysis. This seems to be an artefact of the methodology chosen and language used in the survey, as discussed later in this chapter. Researchers in Europe have fruitful collaboration with both Russian and Chinese communities, and there is even evidence of important RIs in these regions, but most of these have not replied to the contact requests for the survey. The Energy domain chapter is the only one where we find a comparably large fraction of RIs from these regions. This supports the hypothesis that language barriers might be a partial cause for the lack of response, as the Energy domain was the only one that used interviewers who spoke the local languages.

The existence of Roadmaps for RIs is another factor that seems to be important for the existence of major RIs and RI collaborations. In Europe and Australia, we find several generations of RI roadmaps generic for all research domains, and more countries seem to be adopting the practise, e.g. South Africa. This is not the case in most other regions. There is a wealth of strategies, cases of establishing and existence of domain specific RIs and politically driven establishment of RIs. This apparent lack of roadmaps coincides with the lack of (at least discovered) large scale RIs. In the case of the US and Japan, RIs are established and managed in a different way compared to Europe and Australia, and strategies and plans are done differently. We also note that the regions with roadmaps or strategic plans was easier to approach and acquire relevant information from. Again, in some regions there might be strategies that are not public that we are unable to acquire and use.

Research Infrastructure as a separate entity?

Confusion around the concept of an RI often comes from the differing governance and structuring methods for the RI-like activities in different countries. Some, like Europe, like to build their RIs as separate entities, with clear organisational boundaries, own strategies, plans, and rules. For example, the Australian model of an RI is closely aligned (or at least interoperable in this sense) with the European RI landscape. Indeed, some of the project interviewers stated of how easy it was to interview Australian RIs, as they had an extremely similar mindset on organisational questions. In contrast, many US RIs operate within universities, research centres or national laboratories, sometimes making the definition of “which part is the RI” very challenging. Similarly, Japanese RIs can be embedded in large governmental research centres.

11.2.2 Methodological bias

The methodology has deep implications for the results of this international RI landscape report. Some of the limitations were not a priori obvious but became apparent during the project. As mentioned above, the analysis concentrates on large facilities (of scale similar to ESFRI RIs in Europe), which limits the amount of facilities to be analysed, but simultaneously also misses small scale RIs which could, with some level of coordination structures, be considered a distributed RI in Europe. Another key challenge was the consideration of "unknown unknowns", i.e. RIs which are not known in the European RI environment at all. For very large facilities this is a relatively unlikely, but for the fields traditionally less internationally connected, there is a potential for missing some key facilities.

In Physics (Chapter 5), even with the limitations considered above, the RI definition led to a very large number of facilities, and expert help was needed to select the most relevant criteria for the study. In Energy (Chapter 6), the consideration of only public bodies (not commercial research) limited the viewpoint significantly. In the Social Sciences (Chapter 8), and in Cultural Heritage, Digital Humanities & Languages sector (Chapter 9), the definition was removing most of the non-European organisations – forcing them to concentrate on initiatives which would not be, strictly speaking, RIs using the definition in this report.

One of the biggest limitations in this study was the low response rate of potential RIs. This lack of data is a considerable limitation on the coverage of this analysis and might be partly connected to the use of the English language for the initial contact and the interview. As mentioned above, one domain (Energy) used local language interviewers, which increased the response rate significantly. This shortcoming might have been mitigated to some degree by translating the survey into the local language and making the survey shorter.

Methodology is always a challenge when moving out of the RI comfort zone of Europe, which (after years of work) has converged on a relatively coherent and unified language when it comes to RIs. It is noted in several of the domains that there were both misunderstandings and miscomprehensions of the questions in the surveys, underlining the need for a discussion-based interview tool, instead of passive surveys. To some degree, the questions were tailored to the specific domains to try to fit this to the jargon of the domain, and much information was pre-filled before interviews, helping the interviewee to understand what the actual the meaning of the terminology was. Terminology will always be a challenge in this kind of exercise but is surprisingly problematic for many of the terms and concepts used in the survey. For instance, the concept of a distributed RI was in some cases reported to be conceived differently in some regions than it is in Europe. Also, the definition of an RI was, in some cases, also a challenge: There were even cases where an organisation would insist on not being an RI but still fulfil the RISCAPE definition.

We have recorded the process for acquisition of information, both on a general level and also on how it has been done for the individual domains. This process can be used as a template for further landscape exercises and to provide both best practices and lessons learned examples for harvesting this type of information.

11.2.3 Domain specificities

Although there are many similarities among the domains there are three that are notably different from the others others. Social sciences, CH-DH-L, and e-sciences. The reasons for this are probably many-fold, but we try to summarise the most important factors here.

We observed a significant difference between the natural-science-based and social-science-based RIs, in size, numbers, geographical cover and level of maturity. First, we observe that social sciences and CH-DH-L were the two domains for which had relaxed in the criteria for an RI in the RISCAPE analysis, in order to have any presence of large scale RIs outside Europe. In these two domains there are a large set of smaller scale RIs, but also international, global networks and collaborations. A question is why there are so few ESFRI scale RIs for these two domains outside Europe? The domain reports themselves state that with coordination of smaller scale RIs there would be ESFRI scale RIs outside Europe, but that there is currently no driver for this to materialise. Another reason might be connected to the dependence upon e-infrastructures. We expect this to change in the near future, with development of large scale RIs for these two domains also outside Europe.

Third is the e-infrastructure domain. This is the domain that all the other domains are dependent on in order to be an ESFRI scale RI. This is so for a number of reasons, virtual access, data sharing, storing and curating, collaboration, services, running a distributed RI, and many other factors. It is easy to understand this when the four subdomains in the e-infrastructure domain is listed: network, cloud services, computing and data services. All of these pertain to all large ESFRI scale RIs in various degrees. As such, the e-infrastructure is the omnipresent that all the RIs depend upon. In addition, the e-infrastructures also have a self-interest in their own developments, sustainability and collaboration. One observation is that very few of the RIs are using services that do not directly relate to the basic services. It is difficult to find RIs that use higher level services developed in the e-infrastructure domain, but rather they make their own developments of services needed in the respective domains. This also is the case for data services.

11.2.4 Scale issues

This landscape analysis has been concerned with the scale, the size, of the RIs, in order to be able to manage the large amount of Research Infrastructures for this analysis. But the scale issue also pertains to other important attributes for RIs, such as cost of construction, cost of operations, number of users, number of countries involved. In some of the domain reports the cost of the different subdomains or even individual RIs are estimated, and some few have indicated the cost of operations. A challenge here is again related to definitions on what is included in the costs-figures given. The most striking here is not the cost itself, it is rather the challenge it is for many of the RIs to estimate the cost for build-up of a specific RI. This has various reasons, but is particularly relevant for the distributed RIs, where there are many (national) nodes that overall are centrally organised as an RI. This can be illustrated with considerations for including several pre-existing instruments, that themselves have been developed over a long period, often originating with a single scientist or group. Altough the instruments can have some specific value indicated, they do not necessarily represent the true value of the work done for the creation and development of the instrumentation and associated systems. Assigning a value for a such longtime development can be impossible afterwards.

Cost of building and operating an RI can be difficult because of the different ways of estimating the cost. Are the costs for personnel, electricity, instrumental and office space and other, often "hidden", costs included? Also, different countries and/or regions have various ways of estimating cost.

11.2.5 Funding models and sustainability

As research funders and organisations must manage increasingly large and complex portfolios of Research Infrastructures, they must develop together with RI managements and administrators financing and operating models that can ensure the successful operation of RIs beyond their establishment phase, considering the evolving needs of the different scientific communities. There are various definitions of sustainability, encompassing different criteria. Effectiveness and sustainability are dependent on several elements which are interconnected. The practices and policies which are required to promote them depend upon a variety of factors including the nature of the RI (single-site, distribute, virtual), its role and user base, its membership, its financial arrangement, the national or international funding bodies supporting it, and its host (if any). There is clearly no "one size fits all" sustainability model.

Sustainability is a multidimensional feature that includes, competitiveness, funding, attractiveness of key personnel and attractiveness for scientists to use an RI. For some domains it is surprising to observe that the funding horizon is short and, in some cases, very short compared to the conceived lifespan of the RI. There were even RIs that reported that they had a funding horizon of only one year. Little information was gathered about other aspects of sustainability of the RIs, but there are efforts in Europe for training a new generation of RI managers and personnel with the RI-train project that specifically educate people to develop and operate RI organisations.

11.3 Operational perspectives

One of the most important factors for a Research Infrastructure is how it can be accessed and utilised for research. In a perfect world, access is only limited by the needs of the researcher without any restrictions by the Research Infrastructure side. However, this openness can only be supported for services which have minimal marginal costs per user, with archetypical example of scientific data sets produced by or in the infrastructures.

Open access to research data products is very common in all fields of RIs analysed in this report. Limited data access can be related to legal and ethical considerations, particularly on data with a human dimension or other sensitive content, but can be also connected to academic or economic ambitions towards the created data products. For sensitive data, RIs typically have their own rules to determine access based on internal or external review, and such access can also be limited by legal concerns, limiting their access e.g. to foreign researchers, or some specific purposes or in unmodified form. Some facilities utilise time embargo for data, where it becomes openly accessible only after a set time, typically in the range of months to a couple of years. This kind of embargo time is then enabling the data producer to exploit the data for scientific or innovation purposes, before letting it be freely used by the rest of the community. Embargo is typically connected to situations where the data is user-generated using the RI services and only managed in the RI or is considered to have economic potential. It is also relatively rare for RIs to have clear data policies, and defined data licences. Even with these limitations, openness of research data is becoming the global norm in RIs.

When the RI service is limited, by cost or capacity, the access modes change. Decisions on which researchers to give access to is variable and is strongly dependent on e.g. the business models, nationalities of the researchers, research priorities, funding agency requirements, and even the research culture of the field. The most common mode of access is excellence-based, where it is determined by a review of the scientific merits of the planned research (by internal or external board - sometimes connected to research funding evaluation). Other methods are used instead or in conjunction with excellence-based access, requiring the user to have a collaboration with the RI organisation or being part of the consortium, by collecting user fees, and even in some rare cases informal ad-hoc decision. It is also relatively common to give access to or to prioritise only some specific nationalities, organisations, or grant holders, targeting the use of the facility towards communities which have supported its construction. This can also be attained by using specific quotas for selected user groups. In some cases, the physical visits by foreign scientists were considered a welcomed way to support and even increase the excellence of research done at the Infrastructure and associated research facilities. Non-scientific use of the facilities, if relevant, is usually evaluated in other ways and usage fees seem to be more common.

Many RIs are struggling with their data services capacity to build e.g. virtual laboratories, with expectations of data volumes to increase radically in the future. In many countries these issues are handled by establishment of centralised e-infrastructure (or cyber-infrastructure) services, sometimes supported or supplanted using commercial services. Such external services are highly country- and discipline specific, but several commercial service provider initiatives exist around the world for academics to use clouds for data storage and processing.

RIs are major investments and they need to justify their existence and operations. Following the use of the services is a relatively straightforward method for any resource-limited service, and even openly available services (many data repositories) can collect metrics for usage information. Many RIs have started to follow the usage by requiring their users to cite or acknowledge the use of the facilities in their publications, or directly report their research outputs to RIs they have used, with varying levels of success. This kind of bibliographic follow-up is done by the RIs themselves, or in some cases by funding agencies or third parties, or journals where the publication was printed. Although relatively straightforward, publications often come only after years of time-lag after using the RI. This is not the only way to track scientific impact, and many facilities use demand for their services, user surveys, presentations in conferences, expert evaluation groups, presence in national or regional roadmaps and similar documents, or even public perception and press interest as a measure of scientific impact.

There is a clear global pressure for the RIs to demonstrate economic and societal impact. Economic impact is typically followed by number of patents, spin-offs or industrial partnerships, or even some cases following the downstream use of the RI products by companies. Many experimental facilities provide services for private sector, sometimes even almost exclusively. Even more challenging are often the more indirect impacts to the society, increasingly required from the RIs worldwide. Results show that this is extremely difficult to assess. In many cases societal impact is tied on the local economic impact of the RI construction, and the consideration on the boost of the local economy and society with increased innovativeness and economic activity. Some RIs, e.g. in environmental research, attempt to follow direct impact on RI supported research on decision making and governmental policies. As an example, Chinese Ecosystem Research Network is

actively creating recommended ecosystems management practices. Another approach is to consider the increase in the national scientific literacy and education level resulting from the RI activities. However, often the societal impacts are more anecdotal in nature, with single examples or cases where impact could be demonstrated. Very rarely, RIs reported to be satisfied with the methods at their disposal to follow these impacts. Indeed, one can question the feasibility to evaluate the societal impact of an RI providing services for (fundamental) research, particularly in short to medium time scales. Many examples of direct and indirect societal impacts of RIs are mentioned in this study. Consistency in measuring these impacts does not appear likely to be resolved in the near future.

11.4 Reflections and perspectives

One of the key goals of the RISCAPE project was to find complementarities between the ESFRI RIs and non-European RIs. In some cases, the complementarities exist already, with direct examples of ESFRI RIs or other major RIs with a European contribution to some international initiative. An example is the European Euro-Argo Research Infrastructure that is the European operational component integral in the global Argo ocean float observatory system. Similar cases can be found in many international joint activities ranging from fusion research to observation of gravitational waves. In these cases, the collaboration and complementarity already exist, and it only needs consideration of the scale and role the European component have. Geographic complementarity can be seen in e.g. social sciences, where surveys can follow overall similar patterns in different populations around the world, or in many environmental observations, such as in greenhouse observations of European ICOS and US NEON. Natural collaboration patterns are often developed from these similarities but can need external support or supported framework. Sometimes complementarity is about sharing the capacity of facilities. In Physics, access to analytical facitilies has traditionally been excellence based and global. The analysis showed many potential complementarities in all of these categories, and in most fields the collaboration with European RIs was welcomed as an idea, even if not always yet apparent. However, formal collaborations were considered much more cautiously, possibly due to expected complexities.

Knowledge about the existing or potential international complementarities is important for both RIs and funders. International joint planning or at least information sharing is crucial for efficiency, but direct collaborations should be considered. Many already exists (and are in this report), and the potential for additional levels of collaboration is evident. Another aspect are the cases where no corresponding facilities at this scale were found globally. This puts the European RI into a unique position as a potential service provider for a truly global audience. For example, iNSTRUCT-ERIC in the field of structural biology is the only facility of its kind.

Even though the implementation is different, the concept of a Research Infrastructure is clearly global, at least in most of the fields considered. Major exceptions seem to be in the cultural heritage, digital humanities and social sciences, where the European RI-type of organisation was rarely observed in other areas of the world. However, the idea of shared resources and joint activities is natural also in these domains, and many smaller facilities and RIs exists on organisational scales smaller than could be captured in this analysis. In several areas these smaller facilities could be considered similar to individual nodes of the European distributed RI but lack the coordination layer which could help them to provide more consistent services to larger research communities. The European experience shows that relatively small investments to a coordination can lead to increased scientific coordination and productivity.

RISCAPE

Mapping the Research Infrastructure Landscape

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APPENDIX 2 - RISCAPE Questionnaire

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
1	**Name of the respondent**	Text	We need to record the name of the responent. Provenance requires us to know who is answering the questions: For follow-up, and further questions, and to understand the position of the person.	
2	**Job title**	Text	Same reason as the name of the responent. Need to confirm their position in the organisation	
3	**Who can we contact for further comments/queries? Please provide name & email.**	Text	The contact information is crucial for provenance, and makes it possible to return to the person answering (or the organisation)	use English translation if official is found – also record official name in local language is reasonable within Latin alphabet
4	**Organisation full name**	Text	For presentation of results	use English translation if official is found – also record official name in local language if reasonable within latin alphabet
5	**Organisation short name**	Text	For presentation of results	use English translation if official is found – also record official name in local language if reasonable within latin alphabet
6	**Website address of the organisation**	Text	For presentation of results	
7	**Head office address**	Text	For records, and for geographical coverage	Head office: The administrative headquarters of an organisation. This is usually where the director is located

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
8	**Official contact email**	Text	For records, gives the location of information collection. We would need a way for the future users of the RISCAPE reports to contact the organisation if needed. Thus an email address (not personal if possible) is advantageous	

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
9	**ESFRI in Europe divides research infrastructures in three categories:** **1. single-sited** **2. virtual** **3. distributed** **Which do you think best describes your organisation, if any? (you can give additional information in the next question)**	Multiple choice	Categorise the Ris according to the ESFRI definition of Project or Landmark – helps on the comparisons and listing. One is preferred, but in some cases it might be necessary to have several if the organisation has many quite different aspects serving different needs.	ESFRI: European Strategy Forum on Research Infrastructures Research Infrastructure: A science oriented service provider for researchers to do their science. Typically providing services (access) to facilities to too large or expensive to be used without sharing. RISCAPE definition of research infrastructure expects them to be a) science oriented, b) accessible to researchers outside of their own organisation, c) of high scientific importance in the field, and d) have a operational time scale much longer than a typical research project. Single-sited: Research infrastructure, where majority (or all) of the services are provided in one geographical location Distributed: Distributed infrastructure has their main research activities (facilities) distributed geographically wide area. Virtual: Virtual refers to infrastructure, where the direct user access to services done completely on-line (usually data or computing). Typically these are data oriented e-infrastructures (cyberinfrastructures).
10	**If needed, you can give some additional information related to previous question on the type of your organisation**	Text		
11	**Where are your facilities located? For distributed infrastructures, what geographical area do you cover?**	Text		

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
12	**Are there central facilities, and where they are located?**	Text	Central facilities can be important for defining geographical centre of operations. These are also good to determine where the main activities are located. For single-sited RIs this is non-issue, as the facility usually is the main central facility	
13	**Are there significant secondary locations outside of the main locations? If so, where?**	Text	Sometimes a single-sited or area does not make good impression of what is actually done in an infrastructure - this gives a possibility to elaborate e.g. if there is a single site, but outlying additional sites	
14	**What is the primary or main source of funding (e.g. international/national/ regional funding agency, governmental agency, user fees)**	Text	RISCAPE project also is aiming to create new collaborations between the research infrastructures. Knowing the agencies and ministries mainly responsible for the funding makes it easier for involved funding organisations to develop collaboration projects.	
15	**To estimate the scale of your organisation: If you were building your organisation today, what would be the approximate construction costs (order of magnitude estimate, 2018 terms)?**	Text	This information is only important to evaluate the overall scale of the operations,not an accurate estimate of actual value.	
16	**To estimate the scale of operations, what are the approximate total running costs of your organisation (order of magnitude, including secondments, in-kind contributions, etc.)?**	Text	To determine the approximate scale of operations, not to evaluate actual value.	

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
17	**Are these operational costs 'stand alone' or or they calculated on the basis of a larger organisation within which the research infrastructure is located? Please add details** **Please choose only one of the following:** **1. stand alone** **2. larger organisation** **3. other (please specify)**	Multiple choice + text	In some cases, the "research infrastructure" is a part of a larger science performing organisation. This question is intended to help to determine are the scale of operations estimated from the infrastructure or the whole organisation.	Research Infrastructure: A science oriented service provider for researchers to do their science. Typically providing services (access) to facilities to too large or expensive to be used without sharing. RISCAPE definition of research infrastructure expects them to be a) science oriented, b) accessible to researchers outside of their own organisation, c) of high scientific importance in the field, and d) have a operational time scale much longer than a typical research project.
18	**Does your organisation have a business plan or statutes or similar document describing the goals and operations? Are they available?** **Please choose only one of the following:** **1. Business plan** **2. Statutes** **3. Both** **4. Neither** **5. Unsure**	Multiple choice + text	These kinds of documents help us to determine the type of organisation and can be useful for finding collaboration opportunities. (for non-English documents, further clarifying questions can be made afterwards)	Business plan: a comprehensive strategic plan for the organisations business, including all aspects of the operations, cost recovery etc. Statutes: founding or official documents defining the goals, and rules of the organisation. Constitution.
19	**Does your organisation have operational time horizon well beyond a typical science project in your field?** **Please choose only one of the following:** **1. yes** **2. no** **3. unsure**	Multiple choice + text	Time Horizon is necessary to identify organisations which are intended for long time operations (typical for EU research infrastructures). This is imporant to identify potential collaboration opportunities.	

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
20	**Does your statutes or business plan mention a time horizon explicitly? I.e. by referring to operations relatively far in the future, or giving a long term investment roadmap?** **Please choose only one of the following:** **1. yes** **2. no** **3. unsure**	Multiple choice + text	to identify the duration of the organisation. This is one way to get the necessary information in more traceable manner.	
21	**Does your organisation have an existing long term funding decision from your main funding source? Does your organisation receipt multi-annual funding?**	Text	to determine the funding duration and current sustainability situation - this is important to determine potential collaboration opportunities. "Long term" here is the same as in the previous questions: i.e. far longer than usual science projects.	
22	**What other information can you provide to us to determine the time-scale of the organisation?**	Text	to determine the time-scale of operations	
23	**Is there a mission statement (or similar) of your organisation?**	Text	to identify the focus of the organisation	Mission statement: Short official statement of the overall mission of the organisation

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
24	**Are there societal, scientific or other grand challenges do you specifically aim to respond?**	Text	To capture focus of the organisation and to find organisations with similar overarching aims	Grand challenge: Lund Declaration 2009, 2015 identifies the importance of responding to grand societal challenges (eg Ebola, migration); EC identifies seven grand challenges in H2020: 1. Health, demographic change and wellbeing; 2. Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the Bioeconomy; 3. Secure, clean and efficient energy; 4. Smart, green and integrated transport; 5. Climate action, environment, resource efficiency and raw materials; 6. Europe in a changing world - inclusive, innovative and reflective societies; 7. Secure societies - protecting freedom and security of Europe and its citizens. Source: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges Similar grand challenges are in several other fields, such as in engineering, physics, etc. The above is not meant to be limiting list, but to give examples in the European landsape - other examples are free to use, but the overall aim is to find out if there is a specific great goal (of wider interest) the organisation is aiming towards.
25	**Are there specific technical, scientific or societal problems does your organisation aims to address?**	Text	To capture the focus of the organisation and to find out potential pairings in the European landscape	

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
26	**Is supporting science or performing science the key goal of your organisation?** **Please choose only one of the following:** **1. yes** **2. no** **3. Other (please specify)**	Multiple choice + text	To capture science focus	Research performing organisation: Organisation making research activities and products directly by their staff. Typical examples are universities and research centres.
27	**Which one of performing or supporting science has current priority for your organisation?**	Text	Distinguish between primarily research performing organisations and primarily research infrastructures.	
28	**Do you have a centralised (e.g. single document or a website) service catalogue for your research services? If publicly available, please provide link.**	Text	A separate service catalogue ease the analysis of services and finding cooperation opportunities. Also, several European RIs are currently building their own catalogues and examples of these would be very valuable.	
29	**What kind of research services and resources you provide for research or researchers?** **e.g.** **- Local research facilities (i.e. laboratory)** **- Mobile research instruments (i.e. mobile laboratory)** **- Remote sensing instruments (i.e. sensors mounted on aircraft, satellite, other)** **- Datasets (data archive/repository, databases other)** **- Specialised research tools or services (i.e. scientific software, data management system)** **- Computing (local supercomputer, distributed computing based on Grid/Cloud services)** **- Other**	Text	To capture the organisation services	

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
30	**Technical capability** **What are the specific capabilities of your organisation? What are the significant capabilities of your organisation?**	Text		
31	**Are your operations significantly dependent on external service providers? (E.g. data transfer, data analysis, data storage)**	Text		
32	**Do you provide key services to other facilities, research infrastructures or similar?**	Text		

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
33	**What kinds of access for these services (physical, virtual, remote, or other) does your organisation provide?** **Comment only when you choose an answer. Please choose all that apply and provide a comment:** **1. Physical access** **2. Virtual access (inc. data)** **3. Remote access** **4. Other**	Multiple choice	We need to find out what types of access are there in general for this facility. Typical cases are physical, virtual/data, and remote access	Access: Access refers to the legitimate and authorised physical, remote and virtual admission to, interactions with and use of Research Infrastructures and to services offered by Research Infrastructures to Users. Such Access can be granted, amongst others, to machine time, computing resources, software, data, data-communication services, trust and authentication services, sample preparation, archives, collections, the set-up, execution and dismantling of experiments, education and training, expert support and analytical services. Physical: Physical access means direct hands-on access on the facility or service on-site Virtual: Virtual access refers to direct user access to services (usually data or computing) done completely on-line. Remote: Remote access refers to access where the actual use of the physical of virtual service is done by the request of the User, i.e. by user directly
34	**Is access mainly determined using an independent peer review process (excellence based)? Please provide details** **1. yes** **2. no** **3. unsure**	Multiple choice + text	To main access methodology	

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
35	**Can you estimate the proportion of your research infrastructure's services available to external parties (i.e. those not funded by your organisation)?** **1. Less than 25%** **2. 25% to 50%** **3. 50% to 75%** **4. 75% to 95%** **5. 95% to 100%** **6. Not applicable** **7. Other (please specify)**	Multiple choice	To determine possiblity to access the services	Research Infrastructure: A science oriented service provider for researchers to do their science. Typically providing services (access) to facilities to too large or expensive to be used without sharing. RISCAPE definition of research infrastructure expects them to be a) science oriented, b) accessible to researchers outside of their own organisation, c) of high scientific importance in the field, and d) have a operational time scale much longer than a typical research project.
36	**Do you have additional quotas or limitations for external users access (i.e. researchers outside of your own organisation)?** **1. yes** **2. no** **3. Don't know**	Multiple choice	To determine service access (e.g. for European partners)	
37	**How much of the services are actually used by external parties? Does this differ by service type?**	Text		
38	**How can researchers from European organisations currently access your organisations services?**	Text	To determine potential collaboraiton possibilities	
39	**Do you have existing collaboration agreements wtih EU based research organisations? Which ones?**	Text		

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
40	**Do you have an existing data policy publicly available? Can you a provide a link?** **1. yes** **2. no** **3. unsure**	Multiple choice	Data access possiblities	
41	**Do you use open licences for data produced in your organisation?**	Text	Data access evaluation	Research performing organisation: Organisation making research activities and products directly by their staff. Typical examples are universities and research centres.
42	**Is the scientific impact of research done in your facility systematically followed in some way (by you or other parties)?** **1. yes, by you** **2. yes, by third parties** **3. no** **4. Other (please specify)**		Scientific and societal impact is a major part of determining the role and position of a research infrastructure. Methods for this are developing and thus we need to collect information how this is approached	
43	**Do you have other means to demonstrate the scientific and socio-economic impact of your organisation?** **1. yes (if yes, please add details)** **2. no**	Multiple choice + text	Find the documents, for further analysis if needed. Commonly these could be evaluation reports, altmetrics, etc.	Impact study: Any consistent analysis of the impacts of the research infrastructure to scientific field and/or societal goals. Examples include through literature analyses, citation index analyses, patent listing, and societal impact analyses. Research performing organisation: Organisation making research activities and products directly by their staff. Typical examples are universities and research centres.

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
44	**Do you have reports on your (scientific or societal) impact publicly available?** **1. yes (if yes, please add weblink/identifier)** **2. no** **3. unsure**	Multiple choice + text	Find the documents, for further analysis if needed	
45	**Do you have some other means to show the impact of your organisation?**	Text	Impact analyses are not available in all cases, or there might be other ways to present the overall impact and position of the RI	Research performing organisation: Organisation making research activities and products directly by their staff. Typical examples are universities and research centres.
46	**Do you collect metrics (or indicators) for scientic or societal impacts? Please give details**	Text	Determine key metrics used, their values, used in significance evaluation	Metrics are numerical indicators of use. Typically these could be the number of times facility has been referenced, citation indices, number of publications done, data downloads, etc.
47	**How do you collect user statistics of your services or organisation?**	Text	Determine key metrics used, their values, used in significance evaluation	User statistics: Quantitative data on the numbers accessing the facility, the service Research performing organisation: Organisation making research activities and products directly by their staff. Typical examples are universities and research centres.

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
48	**Can you provide this information (or a link) on user statistics, number of users (per service if possible), access times, altmetrics?**	Text	Collect user statistics numbers to determine the scale of operations (for future collaboration purposes)	Altmetrics: altmetrics refer to alternative ways to follow scientific use of the resources, typically used as alternative for traditional bibliometrics. Examples include twitter mentions, data downloads, page registrations, individual IP accesses, etc. Access: access refers to the legitimate and authorised physical, remote and virtual admission to, interactions with and use of Research Infrastructures and to services offered by Research Infrastructures to Users. Such Access can be granted, amongst others, to machine time, computing resources, software, data, data-communication services, trust and authentication services, sample preparation, archives, collections, the set-up, execution and dismantling of experiments, education and training, expert support and analytical services. User: users of Research Infrastructures can be individuals, teams and institutions from academia, business, industry and public services. They are engaged in the conception or creation of new knowledge, products, processes, methods and systems and also in the management of projects. Teams can include researchers, doctoral candidates, technical staff and students participating in research in the framework of their studies.

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
49	**Does your organisation exist on a current international or national roadmap (or similar prioritization document)- and what is your position in there?**	Text	Evaluate the position of the organisation based on the national prioritization, roadmap or similar status.	Roadmap: In research infrastructure terminology, a roadmap is a specific, high level document, describing the long term plans for developing and operating key shared infrastructure services for researchers. Research performing organisation: Organisation making research activities and products directly by their staff. Typical examples are universities and research centres.
50	**If applicable, please give the location of the roadmap (Web address, DOI etc.)**	Text	Provenance and further evaluation	
51	**Are there plans to add new facilities, geographically extend facilities or do major upgrades in your organisation? Can you give a time-scale?** **1. yes (if yes, please provide details)** **2. no**	Multiple choice + text	To evaluate potential for long term collaboration and common development goals, avoid duplication of effort.	
	Next questions are strongly diciplime dependent, and will most likely depend also on subdomain level interest, and in some cases even individual RI dependent. Thus, it is crucial that the person doing the information collection first evaluates what are the crucial points to bring up in here. There are only some general questions, rest must be decided by case-by-case.			
52	**Description of the European (sub)field infrastructures for complementarity** **Short description to the interviewed person on the existing European Ris which have mentioned them, or are otherwise relevant. This is needed to create discussion starting point. (This is filled by the interviewer)**	Text		

No	Question	Data type	Guideline for interviewer (can be shared)	Terminology / clarification
53	**Please give details of how your organisation differs from similar European facilities?** **In Europe, there is a research infrastructure called X which specialises in these capabilities. Are you familiar with it and if so, what do you consider as the main difference in the approaches?**	Text		
54	**What kind of further collaboration with European RIs could be possible in your opinion?**	Text		
55	**Does your organisation belong to global initiatives or collaborations to solve particular challenges ?**	Text		
56	**Other questions/comments (open ended)**	Text	Whatever the interviewed person wishes to bring up	

APPENDIX 3 - Environmental RIs

Table A3.1. Environmental RIs (all were interviewed)

Short name	Organisation	Country/Region	Website
ALA	Atlas of Living Australia	Australia	www.ala.org.au
AMISR	Advanced Modular Incoherent Scatter Radar	U.S., Canada	http://amisr.com/amisr
AuScope	Australian Geophysical Observing System (AGOS)	Australia	www.auscope.org.au
CERN	Chinese Ecosystem Research Network	China	www.cern.ac.cn/oindex/index.asp
CHARS	Canadian High Arctic Research Station	Arctic	https://www.canada.ca/content/canadasite-/en/polar-knowledge/CHARScampus.html
CHIKYU	ChiKyu Ocean Drilling Vessel	Japan	www.jamstec.go.jp/chikyu/e
CONTRAIL	Comprehensive Observation Network for Trace Gases by AiIrliner	Japan	www.cger.nies.go.jp/contrail/index.html
CRIA	Centro de Referência em Informação Ambiental	Brazil	www.cria.org.br
DataONE	DataONE	U.S.	www.dataone.org
DONET	Dense Oceanflor Network System for Earthquakes and Tsunamis	Japan	www.jamstec.go.jp/donet/e
GBIF	Global Biodiversity Information Facility	Global	www.gbif.org
GEM	Global Earthquake Model	Global	www.globalquakemodel.org
GOOS	Global Ocean Observing System	Global	www.goosocean.org
IMOS	Integrated Marine Observing System	Australia	http://imos.org.au
IODP	International Ocean Discovery Program	Global	www.iodp.org
IRIS	Incorporated Research Institutions for Seismology	U.S.	www.iris.edu/hq
LTAR	Long-Term Agroecosystem Research	U.S., Canada, Mexico	https://ltar.nal.usda.gov
MU/EAR	Middle and Upper Atmosphere Radar / Equatorial Atmosphere Radar	Japan/Indonesia	www.rish.kyoto-u.ac.jp/organization_e/collaborative_-research/mur

Short name	Organisation	Country/Region	Website
NCAR	National Center for Atmospheric Research	U.S., Canada, Mexico	https://ncar.ucar.edu
NEON	National Ecological Observatory Network	U.S.	www.neonscience.org
NIED	National Research Institute for Earth Science and Disaster Resilience	Japan	www.bosai.go.jp/e
NIES	National Institute for Environmental Studies	Japan, Russia	www.nies.go.jp
OceanSITES	OceanSITES	Global	www.oceansites.org
OOI	Ocean Observatories Initiative	U.S.	http://oceanobservatories.org
SAEON	South-African Environmental Observation Network	South-Africa	www.saeon.ac.za
SAON	Sustaining Arctic Observing Networks	Arctic	www.arcticobserving.org
SMCRI	Shallow Marine and Coastal Research Infrastructure	South-Africa	https://smcri.saeon.ac.za
TERN	Terrestrial Ecosystem Research Network	Australia	www.tern.org.au
UNAVCO	University NAVSTAR Consortium	U.S.	www.unavco.org
USGS	U.S. Geological Survey	U.S.	www.usgs.gov

APPENDIX 5 - Health and Food RIs

Erratum for the section text (30.12.2019)

1. Pg. 25: Correct number of analysed RIs is 26
2. Pg. 24: Table 4.1:
    a. Euro-Bioimaging is currently an ERIC
    b. Table missed some of the organisations in the European landscape:

Short Name	Name	Status
ANAEE (experimental ecosystem research)	Analysis and Experimentation on Ecosystems	ERIC
Metrofood (Metrology in food)	Metrology in Food and Nutrition	Project
IBISBA (Bioprocess development)	Industrial Biotechnology Innovation and distributed Synthetic Biology Accelerator	Project

Table A4.1. Clinical research

Short name	Organisation	Country	Website	Interviewed
SAMRC	South African Medical Research Council	South Africa	http://www.mrc.ac.za/	N
ARO	ARO Council	Japan	http://www.aro.or.jp	Y
KoNECT	Korea National Entreprise for Clinical Trials	Korea	http://en.konect.or.kr/	Y
SCRI	Singapore Clinical Research Institute	Singapore	https://www.scri.edu.sg/	N
CDRD	The Centre for Drug Research and Development	Canada	http://www.cdrd.ca/	Y
CCTG	Canadian Cancer Trials Group	Canada	https://www.ctg.queensu.ca/	N
NCATS	National Center for Advancing Translational Science	USA	https://ncats.nih.gov/	Y
TIA	Therapeutic Innovation Australia	Australia	https://www.therapeuticinnovation.com.au/	Y
MRINZ	Medical Research Institute of New Zealand	New Zealand	https://www.mrinz.ac.nz/	Y
FIOCRUZ	FIOCRUZ	Brazil	https://portal.fiocruz.br/	N

Table A4.2. Translational research

Short name	Organisation	Country	Website	Interviewed
CSIR	CSIR	South Africa	https://www.csir.co.za/	N
ARO	ARO Council	Japan	http://www.aro.or.jp	Y
RIKEN	RIKEN Center for Life Science Technologies	Japan	http://www.clst.riken.jp/en/	N
CDRD	The Centre for Drug Research and Development	Canada	http://www.cdrd.ca/	Y
ISCT	International Society for Cell & Gene Therapy	Canada	https://isctglobal.org/	N
NCATS	National Center for Advancing Translational Science	USA	https://ncats.nih.gov/	Y
SPARK	SPARK	USA	http://sparkmed.stanford.edu/	Y
TIA	Therapeutic Innovation Australia	Australia	https://www.therapeuticinnovation.com.au/	Y
FIOCRUZ	FIOCRUZ	Brazil	https://portal.fiocruz.br/	N

Table A4.3. Biobanking

Short name	Organisation	Country	Website	Interviewed
	Biobank (listed on the 2016 roadmap)	South Africa		N
ANRRC	Asian Network of Research Resources Centers	Asia	www.anrrc.org/about/mission.jsp	N
	Shanghai Zhangjiang Biobank	China	https://www.biobanking.com/the-shanghai-zhangjiang-biobank/	N
	National Center of Neurology and Psychiatry, Medical Genome Center	Japan	https://www.ncnp.go.jp/mgc/english/bio.html	N
KNRRC	Korea National Research Resource Center	Korea	http://www.knrrc.or.kr/english/intro/introduction.jsp	N
CBSR	Canadian BioSample Repository	Canada	http://www.biosample.ca/	N
CTRNet	Canadian Tissue Repository Network	Canada	https://www.ctrnet.ca/fr/	N
ISBER	ISBER	Canada	https://www.isber.org/	N
	"All of US" research programme	USA	https://allofus.nih.gov/about/program-partners/biobank	N
	Several NIH biobanks	USA	(not specified, but investigated)	N
PHRN	Population Health Research Network	Australia [1]	https://www.phrn.org.au/	Y
HUPO	Human Proteome Organization	International	https://www.hupo.org/	N
	IBYME-CONICET	Argentina	https://www.ibyme.org.ar/	N
UFRJ	Federal University of Rio de Janeiro	Brazil	https://ufrj.br/	N
	Clinical Hospital of the University of Chile	Chile	http://www.uchile.cl/portal/english-version/faculties-and-institutes/49776/faculty-of-medicine	N
GIINT	GIINT	Mexico		N

[1] Australia has a range of high-quality biobanks not currently coordinated

Table A4.4. Genomics

	Organisation	Country	Website	Interviewed
	H3aBionet	South Africa	http://h3abionet.org	Y
BGI	BGI	China	http://en.genomics.cn/	N
NBDC	National Bioscience Database Center	Japan	https://biosciencedbc.jp/en/	N
CRDCN	Canadian Research Data Centre Network	Canada	https://crdcn.org/	N
	Canada's Genomics Enterprise	Canada	http://www.cgen.ca/	N
	NIH Data Commons	USA	https://commonfund.nih.gov/commons	N
	Bioplatform Australia	Australia	https://www.bioplatforms.com/	Y
ARDC	Australian Research Data Commons	Australia	https://ardc.edu.au/	N
	LNBio	Brazil	https://lnbio.cnpem.br/	N

Table A4.5. Imaging

	Organisation	Country	Website	Interviewed
	University of Cape Town	South Africa	https://www.uct.ac.za/	N
	India-BioImaging	India		Y
	National Institute for Basic Biology	Japan	http://www.nibb.ac.jp/en/	Y
ASTAR	Institute of Medical Biology	Singapore	https://www.a-star.edu.sg/imb	N
CCEM	Canadian Centre for Electron Microscopy	Canada	https://ccem.mcmaster.ca/	N
	Gruss Lipper Biophotonics Centre	USA	https://www.einstein.yu.edu/centers/biophotonics/	N
	MicroAUS (formerly AMMRF)	Australia	http://micro.org.au/	Y
	Centro de Microscopías Avanzadas, Facultad de Ciencias Exactas y Naturales – Universitad de Buenos Aires	Argentina	http://cma.fcen.uba.ar/	N

Table A4.6. Structural biology

	Organisation	Country	Website	Interviewed
	University of Cape Town	South Africa	https://www.uct.ac.za/	N
	Institute of Biophysics, Chinese Academy of Sciences	China		N
	Tianjin International Joint Academy of Biomedicine	China	http://en.tjab.org/index.html	Y
	Indian Institute of Science	India		N
	Department of Biotechnology, Indian Institute of Technology	India		N
CeBEM	CeBEM (Center for Structural Biology of MERCOSUR)	South America	http://www.cebem-lat.org/	N
IBR	Instituto de Biología Molecular y Celular de Rosario (IBR)	Argentina		N
INIBIOLP	Instituto de Investigaciones Bioquímicas de La Plata ¨Prof. Dr. R.R.Brenner¨ (INIBIOLP)	Argentina		N
IQUIFIB	Instituto de Química y Fisicoquímica Biológicas (IQUIFIB)	Argentina		N
	Leloir Institute Foundation	Argentina		N
USP	The Universidade de Sao Paulo (USP)	Brazil		N
UdelaR	Universidad de la República (UdelaR)	Uruguay		N
	Institut Pasteur Montevideo	Uruguay		N
CBE	Centro de Biología Estructural (CBE)	Venezuela		N

Table A4.7. Drug discovery

	Organisation	Country	Website	Interviewed
	University of Cape Town (Drug Discovery and Development Centre -H3D)	South Africa	http://www.health.uct.ac.za/fhs/research/groupings/drug	N
CSRI	CSIR (Chemicals cluster)	South Africa	https://www.csir.co.za/	N
SIMM	National Center for Drug Screening at Shanghai Institute of Materia Medica	China		N
	Institute of Chemical Biology at Guangzhou	China		N
GIBH	Institute of Biomedicine and Health, Chinese Academy of Science	China	http://english.gibh.cas.cn/	N
	CSIR-Central Drug Research Institute (CSIR-CDRI) in Luknow	India	https://cdri.res.in/	N
	Drug Discovery Seed Compounds Exploratory Unit at RIKEN	Japan	http://www.riken.jp/en/research/labs/csrs/drug_discov/seed_compds/	N
iCeMS	Chemical Biology at Institute of Integrated Cell-Material Sciences of Kyoto University	Japan	https://www.icems.kyoto-u.ac.jp/en/	N
DDI	Drug Discovery Initiative at University of Tokyo	Japan	https://www.ddi.u-tokyo.ac.jp/en/	N
	Screening Discovery Platform at Institut Pasteur	Korea	http://www.ip-korea.org/RDP/groupinfo.php?dept=SDP	N
	Singapore Screening Centre	Singapore	https://www.a-star.edu.sg/	N
CDRD	The Centre for Drug Research and Development)	Canada	http://www.cdrd.ca/	Y
	Drug Discovery Program at the Ontario Institute for Cancer Research	Canada	https://oicr.on.ca/research-portfolio/drug-discovery/	N
SPARC	BioCentre SickKids Proteomics, Analytics, Robotics & Chemical Biology Centre at University of Toronto	Canada	https://lab.research.sickkids.ca/sparc/	N
	Metabolomics Innovation Centre	Canada	https://www.metabolomicscentre.ca/	N

	Organisation	Country	Website	Interviewed
CDoT	Broad Institute Center for the Development of Therapeutics	USA	https://www.broadinstitute.org/center-development-therapeutics-cdot	N
NCGC	NCATS Chemical Genomics Center	USA	https://ncats.nih.gov/ncgc	N
	Conrad Prebys Center for Chemical Genomics;	USA	https://www.sbpdiscovery.org/medical-discovery/drug-discovery/prebys-center-for-drug-discovery/overview	N
	Scripps High-Throughput Molecular Screening Center	USA	https://www.scripps.edu/science-and-medicine/cores-and-services/high-throughput-molecular-screening-center/index.html	N
	Compounds Australia	Australia	https://www.griffith.edu.au/griffith-sciences/compounds-australia	Y
TIA	Therapeutic Innovation Australia (TIA)	Australia	https://www.therapeuticinnovation.com.au/	Y
	LNBio	Brazil	https://lnbio.cnpem.br/	N
CBIB	TD5 research line at Center for Bioinformatics and Integrative Biology (CBIB)	Chile	https://www.cbib.cl/td5-lab-2/	N

Table A4.8. Systems biology

	Organisation	Country	Website	Interviewed
	Stellenbosch University	South Africa	https://www.sun.ac.za/Home.aspx	N
	University of Hong Kong	Hong Kong	https://www.hku.hk/	N
	Keio University	Japan	https://www.keio.ac.jp/en/	N
	Tokyo University	Japan	https://www.u-tokyo.ac.jp/en/index.html	N
	RIKEN Center for Integrative Medical Sciences	Japan	http://www.riken.jp/en/research/labs/ims/	N
BDR	RIKEN Center for Biosystems Dynamics Research	Japan	http://www.riken.jp/en/research/labs/bdr/	N
	University of Toronto	Canada	https://www.utoronto.ca/	N
	Institute for Systems Biology (Seattle)	USA	https://systemsbiology.org/	N
	University sites (19 in total)	USA	http://community.isbe.eu/affiliations/map	N
	Macquarie University	Australia	https://www.mq.edu.au/	N
	Monash University	Australia	https://www.monash.edu/	N
	The University of Auckland	New Zealand	https://www.auckland.ac.nz/en.html	N
	University of Buenos Aires - National Scientific and Technical Research Council	Argentina	https://www.conicet.gov.ar/?lan=en	N

Table A4.9. Mouse Phenotyping

	Organisation	Country	Website	Interviewed
	University of Cape Town	South Africa	https://www.uct.ac.za/	N
PCDDP	North-West University	South Africa	http://health-sciences.nwu.ac.za/pcddp	N
	Asian Mouse Phenotyping Consortium	Asia	http://ampc.asia/	N
	MARC Nanjing University	China	http://www.nbri-nju.com/en-us/	N
	CAM-SU GRC	China	https://www.cam-su.org/	N
	IISER	India	http://www.iiserpune.ac.in/	N
	RIKEN BRC	Japan	https://en.brc.riken.jp/	N
	Korean Mouse Phenotype Consortium	Korea	http://mousephenotype.kr/	N
	NLAC NARLabs	Taiwan	http://www-old.narlabs.org.tw/en/lab/lab.php?lab_id=5	N
	Toronto Centre for Phenogenomics	Canada	phenogenomics.ca	N
	Jackson Lab	USA	https://www.jax.org/	N
	Charles River Laboratories	USA	https://www.criver.com/	N
	University-based sites	USA		N
	Australian Phenomics Network	Australia	http://australianphenomics.org.au/	N
	International Mouse Phenotyping Consortium	International	https://www.mousephenotype.org/	N

Table A4.10. Marine Biology

	Organisation	Country	Website	Interviewed
SMCRI	Shallow Marine Coastal Research Infrastructure	South Africa	https://smcri.saeon.ac.za/	N
CMFRI	Central Marine Fisheries Research Institute	India	http://www.cmfri.org.in/	N
NMRI	National Maritime Research Institute	Japan	https://ittc.info/members/member-organisations/national-maritime-research-institute/	N
MABIK	Marine Biodiversity Institute of Korea	Korea	http://www.mabik.re.kr/html/en/	N
	Centre de Recherche sur les Biotechnologies Marines	Canada	https://crbm.ca/	Y
	WHOI, Scripps, University of California Berkley	USA	https://scripps.ucsd.edu/news/2591	N
SIMS	Sydney Institute of Marine Science	Australia	https://www.sims.org.au/	N
CSIRO IOMRC	Indian Ocean Marine Research Centre	Australia	https://www.csiro.au/en/Locations/WA/IOMRC	N
	Marine Studies Institute (MSI); University of Sydney	Australia	https://sydney.edu.au/science/our-research/research-centres/marine-studies-institute.html	N
	Secretariat of Government of Science, Technology and Productive Innovation	Argentina	https://www.zsi.at/en/object/partner/1640	N
ECIM UC	Centro de investigacion maritima	Chile	http://ecim.bio.puc.cl/es/	N
	Pontificia Universidad Católica de Chile, Patagonia Station for Interdisciplinary research	Chile	http://ecim.bio.puc.cl/en/	N
	Centro Nacional de Alta Tecnología (National Center of High Technology)	Costa Rica	http://www.cenat.ac.cr/es/	N
	Universidad Nacional Autónoma de Honduras	Honduras	https://www.unah.edu.hn/	N
STRI	Smithsonian Tropical Research Institute	Panama	https://stri.si.edu/	N

	Organisation	Country	Website	Interviewed
INDICASAT AIP	Institute of Scientific Research and High Technology Services	Panama	https://admision.ciudaddelsaber.org/en/foundation/affiliate/institute-scientific-research-high-technology-services-indicasat/341	N
	Faculty of Sciences / Marine Sciences Unit	Uruguay	http://undecimar.fcien.edu.uy/es_ES/	N

Table A4.11. Plant fenotyping

	Organisation	Country	Website	Interviewed
Pheno-Trait	China Plant Phenotyping Network	China	http://www.phenotrait.com/	Y
GIFS	Global Institute for Food Security	Canada	http://www.gifs.ca/	N
NAPPN	North American Plant Phenotyping Network	USA	http://nappn.plant-phenotyping.org/	Y
AAPF	Australian Plant Phenotyping Facility	Australia	https://www.plantphenomics.org.au/	Y
	CSIRO	Australia	https://www.csiro.au/	N
	University of Adelaide	Australia	https://www.adelaide.edu.au/	N
	AGResearch	New Zealand	https://www.agresearch.co.nz/	N
	Licoln Agritech	New Zealand	https://www.lincolnagritech.co.nz/	N
LatPPN	Latin Plant Phenotyping Network	South America		N

Table A4.12. Pathogens

	Organisation	Country	Website	Interviewed
NICD	National Institute for Communicable Diseases, Grahamstown	South Africa	http://www.nicd.ac.za/	N
	Wuhan Institute of Virology of the Chinese Academy of Sciences	China	http://english.whiov.cas.cn/	N
	BSL-4 Zoonotic Network hosted by the Canadian Food Inspection Agency	Canada		N
	Canadian Food Inspection Agency Laboratory / Public Health Agency of Canada: National Microbiology Laboratory- Winnipeg, Manitoba	Canada	http://www.inspection.gc.ca/about-the-cfia/science/our-laboratories/ncfad-winnipeg/eng/1549576575939/1549576643836	N
	International Vaccine Centre	Canada	https://www.vido.org/	N
	Rocky Mountain Laboratory (National Institutes of Health) Hamilton, Montana	USA	https://www.niaid.nih.gov/about/rocky-mountain-laboratories	N
	National Emerging Infectious Diseases Laboratory, Boston, MA	USA	https://www.bu.edu/neidl/	N
	University of Texas Medical Branch Galveston National Laboratory, Galveston	USA	https://www.utmb.edu/gnl	N
AAHL	CSIRO Australian Animal Health Laboratory	Australia	https://www.csiro.au/en/Research/Facilities/AAHL	N

Table A4.13. Microbial resources

	Organisation	Country	Website	Interviewed
	NSCF (listed on the 2016 roadmap)	South Africa		N
ABRCN	Asian Biological Resource Centers Network (China, Japan, Korea, Thailand, Philippines)	Asia	http://www.abrcn.net/	N
	The Center for Microbial Resource and Bid Data, Institute of Microbiology, Chinese Academy of Sciences	China		N
	NBRC NITE Biological Resource Centre	Japan	https://www.nite.go.jp/en/nbrc/index.html	Y
TBRC	Thailand Bioresource Research Center	Thailand	http://www.tbrcnetwork.org/	
	ATTC	USA	http://www.lgcstandards-atcc.org/en.aspx	N
	FIOCRUZ	Brazil	https://portal.fiocruz.br/	N

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EU RIs for having provided information and contacts

Family name	*First name*	*Affiliation*
Alen Amaro	Claudia	**INSTRUCT**
Bietrix	Florence	**EATRIS**
Bosschaerts	Maria-Helena	**MIRRI**
Fauvel	Anne-Charlotte	**EATRIS**
Gras	Sidonie	**EMBRC**
Keppler	Antje	**EuroBioImaging**
Leitner	Frauke	**EuroBioImaging**
Martin	Corinne	**ELIXIR**
Nardello	Ilaria	**EMBRC**
Pietruschka	Roland	**EMPHASIS**
Raess	Michael	**INFRAFRONTIER**
Raoul	Hervé	**ERINHA**
Smith	Andrew	**ELIXIR**
Stechman	Bahne	**EU-Openscreen**
Steinfelder	Erik	**BBMRI**
Stepanyan	Diana	**ERINHA**
Verteeg	Krista	**ERINHA**

International RIs for having participated in the interviews

Family name	*First name*	*Affiliation*
Annan	Rob	**Genome Canada**
Beasley	Richard	**MRINZ**
Berger	Bettina	**APPF**
Bornman	Tommy	**SMCRI**
Chee	Deborah	**KoNECT**
Feroz	Mustapha	**India BioImaging**

Fuery	Caroline	**Microscopy Australia**
Gee	Barry	**CDRD**
Gilbert	Andrew	**Bioplatform Australia**
Han	David	**Phenotrait**
Mochly-Rosen	Daria	**SPARK**
Mulder	Nicola	**H3ABioNet**
Nakanishi	Yoichi	**ARO Council**
Newman	Stuart	**TIA**
Pariser	Anne	**NCATS**
Proctor	Lavinia	**Compounds Australia**
Ritchie	Rachel	**CDRD**
Seita	Junya	**NBRC**
Semprini	Alex	**MRINZ**
Smith	Merran	**PHRN**
Ueno	Naoto	**NIBB**
Viel	Guy	**CRBM**
Yang	Yang	**NAPPN**
Zhang	Wenqiu	**TJAB**

APPENDIX 5 - Physics

Table A5.1 Synchrotrons considered

Short name	Organisation	Location	Start user operation	Electron Energy (GeV)	Web site	Answered
AS	Australian Synchrotron, ANSTO, Australian Nuclear Science and Technology Organisation	Australia	2007	3.0 GeV	https://www.ansto.gov.au/research/facilities/australian-synchrotron/overview	Yes
UVX LNLS	Laboratorio Nacional de Luz Sincrotron	Brazil	1997	1.37 GeV	https://www.lnls.cnpem.br/uvx-en/	Yes
CLS	Canadian Light Source	Canada	2005	2.9 GeV	https://www.lightsource.ca/beamlines.html	Yes
BSRF	Beijing Synchrotron Radiation Facility	China	1991	2.5 GeV	http://english.bsrf.ihep.cas.cn/facilityinformation/beamlinemap/201203/t20120329_83231.html	No
SSRF	Shanghai Synchrotron Radiation Facility	China	2009	3.5 GeV	http://e-ssrf.sinap.cas.cn/#	No
PF	Photon Factory High Energy Accelerator Research Organization, KEK	Japan	1982	PF: 2.5-GeV PFAR: 6.5-GeV	https://www2.kek.jp/imss/pf/eng/apparatus/bl/	Yes
SPring-8	Super Photon ring-8 GeV	Japan	1997	8.0 GeV	www.spring8.or.jp/en/	Yes
SESAME	Synchrotron-light for Experimental Science and Applications in the Middle East	Jordan	2017	2.5 GeV	http://sesame.org.jo/sesame_2018/machine-and-beamlines/beamlines	Yes

Short name	Organisation	Location	Start user operation	Electron Energy (GeV)	Web site	Answered
PLS-II	Pohang Light Source-II	Korea	2011	3.0 GeV	http://pal.postech.ac.kr/paleng/Menu.pal?method=menuView&pageMode=paleng&top=2&sub=3&sub2=1&sub3=0	No
KSRS	Kurchatov Synchrotron Radiation Source	Russia	1999	2.5 GeV	http://eng.nrcki.ru/	No
SSTRC	Siberian Synchrotron Terahertz Radiation Centre	Russia		2.2 GeV	http://ssrc.inp.nsk.su/CKP/eng/	No
SSLS	Singapore Synchrotron Light Source National University of Singapore	Singapore	1999	0.7 GeV	http://ssls.nus.edu.sg/facility/helios2.html	No
NSRRC	National Synchrotron Radiation Research Center	Taiwan	TLS: 1993 TPS: 2016	TLS:1.5 GeV TPS: 3.0 GeV	https://www.nsrrc.org.tw/english/index.aspx	Yes
SLRI	Synchrotron Light Research Institute, Synchrotron Thailand Central Lab	Thailand	2003	1.2 GeV	https://www.slri.or.th/en/	Yes
ALS	Advanced Light Source, Lawrence Berkeley National Laboratory	USA	1993	1.9 GeV	https://als.lbl.gov/	Yes

Short name	Organisation	Location	Start user operation	Electron Energy (GeV)	Web site	Answered
APS	Advanced Photon Source, Argonne National Laboratory	USA	1995	7.0 GeV	https://www.aps.anl.gov/	Yes
CHESS	Cornell High Energy Synchrotron Source	USA	1979	5.3 GeV	https://www.chess.cornell.edu/science/x-ray-technology	Yes
NSLS II	National Synchrotron Light Source II, Brookhaven National Laboratory	USA	2015	3.0 GeV	https://www.bnl.gov/ps/	Yes
SSRL	Stanford Synchrotron Radiation Lightsource	USA	1992	3.0 GeV	https://www-ssrl.slac.stanford.edu/content/	Yes
ESRF	European Synchrotron Radiation Facility	Europe (France)	1994	6.0 GeV	-	Yes
ALBA	ALBA	Europe (Spain)	2012	3.0 GeV	https://www.cells.es/en/beamlines	Yes
BESSY- 2	Helmholtz-Zentrum Berlin	Europe (Germany)	1998	1.7 GeV	https://www.helmholtz-berlin.de/quellen/bessy/index_en.html	Yes
LNLS - SIRIUS PROJECT	Laboratorio Nacional de Luz Sincrotron	Brazil	…	…	https://www.lnls.cnpem.br/sirius-en/sirius-project/	

Table A5.2 Syncrotrons, not considered for analysis

Organisation	Location
International facilities - identified but not corresponding to criteria	
CAMD Center for Advanced Microstructures and Devices	USA
SURF III Synchrotron Ultraviolet Radiation Facility	USA
NSRL National Synchrotron Radiation Laboratory	China
RRCAT Raja Ramanna Centre for Advanced Technology	India
ASTF Aichi Synchrotron Radiation Center	Japan
HSRC Hiroshima Synchrotron Radiation Center	Japan
RITSUMEI Ritsumeikan University SR Center	Japan
SAGA Saga Light Source	Japan
UVSOR Ultraviolet Synchrotron Orbital Radiation Facility	Japan
SLRI Synchrotron Light Research Institute	Thailand
ILSF Iranian Light Source Facility	Iran
DELSY Dubna Electron Synchrotron	Russia
TNK Technical Storage Ring Complex	Russia
CANDLE Center for the Advancement of Natural Discoveries using Light Emission	Armenia
European RIs - corresponding to criteria but not selected	
SOLEIL Source Optimisée de Lumière d'Energie Intermédiaire du LURE	France
PETRA III at DESY	Germany
ELETTRA Synchrotron Light Laboratory	Italy
ALBA Synchrotron	Spain
MAX IV Laboratory	Sweden
SLS Swiss Light Source	Switzerland
Diamond Light Source	United Kingdom
European RIs - not corresponding to criteria	
ISA Institute for Storage Ring Facilities	Denmark

Organisation	Location
ANKA Angstromquelle Karlsruhe	Germany
DELTA Dortmund Electron Storage Ring Facility	Germany
ELSA - Electron Stretcher Accelerator	Germany
MLS Metrology Light Source	Germany
DAFNE Double Annular Factory for Nice Experiments	Italy
SOLARIS Synchrotron	Poland

Table A5.3. Free electron lasers

Short name	Organisation	Location	Start user operation	Electron Energy	Web site	Answered
PAL XFEL	Pohang Accelerator Laboratory- X-Ray Free Electron Laser	South Korea	2016	10 GeV	http://pal.postech.ac.kr/paleng/	No
SACLA	SPRing - 8 Compact Free Electron Laser	Japan	2011	8.5 GeV	http://www.spring8.or.jp/en/ http://xfel.riken.jp/eng/	Yes
LCLS	Linac Coherent Light Source	USA	2009	15 GeV	https://lcls.slac.stanford.edu/overview	Yes
European XFEL	European X-Ray Free Electron Laser	Europe (Germany)	2017	17.5 GeV	https://www.xfel.eu/facility/overview/index_eng.html	Yes
FERMI	Free Electron laser Radiation for Multidisciplinary Investigations - Elettra Laboratory	Europe (Italy)	2012	1.2 - 1.5 Gev	https://www.elettra.trieste.it/lightsources/fermi/fermi-machine/fermi-description.html	Yes
FELIX	Free Electron Laser for Infrared e Xperiments (Radbout University)	Europe (Netherlands)	2013	15 MeV	https://www.ru.nl/felix/about-felix/about-felix/felix-laboratory/	No
SHINE	Shangai High Repetition Rate XFEL and Extreme Light Facility	China	2025	8 GeV		No
LCLS II	Linac Coherent Light Source II	USA	2020		https://lcls.slac.stanford.edu/overview	No

Table A5.4 FEL not considered in the analysis

Organisation	Location
International facilities - identified but not corresponding to criteria	
ITST Institute for Terahertz Science and Technology	USA
JLAB Jefferson Lab	USA
IR Infra Red FEL Research Center	Japan
European RIs - not corresponding to criteria	
CLIO Centre Laser Infrarouge d'Orsay	France
Free Electron Laser at ELBE	Germany
TARLA Turkish Accelerator and Radiation Laboratory at Ankara	Turkey
European RIs -corresponding to criteria but not selected	
FLASH at DESY	Germany
SwissFEL Swiss Free Electron Laser	Switzerland

Table A5.5 Neutron sources

Short name	Organisation	Location	Start user operation	Beam Power (MW)	Source	Web site	Surveyed
LAHN	Bariloche Atomic Centre	Argentina	Under construction	10 MW	Reactor	http://www.lahn.cnea.gov.ar/	No
ACNS	Australian Centre for Neutron Scattering at ANSTO	Australia	2007 (OPAL reactor)	20 MW	Reactor	https://www.ansto.gov.au/research/facilities/australian-centre-for-neutron-scattering	Yes
CARR	China Advanced Research Reactor	China	2010	60 MW	Reactor	https://neutronsources.org/neutron-centres/africa-asia-and-oceania/carr.html	No
CSNS	China Spallation Neutron Source	China	2019	CSNS-I 100kW; CSNS-II 500 kW	Spallation	http://english.ihep.cas.cn/csns/chnl/99/index.html	No
CMRR	China Mianyang Research Reactor	China	2012	20 MW	Reactor	http://english.ihep.cas.cn/ls/cnss/zzsszz/201406/t20140620_123024.html	Yes
BARC	Bhabha Atomic Research Centre	India	1956	100 MW	Reactor	http://www.barc.gov.in/randd/ps.html	No
BATAN	Kartini Reactor - Yogyakarta	Indonesia	1987	15 MW	Reactor	http://www.batan.go.id/index.php/en/neutron-beam-facility	Yes

Short name	Organisation	Location	Start user operation	Beam Power (MW)	Source	Web site	Surveyed
	The GA Siwabessy Multi Purpose Reactor TRIGA Reactor						
J-PARC	- Materials and Life Science facility	Japan	2009	1 MW	Spallation Source	https://www.j-parc.jp/c/en/facilities/materials-and-life-science-experimental/	No
JRR-3	Japan Research Reactor No.3	Japan	1962	20 MW	Reactor	https://jrr3.jaea.go.jp/jrr3e/1/11.htm	Yes
PNPI	Petersburg Nuclear Physics Institute WWR-M reactor	Russia	1961 (WWR-M reactor)	18 MW	Reactor	http://www.pnpi.spb.ru/en/facilities/reactor-wwr-m	Yes
PNPI	Petersburg Nuclear Physics Institute PIK reactor	Russia	2011 First criticality at Low power, Physical start of PIK construction	100 MW	Reactor	http://www.pnpi.spb.ru/en/facilities/reactor-pik	No
HANARO	High Flux Advanced Neutron Application Reactor	South Korea	1996	30 MW	Reactor	https://www.kaeri.re.kr/mpse	Yes

Short name	Organisation	Location	Start user operation	Beam Power (MW)	Source	Web site	Surveyed
NIST	Center for Neutron Research	USA	1969	20 MW	Reactor	https://www.nist.gov/ncnr/neutron-instruments/general-info-and-layout	Yes
HFIR	High Flux Isotope Reactor Oak Ridge National Laboratory Neutron Sciences	USA	Mid - 1960s	85 MW	Reactor	https://neutrons.ornl.gov/hfir	Yes
SNS	Spallation Neutron Source Oak Ridge National Laboratory Neutron Sciences	USA	2006	1.4 MW	Spallation	https://neutrons.ornl.gov/sns	Yes
ISIS	Neutron and Muon Source	Europe- GB	1984	0.2 MW	Spallation	https://www.isis.stfc.ac.uk/Pages/home.aspx	Yes
BRR	Budapest Research Reactor - Budapest Neutron Centre	Europe - Hungary	1959	10 MW	Reactor	https://www.energia.mta.hu/en/content/budapest-research-reactor	Yes
FRM-II MLZ	Heinz Maier-Leibnitz Zentrum	Europe - Germany	2004	20 MW	Reactor	https://mlz-garching.de/ueber-mlz.html	Yes

Short name	Organisation	Location	Start user operation	Beam Power (MW)	Source	Web site	Surveyed
PSI-SINQ	Paul Scherrer Institut - Swiss Spallation Neutron Source	Europe - Switzerland	1996	0.8 MW	Spallation	www.psi.ch/sinq	Yes
ILL	Institut Laue-Langevin	Europe - France	1971	57 MW	Reactor	www.ill.eu	Yes
ESS	European Spallation Source	Europe - Sweden	2023	5 MW	Spallation	https://europeanspallationsource.se/	Yes

Table A5.6 Neutron Sources not considered

Organisation	Location
International facilities - identified but not corresponding to criteria	
Necsa Nuclear Energy Corporation of South Africa	South Africa
CNBC Canadian Neutron Beam Centre	Canada
LANSCE Los Alamos Neutron Science Center	USA
LENS Low Energy Neutron Source	USA
MNR McMaster Nuclear Reactor	Canada
MIT Nuclear Reactor Laboratory	USA
TRIUMF Neutron Irradiation Facility	Canada
MURR University of Missouri Research Reactor Center	USA
LN Laboratório de Metrologia de Neutrons	Brazil
IPEN Peruvian Institute of Nuclear Energy	Peru
KENS Neutron Science Division, KEK IMSS	Japan
KURRI Kyoto University Research Reactor Institute	Japan
NSL ISSP Neutron Science Laboratory, Institute for Solid State Physics	Japan
TRIGA PUSPATI	Malaysia
McMaster University	Canada
European RIs - not corresponding to criteria	
CERIC-ERIC Central European Research Infrastructure Consortium	Italy
NRCPS National Centre of Scientific research Demokritos	Greece
ESS Bilbao European Spallation Source	Spain
FRM-II-MLZ Heinz Maier-Leibnitz Zentrum	Germany
JCNS Jülich Centre for Neutron Science	Germany
HZB Helmholtz-Zentrum Berlin für Materialien und Energie	Germany
HZG-GEMS Helmholtz-Zentrum Geesthacht	Germany
IRMM Institute for Reference Materials and Measurements	Belgium
Johannes Gutenberg University	Germany

Organisation	Location
LLB Laboratoire Léon Brillouin	France
RPI Portuguese Research Reactor	Portugal
TRIGA Mark II Reactor, TU Vienna	Austria
TRIGA Reactor Infrastructure Centre	Slovenia
European RIs - corresponding to criteria but not selected	
MLZ Heinz Maier-Leibnitz Zentrum	Germany
IFE Institute for Energy Technology	Norway
MARIA - National Centre for Nuclear Research	Poland
NPI Nuclear Physics Institute	Czech Republic

Table A5.7. High power lasers

Short name	Organisation	Location	Number of Lasers laboratories	Web site	Surveyed
ELI	Extreme Light Infrastructure	Europe	distributed facility with 3 sites	https://eli-laser.eu/	No
Laserlab Europe	Laserlab Europe	Europe	33 Laser Laboratories/ 22 with access for external users	https://www.laserlab-europe.eu/transnational-access/access-facilities	Yes
ICUIL	International Committee on Ultra-High Intensity Lasers	Global	status 2019: 107 Laser laboratories World Wide	www.icuil.org	No

Table A5.8. High Magnetic Field facilities

Short name	Organisation	Location	Start user operation	Magnetic field range	Web site	Surveyed
WHMFC	Wuhan National High Magnetic Field Center	China	2014	Pulsed fields up to 90 T	http://whmfc.hust.edu.cn/english/Introduction.htm	Yes
CHMFL	Chinese High Magnetic Field Laboratory	China	2008	DC fields up to 45 T	http://english.hmfl.cas.cn/	No
IMGSL	International MegaGauss Science laboratory	Japan	2006	Pulsed fields up to 87 T	https://www.issp.u-tokyo.ac.jp/labs/mgsl/Facility_e.html	No
				Pulsed fields (destructive) up to 730 T	https://www.issp.u-tokyo.ac.jp/maincontents/history_en.html	
				DC fields up to 14 T		
HFLSM	High Field Laboratory for Superconducting Materials	Japan	1981	Continuous fields up to 31 T	http://www.imr.tohoku.ac.jp/en/about/history.html	Yes
					http://www.hflsm.imr.tohoku.ac.jp/cgi-bin/index-e.cgi?num=80318001924	
AHMF	Center for Advanced High Magnetic Field Science	Japan	2014	Pulsed fields up to 50 T	https://www.sci.osaka-u.ac.jp/en/university-facility/strong-magnetic-field-science-center/	Yes
				DC fields up to 16 T	https://www.sci.osaka-u.ac.jp/en/university-facility/strong-magnetic-field-science-center/	
NHMFL	National High Magnetic Field Laboratory (Tallahassee, Gainesville, Los Alamos)	USA	1994	DC fields up to 45 T	https://nationalmaglab.org/user-facilities/dc-field/instruments-dcfield/resistive-magnets	No
				Pulsed fields up to 100 T	https://nationalmaglab.org/about/history	
				Pulsed fields (single turn magnet) up to 300 T		
HLD	Dresden High Magnetic Field Laboratory Hochfeld-Magnetlabor Dresden	Europe (Germany)	2007	Pulsed fields up to 95 T	https://www.hzdr.de/db/Cms?pOid=10379&pNid=580	Yes

Short name	Organisation	Location	Start user operation	Magnetic field range	Web site	Surveyed
HMFL	Nijmegen High Field Magnet Laboratory (Radboud University)	Europe (Netherlands)		DC fields up to 38 T	https://www.ru.nl/hfml/use-our-facility/experimental/magnets/	No

Table A5.9. High Magnetic Field facilities not considered in the survey

Organisation	**Location**
International facilities - identified but not corresponding to criteria	
TML Tsukuba Magnet Laboratory (to be closed in 2018)	Japan
European RIs - not corresponding to criteria	
LNCMI-G Laboratoire National des Champs Magnetiques Intenses-DC facility	France
LNCMI-T Laboratoire National des Champs Magnetiques Intenses-pulsed facility	France

Table A5.10. Particle Physics facilities

	Organisation	Location	Start user operation	Type	Web site	Answered
	PP International facilities					
TRIUMF	Canada's particle accelerator centre	Canada	1969	single-sited	https://www.triumf.ca/technical-services	Yes
BEPC/BEPCII at IHEP	Institute of High Energy Physics	China	2007 - BEPC II	single-sited	http://english.ihep.cas.cn/chnl/18/index.html	No
J-PARC	Japan Proton Accelerator Research Complex	Japan	2009	single-sited	https://j-parc.jp/c/en/facilities/nuclear-and-particle-physics/index.html	No
B-Factory	KEK-High Energy Accelerator Research Organization	Japan	1999	single-sited	https://www.kek.jp/en/Research/IPNS/Belle/	Yes
Budker	Institute of Nuclear Physics	Russia	1958	single-sited	http://www.inp.nsk.su/budker-institute-of-nuclear-physics	Yes
SLAC	National Accelerator Laboratory	USA	1974	single-sited	https://www6.slac.stanford.edu/facilities	No
FERMILAB	Fermi National Accelerator Laboratory	USA		single-sited	http://www.fnal.gov/pub/science/particle-physics/index.html	No
RHIC	Relativistic Heavy Ion Collider Brookhaven National Laboratory	USA		single-sited	www.bnl.gov/rhic/physics.asp	No

	Organisation	Location	Start user operation	Type	Web site	Answered
SNS	Spallation Neutron Source	USA	2006	single-sited	https://www.phy.ornl.gov/overview/facilities.html	No
TJNAF - Jefferson Lab	Thomas Jefferson National Accelerator Facility	USA	1988	single-sited	https://www.jlab.org/research/science	Yes
CSNS – HEP	China Spallation Neutron Source	CHINA	2017	distributed	http://english.ihep.cas.cn/csns/doc/1999.html	No
	PP European facilities					
FRM-II-MLZ	Heinz Maier-Leibnitz Zentrum	Germany	2004	-	https://www.mlz-garching.de/englisch/instruments-und-labs/particle-physics.html	Yes
PSI	Paul Scherrer Institut HIPA/UCN, HIPA	Switzerland	1974 – Muons 2011 - UCN	single-sited	https://www.psi.ch/fr/ltp/facilities	Yes
FZJ-COSY	Nuclear Physics Institute Jülich	Germany	1993	single-sited	https://www.fz-juelich.de/ikp/DE/Forschung/Beschleuniger/_doc/COSY.html	Yes
CERN	CERN	Switzerland	1957 -(LHC 2008)	-	https://home.cern/fr/about/who-we-are/our-history#s2	Yes
DESY	Deutsches Elektronen-Synchrotron	Germany		single-sited	http://particle-physics.desy.de/	Yes

	Organisation	Location	Start user operation	Type	Web site	Answered
FAIR	Facility for Antiproton and Ion Research	Germany	Starting 2025	-	https://www.gsi.de/en/researchaccelerators/fair.htm	Yes

Table A5.11. Nuclear Research Facilities

Short name	Organisation	Location	Start user operation	Magnetic field range	Web site	Answered
iThemba Labs	Laboratory for Accelerator Based Sciences	South Africa	1987	A range of accelerators including: separated sector cyclotron; Injector cyclotrons; Tandetron; k=11 cyclotron; 6 MV tandem; low energy electrostatic accelerators	https://tlabs.ac.za/accelerators/	No
ANU	Australian National University Department of Nuclear Physics	Australia		Heavy Ion Accelerator Facility: 14 UD Pelletron electrostatic accelerator; superconducting linear post accelerator	https://physics.anu.edu.au/nuclear/research/	No
BTANL	Beijing Tandem Accelerator Nuclear Physics National Laboratory	China		15 MW tandem accelerator; 100 MeV proton cyclotron; ISOL		Yes
IUAC	Inter-University Accelerator Centre	India	1991	15 UD Pelletron; superconducting linear accelerator; low energy ion beam facilities	http://www.iuac.res.in/research/np/index.html	No
ATLAS	Argonne Tandem Linear Accelerator System	USA	1978	Superconducting linear accelerator for heavy ions	https://www.phy.anl.gov/atlas/	Yes
ELI-NP	Extreme Light Infrastructure - Nuclear Physics	Europe (Rumania)	2019	Under construction: Very high intensity laser system Very intense brilliant gamma (γ) beam, narrow bandwith	http://www.eli-np.ro/	Yes
Ganil	Grand Accélérateur National d'Ions Lourds	Europe (France)	1983	Cyclotron complex: 5 cyclotrons (2 compact cyclotrons, 2 separated sector cyclotrons, 1 compact cyclotron SPIRAL1 for radioactive beams);SPIRAL2 Superconducting Linear Accelerator	https://www.ganil-spiral2.eu/en/scientists/ganil-spiral-2-facilities/accelerators/	Yes

Short name	Organisation	Location	Start user operation	Magnetic field range	Web site	Answered
JYFL	Physics Department, Accelerator Laboratory	Europe (Finland)	1993	Ion Guide Isotope Separation On-line (IGISOL); K130 cyclotron; MCC30/15 cyclotron; 1.7 MV Pelletron	https://www.jyu.fi/science/en/physics/research	Yes

Table A5.12. Nuclear Facilities not considered for the survey

Organisation	Location
International facilities - identified but not corresponding to criteria	
INT Institute of Nuclear Theory	USA
JLAB-Continuous Electron Beam Accelerator Facility	USA
NSCL National Superconducting Cyclotron Laboratory	USA
Texas A&M University Physics and Astronomy	USA
RHIC Relativistic Heavy Ion Collider	USA
TRIUMF Tri-University Meson facility	Canada
SLEG Shanghai Laser Electron Gamma Source	China
CJPL China Jinping underground Laboratory	China
HIAF Heavy Ion Accelerator Facility, Institute of Modern Physics	China
VECC Variable Energy Cyclotron Centre	India
J-PARC neutrons, muons, hadron physics	Japan
RIKEN Nishina Center for Accelerator-Based Science	Japan
RNCP Research Center for Nuclear Physics, Osaka University	Japan
JAEA Japan Atomic Energy Agency Tandem Accelerator	Japan
ELPH Research Center for Electron-Photon Science, Tohoku University	Japan
RAON Rare isotope Accelerator complex for ON-line experiments, **IBS** Institute for Basic Science	Korea
NICA (HE) Nuclotron – based Ion Collider fAcility	Russia
FLNR (LE) Flerov Laboratory of Nuclear Reactions	Russia
CIADS Chinese Initial ADS	China
CAS Chinese Academy of Sciences **HIRFL** Heavy Ion Research Facility in Lanzhou	China
VECC Variable Energy Cyclotron Centre	India
HIMAC Heavy Ion Medical Accelerator, National Institute of Radiological Sciences	Japan
NewSUBARU Laboratory of Advanced Science and Technology for Industry	Japan
CABAS Center for Accelerator and Beam Applied Science Kyushu University	Japan

Organisation	Location
UTTAC University of Tsukuba, Tandem Accelerator Complex	Japan
CYRIC Tohoku University, Cyclotron and Radioisotope Center	Japan
KOMAC Korea Multi-purpose Accelerator Complex	Korea
KIST Korea Institute of Science and Technology, The Accelerator Laboratory	Korea
KIRMAS Korea Heavy Ion Medical Accelerator at Korea Institute of Radiological and Medical Sciences	Korea
ARTI Advanced Radiation Technology Institute	Korea
RAON National Center for Inter-Universities Research Facilities Electrostatic Ion Accelerator	Korea
Tandem machine at Hanoi University of Natural Science	Taiwan
Military Central Hospital 108	Vietnam
European RIs - not corresponding to criteria	
ECT* European Centre for Theoretical Studies in Nuclear Physics and related areas	Italy
COMPASS Common Muon Proton Apparatus for Structure and Spectroscopy	Switzerland
ELSA Elektronen- Stretcher-Anlage	Germany
INFN Instituto Nazionale di Fisica Nucleare	Italy
MAMI Mainzer Microtron	Germany
ALICE A Large Ion Collider Experiment	Switzerland
AD Antiproton Decelerator	Switzerland
ALTO Accélérateur Linéaire et Tandem à Orsay	France
CCB Centrum Cyclotronowe Bronowice	Poland
COSY Cooler SYnchrotron	Germany
HIL Heavy Ion Laboratory	Poland
IFIN Horia Hulubei National Institute for Physics and Nuclear Engineering	Romania
ILL Institut Laue Langevin	France
KVI-CART Center for Advanced Radiation Technology	The Netherlands

Organisation	Location
LNS Laboratori Nazionali del Sud	Italy
PSI Paul Scherrer Institut	Switzerland
European RIs - corresponding to criteria but not selected	
GSI Gesellschaft für Schwerionenforschung	Germany
ISOLDE CERN	Switzerland
LNL Laboratori Nazionali di Legnaro	Italy
ELI-NP-Extreme Light Infrastructure	Romania

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APPENDIX 6 - Energy

Table A6.1 International research infrastructures by subdomains, countries and continents, (for more information see Chapter 6).

	Number of contacted RIs	RIs interviewed	Continents	
Total	37	11		
Energy Systems Integration	6	3	North America	5
			South America	
			Europe (non-EU)	
			Asia	
			Australia	1
Renewable Energy	17	6	North America	9
			South America	2
			Europe (non-EU)	
			Asia	6
			Australia	
Efficient Energy Conversion and Use	4	2	North America	3
			South America	
			Europe (non-EU)	
			Asia	1
			Australia	
Nuclear Energy	19	6	North America	8
			South America	2
			Europe (non-EU)	2
			Asia	6
			Australia	1
Cross-sectional RIs	13	1	North America	4
			South America	2
			Europe (non-EU)	
			Asia	7
			Australia	1

Table A6.2 Energy RIs investigated

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
Russia	nuclear energy	Joint Stock Company "State Scientific Center Research Institute of Atomic Reactors"	**JSC "SSC RIAR"**	interview, on-line survey	http://niiar.ru/eng
	Description/background: JSC "SSC RIAR" is a research and development center located in Dmitrovgrad (Ulyanovsk region, Russian Federation). Founded in 1956 as a nuclear testing center, granted a status of State Scientific Center in 1994. In 2008 it also became also a joint stock company.				
	Infrastructure: six test reactors; post-irradiation examination facilities; radiochemical facility to perform NFC-related research activities, SNF, RW and minor-actinides handling; radionuclides production area; fuel development and manufacturing area; full-cycle infrastructure, incl. nuclear fuel production, spent nuclear fuel and radioactive waste management, treatment of minor actinides; R&D-related lab-scale, research and design infrastructure. Currently, the new multipurpose fast reactor MBIR is under construction.				
	Services provided: access to local research facilities, databases, research methods and guidelines; production of radioisotopes; practical training of scientific and technical personnel, conferences, seminars, meetings on research and production activities of JSC "SSC RIAR".				
Russia	nuclear energy	Russian-Italian Project of Tokamak IGNITOR	**IGNITOR**	web-site	http://eng.nrcki.ru/pages/eng/international_megaprojects/ignitor/index.shtml
	No data.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
Canada	renewables, energy systems integration	National Research Council Canada Energy, Mining and Environment Research Centre	**NRC EME**	on-line survey	https://nrc.canada.ca/en/research-development/research-collaboration/research-centres/energy-mining-environment-research-centre
	Description/background: EME is one of 14 research centres within National Research Council (NRC) Canada, uniting R&D capabilities and facilities in energy, mining and environment research. In energy research, EME focuses on bioenergy systems, energy storage and novel material for clean energy and aims to support Canadian industry in bringing the latest science and technology achievements to the market. According to expert estimation, the largest part (about 75%) of funding for EME comes from Parliamentary grant through the Department for Innovation, Science and Economic Development with investment plans done for five years and program plans – for eight years. EME also receives funding from "other government funding programs and revenue from industry" with shorter time horizon on one to three years.				
	Infrastructure: EME has facilities to conduct bioenergy research and energy storage research. A new facility related to energy materials development is under construction.				
Canada	renewables	Wind Engineering, Energy and Environment Research Institute	**WindEEE**	on-line survey	http://www.windeee.ca
	Description/background: WindEEE Research Institute was established in 2011 within Western University in Canada. The Research Institute includes a WindEEE Dome facility, which was commissioned in October 2014[1]. According to expert, "the main objective of the WindEEE RI is to advance the development of wind energy, wind engineering, and wind environment through research, education, innovation and collaboration". Since 2015 Wind EEE is recognised by the Group of Senior Officials as part of Global Research Infrastructures[2].				
	Infrastructure: The major infrastructure is WindEEE Dome – a 3D wind chamber, located in Ontario, Canada. WindEEE Dome can accommodate multi-scale, three dimensional and time dependent wind testing[3].				
	Services provided: WindEEE provides physical access to local research facilities and virtual access to datasets either through collaboration on projects or on the commercial basis (fee for use). According to expert estimation, from 95 to 100% of facilities are provided to external parties and actually used.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
Canada	renewables	Fundy Ocean Research Centre for Energy	**FORCE**	web-site	http://fundyforce.ca/
	Description/background: FORCE is a private, non-profit institute, supported by the Governments of Canada and Nova Scotia and participating developers. It is Canada's lead demonstration facility for tidal in-stream energy conversion (TISEC) technology[4].				
	Infrastructure: The natural test site is located in the Bay of Fundy with the world's highest tides. The site is used for testing TISEC devices.				
	Services provided: FORCE acts as a host to TISEC developers, providing a shared observation facility, subsea power cables and grid connection at its test site. FORCE also provides environmental studies, environmental monitoring and applied research acting as a steward of the test site[5].				
Canada	nuclear energy	Canadian Nuclear Laboratories	**CNL**	web-site	http://www.cnl.ca/en/home/default.aspx
	Description/background: Established in the middle of 20th century, Canadian Nuclear Laboratories has been a primary national nuclear research laboratory in Canada. In the past years, CNL recognized the need to formulate a new vision. The modern strategy for years 2016-2026 has a special focus on the revitalization of Chalk River Laboratories site. For the coming years, CNL sets the following priorities in energy R&D: (1) life extension and long-term reliability of existing reactors, (2) development of new methods for next-generation fuels fabrication, (3) small modular reactors, and (4) decarbonisation of transport sector through demonstration of hydrogen-based bulk transport.				
	Infrastructure: For decades until the shutdown in 2018, the National Research Universal reactor was one of the world's most versatile high-flux research reactors. Currently CNL has a ZED-2 research reactor and a number of research facilities for materials research, fuel testing etc.				
	Services provided: CNL offers collaboration opportunities to universities, small and medium-sized enterprises and other interested third parties.				
USA	nuclear energy, renewables, cross-sectional	Oak Ridge National Laboratory	**ORNL**	web-site	https://www.ornl.gov/
	Description/background: ORNL is a multi-program national laboratory under the USA Department of Energy. The scientific portfolio in energy research includes nuclear energy technologies, fusion science and technologies, energy efficiency and renewable energy. ORNL is a member of ITER project.				
	Infrastructure: ORNL provides several user facilities which are open to researchers outside the laboratory. Facilities that can be related to energy research are: High Flux Isotope Reactor, Building Technologies Research and Integrated Center, Carbon Fiber Technology facility and National Transportation Research Center.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
USA	nuclear energy, renewables, energy systems integration	Sandia National Laboratories	**SNL**	web-site	https://energy.sandia.gov/energy/
	Description/background: SNL came to existence in 1945 as a single-mission organization to engineer non-nuclear components of nuclear weapons within a Manhattan project. In 1948 SNL became a Laboratory and in 1979 – a US Department of Energy National Laboratory. Primarily the national security mission and the mission of maintaining national technological direct activities of SNL. Energy studies is a part of SNL's research portfolio and include multiple research areas, namely: energy storage, hydrogen power, electrical grid, solar power, nuclear energy.				
	Infrastructure: SNL includes a number of Technology Deployment Centres assessable by not only US industry, governmental organizations, universities and academic institutions, but by a general scientific community. Some of these user facilities[6] are relevant for energy research, namely: National Solar Thermal Test Facility (solar power), Nuclear Energy and Fuel Cycle Programs (nuclear energy), Advanced Power Source Engineering Facility (energy storage), Combustion Research Facility (hydrogen power), Distributed Energy Technology Laboratory (electrical grid), Nuclear Facilities Resource Center (nuclear energy), Photovoltaic Laboratories (photovoltaics).				
USA	renewables	National Renewable Energy Laboratory	**NREL**	web-site	https://www.nrel.gov/
	Description/background: Many of the most prominent identified RIs are organised as parts of the National Renewable Energy Laboratory under the USA Department of Energy. NREL includes several laboratories, research centres and research programs: **National Bioenergy Centre** conducts research in bio energy, fuels and bioproducts. The research areas comprise analysis and characterization, bioenergetics, studying biochemical and thermochemical processes. **National Centre for Photovoltaics** focuses on increasing solar cell conversion efficiency, cost reduction of solar cells, modules, and systems, improving the reliability of PV components and systems				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Concentrating Solar Power Research focuses on developing materials for use in CSP, materials characterization, field characterization, engineering and techno/economic analysis. **National Wind Technology Centre** conducts research in wind energy, waterpower and grid interaction **Geothermal Program** aims to conduct the full spectrum of research on geothermal energy including geothermal impact analysis, evaluation of hybrid systems (geothermal systems combined with renewable and fossil energy technologies), geothermal exploration and resource assessment, sedimentary and enhanced geothermal systems.				
	Infrastructure: NREL include multiple research facilities: • *For bioenergy studies: Integrated Biorefinery research facility, Thermal and Catalytic Process Development Units.* • *For photovoltaics studies: Solar Energy Research Facility, Science and Technology Facility, Outdoor Test Facility and Related Facilities, Regional Test Centres.* • *For concentrating solar power research: Thin-Film Deposition Laboratory, Advanced Thermal Storage Materials Laboratory, Receiver Test Laboratory, Optical Characterization Laboratory, Large-Payload Solar Tracker, High-Flux Solar Furnace.* • *For wind energy studies: Field research validation sites for wind energy studies (including six wind research turbines, four meteorological towers), Dynamometer research facilities, Structural research facilities, Controllable grid interface.* • *For geothermal energy studies: Energy Systems Integration facility, High-Performance Computing Data Center, Solar Radiation Research Laboratory, Thermal Test Facility.*				
	Services provided: NREL offers opportunities for partnerships and collaborations with industrial, governmental organizations, as well as research and non-profit organizations. NREL provides opportunities to use facilities, to develop technology partnerships and to license technology.				
USA	energy systems integration	Pasific Northwest National Laboratory	**PNNL**	on-line survey	www.pnnl.gov
	Description/background: PNNL is included in the list of national laboratories under the USA Department of Energy. It receives funding mostly from US federal agencies and its projects that typically last for one to five years. The scientific domains that PNNL mostly focused on are catalysis, earth sciences, data analytics, cybersecurity, the electric power system and nuclear science and technology. In energy research the core problem that PNNL aims to address is the creation of energy resilient systems.				
	Infrastructure: PNNL holds several user facilities which are opened for access by a broader scientific community.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Services provided: Facilities provide physical, remote and virtual access to users which is mainly determined by peer review process.				
USA	cross-sectional	Lawrence Berkeley National Laboratory	**LBNL**	web-site	https://www.lbl.gov/
	Description/background: LBNL was founded in 1931 by Ernest O. Lawrence, a Nobel Prize winner in Physics. Now LBNL positions itself as a leading basic sciences national laboratory. It is also a US Department of Energy National Laboratory. Energy Sciences area in LBNL encompasses multiple scientific disciplines with major activities concentrated in Materials Sciences Division and Chemical Sciences Division. In addition to these divisions Basic Energy Sciences programs funded by the US Department of Energy also conducted within Joint Centre for Energy Storage Research (JCESR), led by the Energy Technologies Area), the Centre for Advanced Mathematics for Energy Research Applications (CAMERA, led by the Computational Research Division), and the Centre for Nanoscale Controls on Geologic CO2 (an Energy Frontier Research Centre led by the Earth and Environmental Sciences Area). Implications of Basic Energy Studies relate to multiple energy areas: photovoltaics, photosynthesis, biofuels, energy storage, combustion, catalysis, carbon capture/sequestration.				
	Infrastructure: National user facilities within Energy Sciences area at LBNL include Advanced Light Source, Molecular Foundry, Energy Sciences Network, National Energy Research Scientific Computing Centre.				
	Services provided: Provides external access to its national user facilities.				
USA	nuclear energy	DIII-D National Fusion Facility	**DIII-D NFF**	web-site	http://www.ga.com/diii-d
	Description/background: DIII-D National Fusion Facility is a laboratory operated by General Atomics for the U.S. Department of Energy. The laboratory investigates a broad range of fusion energy research topics from fundamental plasma science to the work of fusion power plants.				
	Infrastructure: DIII-D tokamak operated since mid-1980s.				
	Services provided: In order to provide access to the research facility General Atomics organizes a DIII-D Research Program that is open to research proposals from all countries having a cooperative agreement with US Department of Energy.				
USA		National Energy Technology Laboratory	**NETL**	web-site	https://www.netl.doe.gov/

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Description/background: NETL is owned and operated by US Department of Energy and supports its mission. NETL is the only laboratory among US Department of Energy National Laboratory that specializes in fossil energy studies. Due to its research focus in fossil fuels this laboratory is perhaps less interesting partner for European RIs, as we do not see a European fossil fuel RI.				
USA	nuclear energy	Idaho National Laboratory	**INL**	web-site	https://inl.gov/
	Description/background: INL is one of the US Department of Energy National Laboratories focused on nuclear energy studies.				
	Infrastructure: INL offers numerous user facilities for researchers, such as beamline, ion irradiation, post-irradiation examination and gamma-irradiation facilities. The laboratory also offers access to 10 nuclear reactors each of those offer different capabilities for nuclear research.				
	Services provided: For researchers INL offers access to user facilities, computing resources, access to library and publications as well as access to nuclear infrastructure database.				
USA	nuclear energy, renewables, cross-sectional, efficient energy conversion and use	Savannah River National Laboratory	**SRNL**	web-site	https://srnl.doe.gov/
	Description/background: Established in 1951 Savannah River National Laboratory belongs to US Department of Energy National Laboratories. It is a multi-program applied research and development laboratory working to achieve goals in environmental management, national and homeland security, as well as energy security. SRNL regards as its core capabilities: environmental remediation and risk reduction, nuclear materials processing and disposition, nuclear detection, characterization and assessments, gas processing, storage and transfer systems. In addition, SRNL has research programs and facilities related to hydrogen, bioenergy and energy materials.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Infrastructure: In addition to the main campus (which concentrates the nuclear-related research facilities), SRNL comprises Aiken County Research Laboratory (research portfolio includes research in bioenergy), Hydrogen Technology Research Laboratory and Energy Materials Research Laboratory.				
	Services provided: SRNL provides opportunities of cooperation to industry, government and academic institutions.				
USA	efficient energy conversion and use, energy systems integration, renewables, nuclear energy, cross-sectional	MIT Energy Initiative	**MITEI**	web-site	http://energy.mit.edu/
	Description/background: MIT Energy Initiative is an institute-wide initiative that brings together energy researchers within MIT and promotes collaborations with industry and governmental partners. MITEI focuses on energy solutions that mitigate greenhouse gas emissions and address climate change issues. The Initiative prioritizes eight areas for energy research (advanced nuclear energy systems, carbon capture, utilization and storage, electric power systems, energy storage, energy bioscience, materials in energy and extreme environments, mobility systems, solar energy) and organizes them into corresponding Low-Carbon Energy Centres.				
	Infrastructure: No information about any specific infrastructure/facilities for energy research.				
	Services provided: MITEI provides funding for research and development projects at MIT, promotes collaborations with industry and government, organizes educational programs and disseminates results.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
USA	renewables, nuclear enrgy, energy systems integration, efficient energy conversion and use	Stanford Precourt Institute for Energy	**Stanford Energy**	on-line survey	https://energy.stanford.edu/
	Description/background: Stanford University Precourt Institute for Energy is a focal point for Energy Research across various academic departments, labs and research programs of Stanford University. It focuses on supporting energy research projects in the following areas: renewables (bioenergy, geothermal, photovoltaics, renewable fuels, solar thermal, wind), energy storage and grid modernization, policy and economics, end use and efficiency, fossil and nuclear energy, environmental impacts.				
	Infrastructure: Stanford University Precourt Institute for Energy does not itself operates any user research facilities. However, there are research facilities available at Stanford University.				
	Services provided: funding allocation through a seed grant program, organization of educational programs, disseminations of research results.				
USA	energy systems integration, cross-sectional, renewables	Argonne National Laboratory	**ANL**	web-site	https://www.anl.gov/
	Description/background: ANL was established in 1946 as a chemistry, materials and nuclear engineering laboratory focused on developing peaceful uses for nuclear energy. Nowadays, ANL is a multidisciplinary research centre and a U.S. Department of Energy Office of Science national laboratory. ANL includes a variety of research groups, centres, initiatives and testing facilities related to studies and development of energy storage technologies, transportation, energy networks and hydropower. ANL has strong computational and energy systems modelling capabilities.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Infrastructure: There are five national user facilities some of those are actively used in energy studies, namely: Advanced Photon Source (APS) that includes a Transportation Beamline used by a transportation research team and Argonne Leadership Computer Facility (ALCF). In addition, there are multiple other facilities available at ANL. Among those relevant for energy research are, for example: Advanced Mobility Technology Laboratory, Distributed Energy Research Center, Engine Research Facility, Virtual Engine Research Institute and Fuels Initiative and others.				
	Services provided: ANL provides access to its national users facilities for researchers from industry, universities and other laboratories.				
Brazil	nuclear energy	Centro de Desenvolvimento da Tecnologia Nuclear	**CDTN**	interview, on-line survey	http://www.cdtn.br/en
	Description/background: CDTN is a nuclear institute that conducts research on radiochemistry, radioprotection, radiological metrology and dosimetry, nuclear/radiological safety, radioactive waste management, and nuclear technology (thermodynamics and neutronics). In addition to research activities, this is also an educational organization that holds the Graduate programme (PhD & M.Sc.) of Science and Technology of Radiations, Minerals and Materials.				
	Infrastructure: The main nuclear/radioactive facilities of CDTN are Nuclear Research Reactor TRIGA IPR-R1, Unit for Research and Production of Radiopharmaceuticals –UPPR, and Laboratory of Gamma Irradiation.				
	Services provided: CDTN plays a significant role in the technological development and the provision of specialized services for the mineral and metallurgical sectors. For example, CDTN offers radiopharmaceuticals production for applications in positron emission tomography, calibration of radiation dosimeters and individual monitoring to the community for the health area.				
Brazil	renewables	Brazilian Centre for Research in Energy and Materials	**CNPEM**	interview, on-line survey	http://cnpem.br/
	Description/background: CNPEM is a private non-profit Social Organization supervised by the Ministry of Science, Technology, Innovation and Communications (MCTIC). Located in Campinas, São Paulo State, it consists of four National Laboratories open to the scientific and technological communities, with competencies in biosciences, materials, renewable energies, and advanced instrumentation.				
	Infrastructure: Four laboratories: The Brazilian Synchrotron Light Laboratory (LNLS), The Brazilian Biosciences National Laboratory (LNBio), The Brazilian Bioethanol Science and Technology Laboratory (CTBE), and The Brazilian Nanotechnology National Laboratory (LNNano).				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Services provided: CNPEM implements, maintains, and operates open-access facilities to ensure the access of researchers from all over the country and abroad, including UVX, Sirius, microscopy characterization, the Electron Microscopy and Cryomicroscopy facilities, Atomic Force Microscopy, the microfabrication and functional systems and devices, the nanostructured soft materials facilities, proteomics (MAS), spectroscopy and calorimetry (LEC), nuclear magnetic resonance (RMN), protein crystallization (RoboLab), and the Pilot Plan for Process Development (PPDP).				
Brazil	nuclear energy, renewables	Instituto de Pesquisas Energéticas e Nucleares	**IPEN**	interview, on-line survey	https://www.ipen.br/portal_por/portal/interna.php?secao_id=723
	Description/background: Nuclear and Energy Research Institute is an autarchy of the São Paulo State, associated to the University of São Paulo for educational purposes, supported and operated technically and administratively by the National Nuclear Energy Commission (CNEN). It is recognized as a national leader in research, development and applications in the areas of radiopharmacy, radiation technology, nuclear physics, materials, lasers, biotechnology, environment and clean energy, and also in design and operation of nuclear reactors and radioactive facilities.				
	Infrastructure: There are 11 Research and Development Centres on the campus of University of São Paulo. Other facilities include nuclear electric power plants and petrochemical facilities. The new facility in plan is Brazilian Multipurpose Reactor (RMB).[7]				
	Services provided: Analysis of radionuclides in environmental and food samples; environmental radiological impact evaluation; external and internal individual monitoring and dose calculation; clinical and high-dose dosimetry; production of dosimetric materials; calibration of radiation detectors; radiation protection services; treatment of radioactive waste, and responses to radiological emergencies.				
China	nuclear energy, cross-sectional	Institute of Plasma Physics, Chinese Academy of Science	**ASIPP**	web-site	http://english.ipp.cas.cn/
	Description/background: ASIPP was founded in September 1978 for the peaceful utilization of fusion energy through the tokamak approach. As one of the most important laboratories in China, ASIPP has been conducting researches in high temperature plasma physics and magnetically confined fusion engineering, and it has built the world's first non-circle cross-section full superconducting tokamak, namely Experimental Advanced Superconducting Tokamak (EAST). ASIPP is a major contributor in China for ITER, having undertaken up to 73% of China's ITER Procurement Packages tasks which include superconducting conductors, correction coils, superconducting current leads, and so on. It has established close cooperation relationship with more than 30 countries and regions such as EU, the US, Russia and Japan.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Infrastructure: ASIPP has built various tokamak fusion experimental facilities including HT-6B, HT-6M, HT-7 and EAST.				
	Services provided: ASIPP has established nearly 20 companies which create both economic and social benefits. Hainan New Energy Research Centre is one example, forming a complete chain from basic researches to industrialization. ASIPP hosts various international seminars and workshops, and actively support fusion research in the developing countries. *Plasma Science and Technology* is the journal founded by ASIPP for reporting novel experimental and theoretical results in the fields related to plasma.				
China	nuclear energy, cross-sectional	Nuclear Power Institute of China	**NPIC**	web-site	http://en.npic.ac.cn/
	Description/background: Founded in 1965, NIPC is the only large-scale comprehensive R&D base in China incorporating reactor engineering research, design, test, operation and small batch production. It has established a complete research and development system, including nuclear power engineering design, reactor operation and application research, nuclear fuel and material research, nuclear technology application research and services, etc.				
	Infrastructure: NIPC has established 90 laboratories, including two national key laboratories and two national energy R&D centres. It has designed seven nuclear facilities on self-reliance such as the first High Flux Engineering Test Reactor in China. There are 18 large scale test installations for R&D of reactor engineering. It has developed nuclear power plants CP600/CP1000/CPR1000, and undertakes the R&D of next generation of nuclear power plants ACP100, ACP600 and ACP1000. A new comprehensive R&D base in under construction.				
	Services provided: NIPC provides a series of specialized technical services for nuclear power plants and research reactors, such as the overhaul and regular maintenance, supply of special tools, qualification of nuclear equipment and treatment of radioactive wastes. It has also developed a series of primary products. [8]				
China	nuclear energy, cross-sectional	Shanghai Synchroton Radiation Facility	**SSRF**	web-site	http://e-ssrf.sinap.cas.cn/
	Description/background: SSRF is the largest synchrotron research facility to date in China, and it is one of the advanced third generation light sources in the world, supporting and pushing the cutting-edge scientific research and the innovation.				
	Infrastructure: SSRF is composed of one 150 MeV linear accelerator, one 3.5 GeV booster, one 3.5 GeV storage ring, beamlines and experimental stations[9].				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Services provided: Since 2009 SSRF has provided bright x-ray beams to more than 10000 users from universities, institutes, hospitals and high-tech companies around China and the world. The facilities has been used in various areas of scientific research and industrial development, including biology, physics, material science, chemistry, environmental science, archeology, biomedical applications, medicine and drug development, etc. SSRF is also actively involved in the training and education of the next generation of scientists and engineers.				
China	renewables	Institute of Electrical Engineering, Chinese Academy of Science	**IEE,CAS**	web-site	http://english.iee.cas.cn/intro/
	Description/background: IEE is a national research institution oriented to the development of electrical science and engineering, and it is also one of the important institutes which engages in energy research in CAS. Its research fields include renewable energy technologies, new electric power technologies, and frontier inter-discipline subjects of electrical science. It has become a strategic backbone of innovations in related fields of China.				
	Infrastructure: IEE has six Laboratories and one Interdisciplinary Research Centre[10].				
Japan	nuclear energy	Japan Atomic Energy Agency	**JAEA**	on-line survey	https://www.jaea.go.jp/english/
	Description/background: As Japan's sole comprehensive nuclear research and development institution, JAEA aims to make contribution to welfare and prosperity of human society through nuclear science and technology. Its priorities are the research into improving nuclear power safety, basic and fundamental research of nuclear power, and R&D on nuclear fuel cycle. In response to the accident at Fukushima Daiichi Nuclear Power Plant, it has been conducted the R&D for decommissioning and environmental restoration. It also strives for the promotion of international cooperation, and has developed cooperation with countries in Europe, North America, Asia, and so on[11].				
	Infrastructure: "Fugen", "Monju" and Tokai Reprocessing Plant.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Services provided: In an event of nuclear or radiological incident, Nuclear Emergency Assistance and Training Centre, launched by JAEA, provides support to central and local governments in various technical ways including prompt dispatch of experts for emergency radiation monitoring and provision of technical advice to the governments and the public[12].				
Japan	cross-sectional	Global Research Centre for Environment and Energy Based on Nanomaterials Science	**GREEN**	web-site	https://www.nims.go.jp/GREEN/en/index.html
	Description/background: GREEN was established in October 2009 with NIMS as the host institution. Building upon the strength of Japan in the field of nanotechnology and materials science, GREEN engages in the fundamental research of environmental technology, contributing to the creation of new materials for solving environmental and energy problems.				
	Infrastructure: NanoGREEN Building was opened in 2012. It is an eco-friendly laboratory featuring solar panels, LED lightings and photocatalyst glass watering systems,etc. It consists of research facilities such as super dry room (DP of SA <-90°C), Femtosecond Laser System, and Photocatalysis Reaction System.				
	Services provided: GREEN invites researchers from universities and research institutes in Japan to work on the topics well linked to GREEN's mission through a public recruiting process. GREEN open-lab guest researchers have the opportunity to communicate with NIMS researchers from various fields, and jointly analyse the experimental results obtained by using the cutting-edge facilities at NIMS. Green is also the host of Green Symposium, NBCI-NIMS Joint Seminar, Battery Research Platform, and Analysis Forum for Battery Materials[13].				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
Japan	renewables, efficient energy conversion and use, cross-sectional	Research Institute for Energy Conservation, The National Institute of Advanced Industrial Science and Technology	**iECO, AIST**	on-line survey	https://unit.aist.go.jp/ieco/en/
	Description/background: Description/Background: iECO is one of the research institutes of the Department of Energy and Environment, AIST[14]. It conducts R&Ds on energy technologies to improve the efficiency of utilization and conversion. Infrastructure: iECO has eight research groups: Thermofluid System Group, Thermal Energy Applications Group, Thermoelectric Energy Conversion Group, Energy Interface Technology Group, Energy Conversion Technology Group, Energy Storage Technology Group, Turbomachinery Group and Engine Combustion and Emission Control Group. It has three laboratories: Collaborative Engine Research Laboratory for Next Generation Vehicles, Energy NanoEngineering Research Laboratory and Advanced Technology Laboratory for Solid State Energy Conversion (ALSEC)[15]. Description/background: AIST is one of the largest public research organizations in Japan. It focuses on the creation and practical realization of technologies useful to Japanese industry and society, and on bridging the gap between innovative technological seeds and commercialization. Infrastructure: AIST consists of five departments and two centres which are Department of Energy and Environment, Department of Life Science and Biotechnology, Department of Information Technology and Human Factors, Department of Materials and Chemistry, Department of Electronics and Manufacturing, Geological Survey of Japan, and National Metrology Institute of Japan. AIST has eight research bases throughout Japan for improving regional innovation. Fukushima Renewable Energy Institute, AIST (FREA) is established in Fukushima, promoting R&D in renewable energy and open to the world.				
	Services provided: AIST promotes collaborative work with leading companies, research institutions and universities worldwide. It strives to build international cooperative relationship between academia and industry through its global research network. It is one of the major research and innovation hubs where there is a high potential for creating new business opportunities[16].				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
Japan	renewables	The New Energy and Industrial Technology Development Organisation	**NEDO**	web-site	https://www.nedo.go.jp/english/index.html
	Description/background: As one of the largest public research and development management organizations in Japan, NEDO has two missions, namely addressing energy and global environmental problems, and enhancing industrial technology. NEDO coordinates and integrates the technological capabilities and research abilities of industry, academia, and government instead of employing its own researchers. NEDO aims to introduce advanced Japanese technologies to countries and regions around the world having diverse needs and infrastructures[17].				
	Infrastructure: Barge-type floating offshore wind turbine system demonstrator, Real-grid operation of high-temperature superconducting cables, Demonstration facilities for oxygen-blown IGCC, Environmentally-friendly waste oil recycling system demonstration plant, High-efficiency wind lens turbines, and so on.				
	Services provided: NEDO provides small and medium-sized enterprises and venture businesses with support at various phases, ranging from support for technology seeds to practical application by businesses. NEDO has been offering support for practical application in renewable energy and welfare equipment fields. It has also built systems that allow experts to provide advice on topics such as venture capital financing, legal issues, accounting, and intellectual property as they relate to commercialization.				
India	nuclear energy, cross-sectional	Bhabha Atomic Research Centre	**BARC**	web-site	http://www.barc.gov.in/index.html
	Description/background: The establishment of BARC dated back to 1954, for multidisciplinary research program essential for the ambitious nuclear program of India. It is the parent body of the R&D institutions such as IGCAR, RRCAT, VECC, etc. It carries out pioneering research on nuclear and accelerator technologies and industrial establishments. Infrastructure: BARC has active groups for R&D in reactor technologies, fuel reprocessing and waste management, isotope applications, radiation technologies, and so on. There are multiple research reactors constructed by BARC such as APSARA, ZERLINA and CIRUS Reactor[18].				
India	renewables	Solar Energy Research Cente for India and the United States	**SERIIUS**	web-site	https://www.seriius.org/

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Description/background: SERIIUS facilitates joint R&D and related activities on clean energy by teams from India and the United States. Through an environment of cooperation and innovation "without borders", it will develop and ready emerging and revolutionary solar electricity technologies. It will achieve this goal by lowering the cost per watt of photovoltaics (PV) and concentrated solar power (CSP). Infrastructure and Services Provided: SERIIUS has three research thrusts, including Sustainable Photovoltaics, Multiscale Concentrated Solar Power, and Solar Energy Integration, to ensure high-impact research and development to address key technical barriers in solar electricity generation. Under each research thrust there are respective infrastructures and services provided[19].				
India	renewables	DTB-ICGEB Centre for Advanced Bioenergy	**DTB-ICGEB**	web-site	http://icgeb-bioenergy.org/
	Description/background: Thriving upon ICGEB, DBT-ICGEB is established for strengthening the existing capacity in synthetic biology and to promote the cutting edge research in biofuel area. It mainly performs research in molecular biology and biotechnology, using advance genetic tools, metabolic engineering and system biology approaches, and will serve as platform for the synthetic biologists to work in diverse bioenergy areas such as microbial engineering, biochemical engineering, algal engineering and systems biology.				
	Infrastructure: There are 41 facilities in DBT-ICGEB. The detailed list of facilities can be found here http://icgeb-bioenergy.org/facilities/				
	Services provided: DBT-ICGEB involves in skill development programs and organizes various workshops and training programs. It supports Mission Innovation of India in which it will coordinate the activities of Mission Innovation initiatives of India with other partnering countries, and it will sync with the main/apex Mission Innovation Secretariat worldwide. The Unit will encourage liaising between public/private partnership in India and other partner countries for various collaboration activities, share information and coordinate with interested potential business investors.				
South Korea	nuclear energy	National Fusion Energy Institute	**NFRI**	web-site	https://www.nfri.re.kr/eng/index
	Description/background: NFRI is the national institute dedicated to conducting research and development of fusion energy. It has constructed the world's highest-ranking fusion research device named Korea Superconducting Tokamak Advanced Research (KSTAR), and has been actively involved in ITER. It collaborates with other RIs in countries such as the US, Russia, China, Japan, India as well as European countries including the UK, Netherlands, France, Germany, Italy and Hungary.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Infrastructure: NFRI has constructed KSTAR, the high efficient tokamak. The research for Korean Fusion Demonstration Plant (K-DEMO) is carried out.				
Australia	nuclear energy	OPAL at Australian Nuclear Science and Technology Organization	**OPAL (ANSTO)**	on-line survey	https://www.ansto.gov.au/
	Description/background: ANSTO is the home of Australia's most significant landmark and national infrastructure for research. It partners with scientists and engineers, and applies new technologies to provide real-world benefits. Its work improves human health, saves lives, builds industries and protects the environment.				
	Infrastructure: ANSTO operates much of Australia's landmark infrastructure including one of the world's most modern nuclear research reactors, OPAL; a comprehensive suite of neutron beam instruments; the Australian Synchrotron; the National Imaging Facility Research Cyclotron, and the Centre for Accelerator Science.				
	Services provided: health products, mineral consultancy, radiation services, Silicon irradiation, Gamma irradiation, Neutron Activation Analysis and Neutron Irradiation, measurement, and ANSTO Synroc-Waste Treatment Technology[20].				
Australia	energy systems integration	Centre of Excellence in Exciton Science, Australian Research Council	**ACEX**	web-site	https://excitonscience.com/
	Description/background: The Centre is funded by the Australian Research Council, working with researchers and industry, to research better ways to manipulate the way light energy is absorbed, transported and transformed in advanced molecular materials. It finds innovative solutions for renewable energy in solar energy conversion, energy-efficient lighting and displays, ad security labelling and optical sensor platform for defence.				
	Infrastructure: The Centre is a collaboration of researchers at the University of Melbourne, Monash University, RMIT, University of NSW and the University of Sydney. It works with Industry Partners such as Reserve Bank of Australia, CSIRO and Department of Defence: Defence Science & Technology Group. The Centre has extensive infrastructure for device fabrication including complete solar cell characterisation systems, wide range of printing and deposition technologies, clean room access, wide range of deposition methods and roll-to-roll printing and slot die coating facilities at CSIRO.				

Country	Sub-domain	Long name	Short name	How information was collected	Web-page
	Services provided: one of the Centre's core drivers is translating research into commercially viable products and services. In 2018, the Centre ran Entrepreneurship Bootcamp for its postdocs and researchers. It engaged a more strategy-based entrepreneurial focus by taking on Availer as consultants to audit its research and to determine if any has the potential to be commercialized.				
Australia	cross-sectional	Australian National Fabrication Facility	**ANFF**	web-site	http://www.anff.org.au/
	Description/background: ANFF links eight university-based nodes to provide researchers and industry with access to state-of-the-art fabrication facilities. The nodes, located across Australia, draw on existing infrastructure and expertise. Each offers a specific area of expertise including advanced materials, nanoelectronics & photonics and bio nano applications.				
	Infrastructure: ANFF has a network of eight nodes including 21 institutions throughout Australia[21]. Its facility portfolio consists of over 500 instruments with projects valued over $200 million[22].				
	Services provided: ANFF provides services for both academic researchers and industry. It enables users to process hard materials (metals, composites and ceramics) and soft materials (polymers and polymer-biological moieties) and transform these into structures that have application in sensor medical device, nano photonics and nanoelectronics. Researchers are able to either gain direct access to facilities under expert guidance, contract for specialised products to be made or undertake contract research projects				

APPENDIX 7 – Astronomy and astroparticle research

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Agua Negra Deep Experiment Site	ANDES	astroparticles	Argentina	http://andeslab.org/	yes	Complete
Deep underground laboratory that will provide the science community a world class site for leading experiments to operate in the Southern Hemisphere. It will have his underground installations located in the Agua Negra tunnel to be built between Argentina and Chile. Two close-by support laboratories will be installed in both sides of the tunnel.						
SNOLAB	SNOLAB	astroparticles	Canada	https://www.snolab.ca	yes	Complete
Deep underground research facility located within an operational mine, near Sudbury, Ontario, Canada. The science programme at SNOLAB is currently focused on sub-atomic physics, largely neutrino and dark matter physics. These pose some of the most pressing questions in contemporary physics.						
Large High Altitude Air Shower Observatory	LHAASO	astroparticles	China	http://english.ihep.cas.cn/	yes	Complete
High altitude cosmic rays experiment, to search for the galactic cosmic ray sources, and studies on new physics, such as dark matter particle.						
Very Energetic Radiation Imaging Telescope Array System	VERITAS	astroparticles	United States	https://veritas.sao.arizona.edu/	yes	Complete
VERITAS (Very Energetic Radiation Imaging Telescope Array System) is a major ground-based gamma-ray observatory located at the basecamp of the Fred Lawrence Whipple Observatory in southern Arizona. VERITAS comprises an array of four 12m optical reflectors for gamma-ray astronomy in the very high energy (VHE: 50 GeV - 50 TeV) range.						
Laser Interferometer Gravitational-Wave Observatory	LIGO	gravitational waves	United States	https://www.ligo.caltech.edu/	yes	Complete
LIGO is a sophisticated physics experiment designed to detect gravitational waves from some of the most violent and energetic events in the Universe. LIGO is comprised of four distinct facilities across the United States: two gravitational wave detectors (the interferometers) and two university research centers.						

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Kamioka Gravitational Wave Detector	KAGRA	gravitational waves	Japan	https://gwcenter.icrr.u-tokyo.ac.jp/en/	yes	Complete
Gravitational wave detector in Japan. Recently finalised construction phase.						
Thirty Meter Telescope	TMT	infrared / optical	United States	https://www.tmt.org/	yes	Complete
30m aperture telescope currently under construction. The TMT will be an infrastructure enabling scientific research to be carried out by the international astronomical community.						
Daniel K. Inouye Solar Telescope	DKIST	infrared / optical	United States	https://dkist.nso.edu/	yes	Complete
When completed, DKIST will be the world's most powerful solar observatory, poised to answer fundamental questions in solar physics by providing transformative improvements over current ground- based facilities.						
Giant Magellan Telescope	GMTO	infrared / optical	United States	https://www.gmto.org/	yes	Complete
The GMT will have a transformative impact on areas spanning observational astrophysics from exoplanets around neighboring stars to the formation of the first, most distant stars, galaxies, and black holes in the universe.						
Southern African Large Telescope	SALT	infrared / optical	South Africa	https://www.salt.ac.za/	yes	Complete
Largest single optical telescope in the southern hemisphere and among the largest in the world. Its mission includes leading the advancement and development of optical astronomy on the African continent and inspire and educate new generations of scientists and engineers worldwide.						
Event Horizon Telescope	EHT	mm	United States	https://eventhorizontelescope.org/	yes	Complete
The EHT links radio dishes in a VLBI network and processes the data at correlation centers in order to create a virtual Earth-sized telescope capable of resolving the event horizon of a black hole.						

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Five-hundred meter Aperture Spherical radio Telescope	FAST	radio	China	http://www.bao.ac.cn	yes	Complete
Megascience project to build the largest single dish radio telescope in the world. The main observables of FAST are pulsars, the 21cm atomic hydrogen hyperfine transition, molecular transitions including masers, and radio continuum.						
VLBI Exploration of Radio Astrometry	VERA	radio	Japan	http://www.miz.nao.ac.jp/en	yes	Complete
Network of 4 radio telescopes of VERA spread over Japan. These 4 telescopes are operated as a VLBI array to synthesize a telescope as big as Japan.						
Giant Metrewave Radio Telescope	GMRT	radio	India	www.ncra.tifr.res.in	yes	Complete
Radio telescope, very versatile instrument for investigating a variety of radio astrophysical problems ranging from nearby Solar system to the edge of observable Universe.						
Ukrainian T-shaped radio telescope	UTR-2	radio	Ukraine	http://rian.kharkov.ua/index.php/en/	yes	Complete
T-Shaped radio telescope composed of 12 sub-arrays. Its mission is the investigation of Universe at low radio frequencies.						
Ukrainian Radio interferometer of the Academy of Sciences	URAN	radio	Ukraine	http://rian.kharkov.ua/index.php/en/	yes	Complete
Network of radio telescopes spread in 4 sites in Ukraine, reaching a maximal baseline of 950 km						
Giant Ukrainian Radio Telescope	GURT	radio	Ukraine	http://rian.kharkov.ua/index.php/en/	yes	Complete
Radio telescope designed to operate at very low frequencies currently under construction. Expected to be operational in 2025.						

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
KVN and VERA array KaVa	KaVa	radio	Korea	https://radio.kasi.re.kr/kava/main_kava.php	yes	Complete
KaVA is an international VLBI facility consisting of 7 radio telescopes located at Korea and Japan. It aims to unveil major astrophysical issues by high-resolution VLBI observations, especially birth, evolution, and death of stars; physical properties around supermassive black holes in active galactic nuclei; galaxy structure and dynamics.						
East Asia VLBI Network	EAVN	radio	Korea	https://radio.kasi.re.kr/eavn/main_eavn.php	yes	Complete
EAVN is an international VLBI facility consisting of more than 20 radio telescopes located at China, Korea, and Japan.						
International VLBI Service for Geodesy and Astrometry	IVS	radio	United States	https://radio.kasi.re.kr/eavn/main_eavn.php	yes	Complete
International collaboration of organizations which operate or support Very Long Baseline Interferometry (VLB I) components. Aims at providing highly precise reference coordinates on Earth and in space required for monitoring Global Change. At the same time, it monitors the variable rotation of the Earth for securing terrestrial positioning and navigation carried out with global navigation satellite systems such as GPS.						
W.M. Keck Observatory	Keck	infrared / optical	United States	http://www.keckobservatory.org/	no	Declined
The twin Keck Observatory telescopes operate in the optical and infrared. The telescopes' primary mirrors are 10-meters in diameter and are each composed of 36 hexagonal segments that work in concert as a single piece of reflective glass.						
Australia Telescope Compact Array	ATCA	radio	AU	https://www.narrabri.atnf.csiro.au/	no	Declined
Array of six 22-m antennas used for radio astronomy. It is operated by CSIRO's Astronomy and Space Science division.						
Long Wavelength Array	LWA	radio	United States	http://lwa.unm.edu/	no	Declined
The LWA is an effort to advance astronomy by using inexpensive antenna stations to build a very large aperture to probe the depths of space at the lowest frequencies. Currently under development.						

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Murchison Wide Field Array	MWA	radio	Australia	http://www.mwatelescope.org/	no	Declined
Low-frequency radio telescope, developed by an international collaboration, including partners from Australia, New Zealand, Japan, China, Canada and the United States.						
Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy	TAIGA	astroparticles	Russia	https://taiga-experiment.info/	no	No answer
Detector system for ground-based gamma-ray astronomy from a few TeV to several PeV, and for cosmic ray studies from 100 TeV to several 100's of PeV. Collaboration between Russian and Germany.						
High Altitude Water Cherenkov Gamma ray Observatory	HAWC	astroparticles	Mexico	https://www.hawc-observatory.org/	no	No answer
Facility designed to observe gamma rays and cosmic rays between 100 GeV and 100 TeV. Operated by a collaboration between US and Mexico.						
Telescope Array Project	TA	astroparticles	United States	http://www.telescopearray.org/	no	No answer
The Telescope Array project is a collaboration between universities and institutions in the United States, Japan, Korea, Russia, and Belgium. The experiment is designed to observe air showers induced by cosmic rays with extremely high energy.						
Major Atmospheric Cherenkov Telescope Experiment	MACE	astroparticles	India		no	No answer
21 m diameter γ-ray telescope which is presently being installed in India. It will help to explore the exciting energy range of gamma ray energy region in between satellite and the traditional Atmospheric Cerenkov experiments.						

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Astrophysical Radiation with Ground-based Observatory at YangBaJing Experiment	ARGO YBJ	astroparticles	China	http://argo.na.infn.it/	no	No answer
Experiment is to study cosmic rays, mainly cosmic gamma-radiation, at an energy threshold of ~100 GeV, by means of the detection of small size air showers.						
Yakutsk Array	-	astroparticles	Russia	https://ikfia.ysn.ru/en/eas/	no	No answer
Air shower array experiment that studies cosmic rays of extremely high energies above 10 PeV (=1016 eV), i.e. in the field of cosmic ray astrophysics. The main goals are the investigation of cascades of elementary particles in atmosphere initiated by primary cosmic rays; reconstruction of astrophysical properties of the primaries – intensity, energy spectrum, mass composition and their origin.						
Super Kamiokande	SuperK	astroparticles	Japan	http://www-sk.icrr.u-tokyo.ac.jp/sk/index-e.html	no	No answer
Large water Cherenkov detector operated by an international collaboration between Japan, the United States, Korea, China, Poland, Spain, Canada, UK, Italy and France.						
Gemini Observatory (N+S)	-	infrared / optical	Chile, United States	https://www.gemini.edu/	no	No answer
The Gemini Observatory consists of twin 8.1-meter diameter optical/infrared telescopes located on two of the best observing sites on the planet. From their locations on mountains in Hawai'i and Chile, the telescopes can collectively access the entire sky.						
Global Oscillation Network Group	GONG	infrared / optical	United States	https://gong.nso.edu/	no	No answer
The Global Oscillation Network Group (GONG) is a community-based program to conduct a detailed study of solar internal structure and dynamics using helioseismology. In order to exploit this new technique, GONG has developed a six-station network of extremely sensitive, and stable velocity imagers located around the Earth to obtain nearly continuous observations of the Sun's "five-minute" oscillations, or pulsations.						
Dunn Solar Observatory	DST	infrared / optical	United States	https://www.nso.edu/telescopes/dunn-solar-telescope/dunn/	no	No answer
Once the finest instrument of its kind in the world. Managed by NSO for almost half a century, its 0.2 arc-seconds resolution unveiled a multitude of secrets surrounding the complex magnetic fields that dominate the solar atmosphere.						

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Large Binocular Telescope	LBT	infrared / optical	United States	http://www.lbto.org/	no	No answer
The binocular design of the Large Binocular Telescope (LBT) has two identical 8.4m telescopes mounted side-by-side on a common altitude-azimuth mounting for a combined collecting area of a single 11.8m telescope. Located in southeastern Arizona at an altitude of 3200m.						
Fuxian Solar Observatory	FSO	infrared / optical	China	http://fso.ynao.ac.cn/	no	No answer
The 1m New Vacuum Solar Telescope (NVST), formerly known as 1m Yunnan Solar Telescope (YNST), is the primary facility of FSO, which mains goals are high resolution imaging and spectral observations, including measurements of the solar magnetic field.						
Subaru	-	infrared / optical	United States	https://subarutelescope.org/	no	No answer
Submillimeter Array	SMA	mm	United States	https://www.cfa.harvard.edu/sma/	no	No answer
Korean VLBI Network	KVN	radio	Korea	https://radio.kasi.re.kr/kvn/main_kvn.php	no	No answer
Very Long Baseline Array	VLBA	radio	United States	https://science.nrao.edu/facilities/vlba	no	No answer
Long Baseline Array	LBA	radio	Australia	http://astronomy.swin.edu.au/cosmos/L/Long+Baseline+Array	no	No answer
African VLBI Network	AVN	radio	Ghana, South Africa	http://www.aerap.org/africanradioastronomy.php?id=32	no	No answer
21 CentiMeter Array	21CMA	radio	China	http://english.nao.cas.cn/Research2015/rp2015/201701/t20170120_173603.html	no	No answer
BICEP	-	astroparticles	United States	https://www.cfa.harvard.edu/CMB/bicep1/	no	Not contacted
Big Bear Solar Observatory	BBSO	infrared / optical	United States	http://www.bbso.njit.edu/	no	Not contacted
Udaipur Solar Observatory	USO	infrared / optical	India	https://www.prl.res.in/~uso/	no	Not contacted
Mauna Loa Solar Observatory	MLSO	infrared / optical	United States	https://www2.hao.ucar.edu/mlso/mlso-home-page	no	Not contacted

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Global Millimeter VLBI Array	GMVA	radio	Global, coordinated by MPIfR Bonn	https://www3.mpifr-bonn.mpg.de/div/vlbi/globalmm/	no	Not contacted
Hydrogen Epoch of Reionization Array	HERA	radio	United States	https://reionization.org/	no	Not contacted
Expanded Owens Valley Solar Array	eOVSA	radio	United States	http://www.ovsa.njit.edu/	no	Not contacted
Nobeyama Radioheliograph	NoRH	radio	Japan	https://solar.nro.nao.ac.jp/norh/	no	Not contacted
Parkes	-	radio	Australia	https://www.parkes.atnf.csiro.au/	no	Not contacted
Canadian Hydrogen Intensity Mapping Experiment	CHIME	radio	Canada	https://chime-experiment.ca/	no	Not contacted
Very Large Array	VLA	radio	United States	https://public.nrao.edu/telescopes/vla/	no	Not contacted
MeerKAT	-	radio	South Africa	https://www.ska.ac.za/gallery/meerkat/	no	Not contacted
Australian Square Kilometre Array Pathfinder	ASKAP	radio	Australia	https://www.atnf.csiro.au/projects/askap/index.html	no	Not contacted
Tibet AS-gamma Experiment	-	astroparticles	China	Tibet AS-gamma Experiment	no	Not eligible
LIGO-India	IndIGO	gravitational waves	India	http://www.gw-indigo.org/tiki-index.php	no	Not eligible
TAMA300 Interferometer	TAMA300	gravitational waves	Japan	http://tamago.mtk.nao.ac.jp/spacetime/tama300_e.html	no	Not eligible
McMath-Pierce Solar Telescope	-	infrared / optical	United States	https://www.noao.edu/outreach/kptour/mcmath.html	no	Not eligible

Organization	Short name	Sub-domain	Country (head office)	Website	Answer	Status
Distributed Array Radio Telescope	DART	radio	United States	http://www.erau-prescott-observatory.com/DART.htm	no	Not eligible
Korean Space Weather Center	KSWC	radio	Korea	https://spaceweather.rra.go.kr/?lang=en	no	Not eligible

APPENDIX 8 – Social Sciences

Table A8.1 Social Science initiatives considered in the report preparation

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
World Values Survey (WVS)	*Austria*	*1981*	*Distributed*		*http://www.worldvaluessurvey.org.*
The World Values Survey (www.worldvaluessurvey.org) is a global network of social scientists studying changing values and their impact on social and political life, led by an international team of scholars, with the WVS association. Its secretariat is based in Austria at the Institute for Comparative Survey Research, Vienna. The survey, which started in 1981, seeks to use the most rigorous, high-quality research designs in each country. The WVS consists of nationally representative surveys conducted in almost 100 countries which contain almost 90 percent of the world's population, using a common questionnaire. The WVS is the largest non-commercial, cross-national, time series investigation of human beliefs and values ever executed, currently including interviews with almost 400,000 respondents. Moreover, the WVS is the only academic study covering the full range of global variations, from very poor to very rich countries, in all of the world's major cultural zones.					
Gallup World Poll (GWP)	*USA*	*2005*		*https://www.gallup.com/contact.aspx*	*https://www.gallup.com/17867/gallup-world-poll-work.aspx*
The Gallup World Poll tracks the most important issues worldwide, such as food access, employment, leadership performance, and well-being. It uses different modes (telephone and face to face). With some exceptions, all samples are probability based and nationally representative of the resident population aged 15 and older.					
International Social Survey Programme (ISSP)	*Germany*	*1984*	*Distributed*	*Secretariat* *issp.sec@gmail.com*	*http://www.issp.org/menu-top/home/*
ISSP is a cross-national collaboration programme conducting annual surveys on diverse topics relevant to social sciences. Established in 1984 by its founding members Australia, Germany, Great Britain and the US, the ISSP has since included members covering various cultures around the globe. Its institutional members, each of them representing one nation, consist of academic organizations, universities, or survey agencies. Since its foundation, over one million respondents have participated in the surveys of the ISSP.					
Global barometer	*Taiwan*	*2004*	*Distributed*	*asianbarometer@ntu.edu.tw*	*https://www.globalbarometer.net/*

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Global Barometer Surveys (GBS) is a collaborative research project consisting of six regional barometers. It is the first comprehensive effort to measure, at a mass level, the current social, political, and economic climate around the world. It provides an independent, non-partisan, scientific and multidisciplinary view of public opinion on a range of policy-relevant issues. Currently, the GBS network covers 70% of the world's population and is still expanding.					
Pew Global Attitudes Survey at Pew Research Centre	*USA*	*2002*	*Single sited*		*https://www.pewresearch.org/*
Pew Research Center is a nonpartisan fact tank that informs the public about the issues, attitudes and trends shaping the world. It conducts public opinion polling, demographic research, media content analysis and other empirical social science research. Pew Research Center does not take policy positions. It is a subsidiary of The Pew Charitable Trusts.					
Gateway to global ageing data	*US*		***Platform***		https://g2aging.org/#
Description: Gate way to global ageing data is a free public resource designed to facilitate cross-national and longitudinal studies on aging using the family of health and retirement studies around the world. Coordinated by University of Southern California, Center for Economic and Social Research (CESR) cesr.usc.edu					
International Population Data Linkage Network					https://www.lpdln.org;
International Social Science Council: Survey of international social surveys					*http://www.worldsocialscience.org/resources/survey-surveys/*

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Afro-barometer		*1999*	*Distributed*		*https://www.afrobarometer.org/*
A pan-European survey research project that measures citizens' attitudes on democracy and governance, the economy, civil society, to give the public a voice in policy making. Surveys and other activities are carried out by a network of national partners in over 30 countries. There are four core partners – Ghana Centre for Democratic Development; Institute for Development Studies, University of Nairobi; Institute for Justice and Reconciliation; and Institute for Empirical Research in Political Economy, with 2 support units (Michigan State University, US, University of Cape Town, SA)					
Latino-barometro	*Chile*	*2006 (available data)*			*http://www.latinobarometro.org/lat.jsp*
Latinobarómetro conducts an annual survey in 18 Spanish and Portuguese speaking countries, using representative samples. Latinobarómetro Corporation is a private non-profit organization, based in Santiago, Chile, that is responsible for carrying out the Latinobarómetro survey and for distributing the data. It has a board of directors, whose members are Chilean and which is governed by Chilean law, and an International Advisory Council that advises its executive director.					
Arab Barometer	*USA*	*2005*	*Distributed*		*https://www.arabbarometer.org/*
The Arab Barometer is a regional public opinion survey established in 2005 and conducted in the twelve Middle Eastern countries Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Palestine, Qatar, Saudi Arabia, Sudan, Tunisia, and Yemen. The first wave was conducted from 2006-2008.					
Asian Barometer	*Taiwan*		*Distributed*		*http://www.asianbarometer.org/*
The Asian Barometer includes 14 countries and territories in East and South East Asia. It uses the Global Barometer Survey (GBS) report as the model and is administered by country teams.					
East Asian Social Survey (EEAS)	*Korea*	*2003*	*Distributed*		*http://www.essda.org*
EEAS is a biennial social survey that aims to produce and disseminate academic survey datasets in East Asia.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Harvard Law School, Labor & Worklife Program	*Cambridge US*				https://lwp.law.harvard.edu/
Description *The Labor & Worklife Program is Harvard University's center for research, teaching and creative problem solving related to the world of work and its implications for society. Located at Harvard Law School, LWP brings together scholars, students, practitioners, community members and policy experts from a variety of disciplines. LWP organizes projects and programs that (1) examine critical changes in labor markets, labor law, and the experiences of working people and (2) analyze the role of advocates, unions, worker organizations, business, and government in improving the quality of life for working families in the U.S. and around the world. The faculty, staff, fellows and research associates of LWP include an array of nationally and internationally renowned scholars, experts and intellectuals.*					
Health and retirement study	*Michigan, US*	*1990*	*project*		*http://hrsonline.isr.umich.edu/*
Description: *The Health and Retirement Study is a longitudinal is a longitudinal panel study that surveys a representative sample of approximately 20,000 people in America, sponsored by the National Institute on Aging (NIA U01AG009740) and the Social Security Administration. It is undertaken by the Survey Research Center at the University of Michigan's Institute for Social Research*					
National Opinion Research Center, at University of Chicago	*Chicago, USA*	*1941*	*Independent research corporation*		
Description: NORC conducts research in five main areas: Economics, Markets, and the Workforce; Education, Training, and Learning; Global Development; Health and Well-Being; and Society, Media, and Public Affairs.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
IPUMSi, University of Minnesota	*Minnesota,US*		*Single sited*		https://international.ipums.org/international/
IPUMS-International is dedicated to collecting and distributing individual and household level census data from around the world. The project goals are to collect and preserve data and documentation, harmonize data, and disseminate the harmonized data free of charge. Currently, census data from 94 countries, with 365 censuses and over one billion person records are available.					
ICPSR, University of Michigan	*Michigan, US*				*https://www.icpsr.umich.edu/icpsrweb/*
ICPSR (International Consortium for Political and Social Research) is the one of the leading data archives in the USA for access to social and economic data. It operates via a membership scheme, with organisations joining on payment of an annual fee, ranging from less than $100 for school students to almost $20,000 for large and prestigious universities. Currently there are nearly 800 member institutions and approximately 30 US agencies contributing data. The Institute houses over 11,000 separate studies with 5.3 million variables. ICPSR is a trusted digital repository, having gained CoreTrustSeal accreditation. CoreTrustSeal Data Repository certification demonstrates to researchers that data repositories are taking appropriate measures to ensure sustainable and trustworthy data infrastructures. CoreTrustSeal is a legal entity under Dutch law governed by a Standards and Certification Board composed of 12 elected members representing the Assembly of Reviewers. ICPSR is linked into the European Data Landscape via membership of CESSDA ((Consortium of European Social Science Data Archives).					
Center for Open Science	*Virginia, US*				https://cos.io/about/mission/
The Center for Open Science, based in Charlottesville, Virginia, aims to provide researchers with shared tools, space to deposit projects (source code, working papers, interim results, etc.)					
Administrative Data Facility (Coleridge Initiative)	*US*				https://coleridgeinitiative.org
The goal of the Coleridge Initiative in general is to use data to transform the way governments access and use data for the social good. The infrastructure itself is a secure remote access facility, which provides access to and use of confidential micro data, and associated training programs. The goal of the partnerships is to lower the barriers to other universities to do the same. Coleridge has partnered with a variety of universities. Our program directors – Julia Lane, Rayid Ghani, Bob Goerge and Frauke Kreuter – all have academic affiliations (NYU, UChicago, University of Maryland and University of Mannheim). They have designed and implemented joint training programs with their own institutions. Other partnerships include work with Ohio State University, Cal Poly, University of Michigan, Indiana University Purdue University Indianapolis, the University of Missouri and the University of California.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Institute for Quantitative Social Science	*US*				*https://www.iq.harvard.edu/about*
IQSS states in its mission statement that: 'The goal of IQSS is to transform social science research from the art of studying the greatest problems that affect human societies to the science of understanding and solving these problems. After generations of trial and error, social scientists in this generation have finally figured out how to collect unprecedented privacy-preserving information about people, groups, firms, and countries and to invent the statistical methods, data science approaches, theories, and technologies necessary to make this data actionable.					
Institute for Research on Innovation and Science	*US*	*2015*			*https://iris.isr.umich.edu*
Description: (IRIS) is a member consortium of universities anchored by an IRB-approved data repository hosted at the University of Michigan's Institute for Social Research. IRIS was founded in 2015 with support from the Alfred P. Sloan and Ewing Marion Kauffman foundations. IRIS collects record level administrative data from its members to produce a de-identified dataset for research and reporting that will improve our ability to understand, explain and improve the public value of research. Its mission is to be a trusted resource for high quality data that supports independent, frontier research on science and innovation in the service of the public interest.					
National Bureau of Economic Research	*US*				https://www.nber.org
The NBER is a private, non-profit, non-partisan membership organization dedicated to conducting economic research and to disseminating research findings among academics, public policy makers, and business professionals. NBER-affiliated researchers study a wide range of topics and they employ many different methods in their work. Key focus areas include developing new statistical measurements, estimating quantitative models of economic behaviour, and analysing the effects of public policies. Access to research resources via the NBER requires the applicant to have a research link with the NBER, usually via research cooperation with a member.					

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Bureau of Labor Statistics	*US*				https://www.bls.gov/data
The Bureau of Labor Statistics houses the largest collection of data relating to the labour market in the US. Much of this data can be accessed via 'Datafinder' – a flexible crosstabulation device. Access to person and household level data is possible but under restricted access conditions.					
Databrary	*US*				https://www.databrary.org
Databrary describes itself as 'a video data library for behavioural scientists. Its mission statement is: 'Our mission is to promote sharing and reuse of video data. Most developmental scientists rely on video recordings to capture the complexity and richness of behavior. However, researchers rarely share video data, and this has impeded scientific progress. Enabling reuse of video data is essential to increasing openness, maximizing the efficiency of limited resources, and accelerating the pace of discovery in the developmental and learning sciences. We aim to provide tools that encourage good data management, facilitate open data sharing, enable discovery, and foster data reuse and integration. We are working to build functionality that allows researchers to organize, store, code, and share identifiable video data and other contextual information about the videos with other researchers through a secure web-based library.' The project is based at New York University and Penn State. It has grant support from the U.S. National Science Foundation (NSF) and the National Institutes of Health (NIH). The overall goal is to accelerate the pace of discovery, improve scientific transparency and accountability, and transform research practices in psychology and developmental science.					
Roper Center	*US*				https://ropercenter.cornell.edu/
The Roper Center states that its mission is: 'to collect, preserve, and disseminate public opinion data; to serve as a resource to help improve the practice of survey research; and to broaden the understanding of public opinion through the use of survey data in the United States and around the world'. Access to it collection of over 710,000 polling questions is via a membership scheme, with costs ranging from just over $500 for a High School, to more than $7,000 for a major university					

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UC Berkeley D-Lab	*Berkeley CA*				https://dlab.berkeley.edu/
D-Lab promotes research links with the global social science research community, but its primary focus is on building research capacity within the Berkeley science community. UC Berkeley D-Lab describes itself in the following terms: 'D-Lab helps Berkeley faculty, staff, and graduate students move forward with world-class research in data intensive social science. We think of data as an expansive category, one that is constantly changing as the research frontier moves. We offer a venue for methodological exchange from all corners of campus and across its bounds. D-Lab provides cross-disciplinary resources for in-depth consulting and advising, access to staff support, and training and provisioning for software and other infrastructure needs. Networking with other Berkeley centers and facilities and with our departments and schools, we offer our services to researchers across the disciplines and underwrite the breadth of excellence of Berkeley's graduate programs and faculty research. D-Lab builds networks through which Berkeley researchers can connect with users of social science data in the off-campus world.'					
CEBRAP Centro Brasileiro de Analise e Planejamento	*Sao Paulo, Brazil*				*https://cebrap.org.br*
CEBRAP is an independent research institute based in Sao Paulo, with links to researchers in universities across Brazil. It provides access and research support to many of the key datasets held at the IBGE (Brazilian Statistical Institute) and by other departments of state and national government. It is open to a wide variety of research partnerships, including: Joint research, short-term and long term research projects; Consultancy activities, applied research for government, international agencies and private sector; Participation in or co-coordination of seminars and academic meetings on issues related to our research interests; Formal institutional agreement of cooperation; Special academic programs with exchange of scholarships and/or exchange of staff members;					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Instituto Brasileiro de Geografia e Statística (IGBE)	*Brazil*	*1934*			*http://www.igbe.gov.br*
The Brazilian Institute of Geography and Statistics - IBGE is the main provider of data and information in the country, which meets the needs of the most diverse segments of civil society, as well as federal, state and municipal government agencies. IBGE offers a complete and current view of the country through the performance of its main functions: Production and analysis of statistical information *Coordination and consolidation of statistical information* *Production and analysis of geographic information* *Coordination and consolidation of geographic information* *Structuring and implementation of an environmental information system* *Documentation and information dissemination* *Coordination of national statistical and mapping systems*					
DIEESE - Departamento Intersindical de Estatística e Estudos Socioeconômicos, São Paulo	*Sao Paulo, Brazil*	*1955*			*https://www.dieese.org.br/materialinstitucional/aboutUs.html*
DIEESE, Inter-Union Department of Statistics and Socio-Economic Studies was born from struggles led by Brazilian trade unions. It was founded in 1955 to develop research to be used as support for workers' demands, to be a starting point on their labor issues. Most national workers confederations and federations as well as main trade unions are affiliated to DIEESE, being at the top of it and contributing to its support, taking profit of its services and scientific production. Currently there are more than 700 entities affiliated to DIEESE. It has informal links and continuous cooperation regarding the Collective Agreements Database WageIndicator Survey.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
ELSI-Brasil - Estudo Longitudinal de Saúde do Idoso	*Brazil*				*http://elsi.cpqrr.fiocruz.br/en/*
ELSI-Brazil (The Brazilian Longitudinal Study of Aging) is a longitudinal, home-based survey, conducted in a nationally representative sample of older adults. The research aims to examine the social and biological determinants of aging and its consequences for the individual and for the society. ELSI-Brazil is coordinated by the Oswaldo Cruz Foundation – Minas Gerais (FIOCRUZ-MG) and the Federal University of Minas Gerais (UFMG).					
Instituto Nacional de Estadistica y Censos The National Institute of Statistics and Censuses (INDEC)	*Argentina*			*https://www.indec.gob.ar/indec/web/Institucional-Indec-Contacto*	*https://www.indec.gob.ar/indec/web/Institucional-Indec-QuienesSomosEng*
The National Institute of Statistics and Censuses (INDEC, in its Spanish acronym) is a public deconcentrated body, of a technical nature, within the scope of the Ministry of Treasury of Argentina, and which runs all the official statistical activities carried out throughout the country. Argentine Law 17622, Executive Orders 3110/70, 1831/93, and Provision 176/99 on Statistical Secrecy establish the creation and operation of INDEC. Its responsibilities are: apply the statistical policy of the National Government; organise and run the National Statistical System (NSS); design the methodology, organise and run the national operations to gather and collect information through censuses and statistics; produce basic indicators and social and economic data.					
Centro de Estudios de la Nueva Economia (CENE)	*Buenos Aires, Argentina*				*http://www.ub.edu.ar/centros-de-estudios-ub/centros-de-estudio-cene*
CENE is located at the University of Belgrano					

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China Health and Retirement Longitudinal Study	*Beijing, China*	*2011*			*http://charls.pku.edu.cn/index.html*
The China Health and Retirement Longitudinal Study (CHARLS) aims to collect a high quality nationally representative sample of Chinese residents ages 45 and older to serve the needs of scientific research on the elderly. The baseline national wave of CHARLS is being fielded in 2011 and includes about 10,000 households and 17,500 individuals in 150 counties/districts and 450 villages/resident committees. The individuals will be followed up every two years. All data will be made public one year after the end of data collection. (https://www.nia.nih.gov/research/resource/china-health-and-retirement-survey-charls <accessed 11/11/2019); https://en.wikipedia.org/wiki/China_Health_and_Retirement_Longitudinal_Study. Details in English: https://g2aging.org/?section=study&studyid=4					
China Family Panel Studies	*China*	*2010*			*https://opendata.pku.edu.cn/dataverse/CFPS?language=en*
China Family Panel Studies (CFPS) is a nationally representative, annual longitudinal survey of Chinese communities, families, and individuals launched in 2010 by the Institute of Social Science Survey (ISSS) of Peking University, China. Interviews will be conducted using computer assisted personal interviewing (CAPI) technology, provided by the Survey Research Center (SRC) at the University of Michigan.					
Chinese Household Income Projects	*China*	*1988*			*https://www.icpsr.umich.edu/icpsrweb/ICPSR/series/243*
The purpose of the Chinese Household Income Project was to measure and estimate the distribution of personal income in both rural and urban areas of the People's Republic of China. The principal investigators based their definition of income on cash payments and on a broad range of additional components: payments in kind valued at market prices, agricultural output produced for self-consumption valued at market prices, the value of ration coupons and other direct subsidies, and the imputed value of housing. Data were collected through a series of questionnaire-based interviews conducted in rural and urban areas in 1988, 1995, 2002, and 2007. Individual respondents reported on their economic status, employment, level of education, sources of income, household composition, and household expenditures. The Chinese Household Income Project collected data in 1988, 1995, 2002, and 2007. ICPSR holds data from the first three collections. Data collected in 2007 are available through the China Institute for Income Distribution.					

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Chinese National Survey Data Archive, Renmin University of China	*China*				http://cnsda.ruc.edu.cn/index.php?r=projects/index
CHSDA Hosts data sets from major longitudinal and cross-sectional studies in mainland China on social, economic and political topics, such as the Chinese General Social Survey (CGSS). Supported by the National Survey Research Center, Renmin University of China.Access: Registration required					
Network Building of the Integrated Social Science Data Base Solution	*Graduate School of Decision Science and Technology, Tokyo Institute of Technology*	*2010*	***Project***		*http://www.dst.titech.ac.jp/index_en.html*
Large scale project identified in the Large Scale Research Project master plan 2010 - http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-21-h135-1-2e.pdf					
Practical Intercommunity Platform for Facilitating Global Understanding of Regional Knowledge	*Aoyama Gakuin University*	*2010*	***Project***		*https://www.aoyama.ac.jp/en/*
Large project in the Large Scale Research Project master plan 2010 - http://www.scj.go.jp/ja/info/kohyo/pdf/kohyo-21-h135-1-2e.pdf					

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Social Science Japan Data Archive (SSJDA)	*Institute of Social Science, University of Tokyo*		***Project***		https://csrda.iss.u-tokyo.ac.jp/en/ssjda/about/
The Social Science Japan Data Archive (SSJDA) is located in Information Centre for Social Science Research on Japan. It collects, maintains, and provides access to the academic community, a vast archive of social science data (quantitative data obtained from social surveys) for secondary analyses. The Information Centre for Social Sciences Research on Japan is an identified large project in the Large-Scale Research Project master plan 2010					
A comprehensive Study of Life Course and Inequality	*Institute of Social Science, Centre for Social Research and Data Analysis, University of Tokyo*				https://csrda.iss.u-tokyo.ac.jp/en/
Japanese Life Course Panel Surveys	*Centre for Social Research and Data Analysis University of Tokyo*				*https://csrda.iss.u-tokyo.ac.jp/en/joint/jgss/*
The Institute of Social Science conducted panel surveys focusing on three demographics: youth, middle-aged, and high-school graduates					

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Japanese General Social Surveys (JGSS)					http://www.jgss.daishodai.ac.jp/english/index.html
The Japanese General Social Surveys (JGSS) Project is a Japanese version of the General Social Survey (GSS) project closely replicating the original GSS of the National Opinion Research Center at the University of Chicago. http://www.jgss.daishodai.ac.jp/english/index.html.					
The Japanese Study of Ageing and Retirement (JSTAR)	*Research Institute of Economy, Trade and Industry (RIETI), Hitotsubashi University and the University of Tokyo*				*https://www.rieti.go.jp/en/projects/jstar/*
This website provides information regarding the Japanese Study of Aging and Retirement (JSTAR), a panel survey of elderly people aged 50 or older conducted by the Research Institute of Economy, Trade and Industry (hereinafter "RIETI"), Hitotsubashi University, and the University of Tokyo. Detailed survey results as well as information regarding the use of the micro-data collected in the survey, which are made available (subject to approval by RIETI) to researchers belonging to universities and/or research institutes, can be found here.					
Australian Data Archive	*Australia*	*1981*			***https://ada.edu.au/***
The Australian Data Archive (ADA) is a Core Trust Seal certified repository, based in the ANU Centre for Social Research and Methods (CSRM) at the Australian National University (ANU). ADA was established at the ANU in 1981 with a brief to provide a national service for the collection and preservation of digital data relating to social, political and economic affairs and to make these data available for further analysis.					

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National e-Research Collaboration, Tools and Resources:	*Australia*	*2009*	***Distributed***		*www.nectar.org.au*
The National e-Research Collaboration Tools and Resources project (Nectar) provides an online infrastructure that supports researchers to connect with colleagues in Australia and around the world, allowing them to collaborate and share ideas and research outcomes, which will ultimately contribute to our collective knowledge and make a significant impact on our society. Nectar was established in 2009 by the Australian Government following a 2009/10 Budget announcement of $47 million to support Nectar as part of the Super Science initiative financed by the Education Investment Fund (EIF). Nectar has received $61 million in government funding, matched by co-investment of $54 million from Australian universities and research organisations. Nectar partners with Australian research institutions and research communities through a portfolio of sub-projects to develop and operate: 12 Virtual Laboratories , 16 eResearch Tools, a national Research Cloud with over 10,000 users and the National Server Program.					
Population Health Research Network	*Australia*		***Distributed***		www.phrn.org.au
PHRN is included on the Australian Government's National Research Infrastructure Roadmap (2016), recognized as a national research infrastructure capability (www.education.gov.au/2016-national-research-infrastructure-roadmap. PHRN is a national network of data linkage units, a secure data laboratory and e-research services which support researchers access to linked population data.					
Australian National Data Service, Research Data Services	*Australia*		***Distributed***		https://www.ands.org.au/ https://ardc.edu.au/
National Research Data Storage Infrastructure (Australian National Research Infrastructure Roadmap 2016, p21). Australia now has cost-effective, scaled up, shared research data storage services provided through Research Data Services (RDS) that are aimed at improving research collaboration through the storage and provision of access to research data collections of national significance. RDS complements institutional investments by providing infrastructure for the ever-growing volume of new and complex data. The Research Data Services (RDS) project is a continuation of foundations project the Research Data Storage Infrastructure. The foundations project established a number of components including: a number of high-capacity storage nodes; *a dedicated high-bandwidth, low-latency inter-connection network to support data transfer and replication, together with the implementation of common access infrastructure that provides a uniform user access experience, and* *appropriate specialised access infrastructure, including the hosting of specialist access tools related to national collections.*					

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Life in Australia	*Centre for Social Research & Methods ANU College of Arts & Social Sciences, ANU Canberra*		***Project***		***https://www.srcentre.com.au/our-research/life-in-australia-study***
Australia's most methodologically rigorous online panel. It exclusively uses random probability-based sampling methods and covers both online and offline population. Results from Life in Australia™ surveys are generalisable to the Australian population and the sampling approach ensures that sampling errors and confidence intervals can be calculated. By comparison, non-probability 'opt in' online panels do not have these statistical properties. Panel members are randomly recruited via their landline or mobile phone and provide their contact details so that they can take part in surveys on a regular basis. Life in Australia™ hosts standalone and omnibus surveys.					
Agincourt, Mpumalanga (Wits)	*Johannesburg and Bushbuckridge*	*1992*	*a health and socio-demographic surveillance system (HDSS); distributed*		https://www.agincourt.co.za/

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Africa Centre for Population Health	*Nairobi, Kenya*				https://aphrc.org/

The African Population and Health Research Center is the continent's premier research institution and think tank, generating evidence to drive policy action to improve the health and wellbeing of African people. As a progressive African-led global research center invested in creating legacy impact, our work is centered in three integrated programmatic divisions:
Research: Our teams orient their research agendas to global and continental development priorities bringing independent evidence to the forefront of decisions supporting improved growth and development in the region. The center's research priorities fall within six thematic units: Aging and Development; Education and Youth Empowerment; Health and Systems for Health; Maternal and Child Wellbeing; Population Dynamics and Sexual Reproductive Health and; Urbanization and Wellbeing in Africa. Anchoring the six is our Data, Measurement and Evaluation Unit providing internal support for robust data systems and outward looking technical assistance in program evaluation and data use.
Research capacity strengthening: Through strategic partnerships, the Center strives to nurture African research leadership by building a critical mass of researchers to meaningfully engage with policy actors in developing, reviewing and implementing policies and programs relevant to the continent's development.
Policy engagement and communications: The Center builds relationships with key decision-making bodies at the national, regional and global levels to encompass engagements with government and non-government entities, as well as academic, advocacy and research institutions: all in service to our agenda of ensuring contextual, relevant and localized knowledge as a driver of change. Our goal is to become a continental model for robust, policy-oriented, rigorous research that emphasizes synergy and collaboration.

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KwaZuluNatal (University of KwaZulu-Natal), and Dikgale	*South Africa*				https://www.ukzn.ac.za/
The Information Services at UKZN libraries strive to provide a proactive information service guided by user needs for all UKZN students, staff members and researchers; and visitors to the libraries. Subject librarians, who specialize in various subject areas and disciplines, are available in all libraries to provide - *· In-depth assistance and expertise* *· Advice on the use of suitable print and electronic resources* *· Literature searches* *· Research support* *Information officers are available in some libraries to provide specialist help with particular collections.* *Programmes in all libraries aim to develop and equip students with the information skills necessary to effectively locate library and information resources and to use these resources to enhance their research and learning. Subject librarians customize orientation and training sessions to the requirements of users and may take the form of -* *· Library tours* *· General library orientation* *· Online demonstrations* *· Interactive hands-on training* *· Group sessions* *· Individual assistance and training*					
Limpopo (University of Limpopo	*South Africa*				https://www.ul.ac.za/
Vision - To be a leading African University focused on the developmental needs of its communities and epitomising academic excellence and innovativeness *Mission - A University which responds actively: to the development needs of its students, staff and communities, through relevant and higher quality education and training, research and community engagement, and in partnership and collaboration with its stakeholders.* *Values: Accountability, Transparency, Integrity, Academic Freedom, Excellence and Professionalism*					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
The South African Data Archive at the National Research Foundation	*South Africa*				http://sada.nrf.ac.za/

Description: The South African Data Archive serves as a broker between a range of data providers (for example, statistical agencies, government departments, opinion and market research companies and academic institutions) and the research community. The archive does not only preserve data for future use, but all adds value to the collections. It safeguards datasets and related documentation and attempts to make it as easily accessible as possible for research and educational purposes. Existing research data can be an invaluable source for further studies. Such data are, however, currently scattered throughout the country. By preserving this research information in a single resource centre like SADA, unnecessary and costly duplication of research are decreased while the quality of the research findings is enhanced by using data from experienced researchers both locally and internationally. Objectives of SADA are to:
acquire and catalogue survey data and related information.
preserve such data against technological obsolescence and physical damage.
re-disseminate such information for use by other researchers, for re-analysis of data, longitudinal and comparative studies, research training, teaching and policy-making decision purposes.
formulate policies for the scope and content of data and data preservation.
promote the optimal use of data.
SADA adds value to its collections in the following ways:
Comprehensive machine-readable codebooks are developed, which include an abstract, sampling methodology and questionnaire. This documentation is published in open access on the data portal.
Metadata is added to the datasets and made accessible through electronic search and retrieval systems, for example Internet.
Advantages of data archiving
Data archives ensure that the depositors' work is protected from extinction, and whenever depositors need to make use of it, they would simply request it from the archive, which stores the data in an orderly and compact manner.
Data that has been archived can also be used to test or develop new theories, generalize or extend findings and/or answer new questions.
Archiving leads to data sharing across disciplines, often resulting in new methodologies and theories being developed.
Research students in particular, often have a limited time frame within which to complete their programmes. It would not be feasible to undertake a reasonably good project conducting primary research within such a limited time. In this respect, a data archive would provide an answer, matching research quality, costs and time.

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Statistics South Africa	*Salvokop, Pretoria*			*info@statssa.gov.za*	http://www.statssa.gov.za/
Description: *Vision - To deliver: The South Africa I know, the home I understand.* *Mission - To lead and partner in statistical systems for evidence-based decisions.*					
South African Social Attitudes Survey (SASAS)	*Human Sciences Research Council, Cape Town*				http://www.hsrc.ac.za/en/departments/sasas
Description: The South African Social Attitudes Survey (SASAS) is a nationally representative, repeated cross-sectional survey that has been conducted annually by the Human Sciences Research Council (HSRC) since 2003. The survey series charts and explains the interaction between the country's changing institutions, its political and economic structures, and the attitudes, beliefs and behaviour patterns of its diverse populations. Designed as a time series, SASAS is increasingly providing a unique, long-term account of the speed and direction of change in underlying public values and the social fabric of modern South Africa. The HSRC was established in 1968 as South Africa's statutory research agency and has grown to become the largest dedicated research institute in the social sciences and humanities on the African continent. Link to ESS					
The National Library of Serbia	*Belgrade, Serbia*				https://www.nb.rs/?change_lang=en
Description: information on strategy or history not available on website.					
Matica Srpska	*Novi Sad, Serbia*				http://www.maticasrpska.org.rs/en/

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
University Library "Svetozar Marković"	*Belgrade, Serbia*				http://ubsm.bg.ac.rs/engleski/
Description: University Library "Svetozar Markovic" is the oldest and largest university library in the country and the central library of the University of Belgrade. The library is intended primarily for students, teachers and researchers, but is open to all citizens. The library collection consists of the scientific and special publications, mostly in foreign languages, as well as electronic publications which can be accessed via the Academic Network. *Library building at 71 King Alexander Boulevard is the first building intentionally built as a library in Serbia in 1926 with donations from the Carnegie Endowment for International Peace. Department of Folk Literature is located outside this building in the House of Vojislav Jovanovic Marambo in 24 Bircaninova Street.*					
University Library	*Kragujevac, Serbia*	*1977*			http://www.kg.ac.rs/eng/university_library.php
Description: The University Library in Kragujevac is a library of a generally scientific character, and its activity has the function of teaching, scientific and researching processes at the University. This is how it contributes to successful studying, spreading and affirmation of knowledge, teaching and scientific advanced training and creative work of professors and researchers on faculties and institutes of the University in Kragujevac. The Library users are, primarily, students, postgraduates, university professors, workers in the field of science, and all other citizens under special conditions. *The Library is situated in a part of the University complex, taking space of 1500m2, and it includes: the main reading room with 50 places for readers and 10 places for free Internet access, periodical reading room with 20 places for readers, several storage rooms (depots) for storing publications, working offices for employees and University Gallery.* *The active Library holdings total around 100.000 copies of domestic and foreign books, 2.500 copies of doctoral dissertations and master theses, defended on faculties of the University in Kragujevac, as well as 450 titles of domestic and 105 titles of foreign journals. A reference collection of domestic and foreign references is of special importance (encyclopaedias, dictionaries, reference books, bibliographies) as well as several legacies of important institutions of this town and of outstanding people of this region. All Library holdings have been catalogued, they are in computer base of the Library and are available to users.* *Following contemporary tendencies in library science, the Library has accepted a unique user software package COBISS. The software is an organizational model of connecting library and information system, with mutual cataloguing, mutual bibliography and catalogue database (COBIB) and local databases of libraries which are members of Virtual Libraries of Serbia (VBS). The COBISS system is based on on-line communications which are conducted via Internet, i.e. Academic network to which the Library is connected. In that way, numerous databases are available to users via KoBSON (consortium of libraries in Serbia for united acquisitions), the license of which has been provided by the Department of Science and Environmental Conservation. One hundred and sixty libraries have been connected via COBISS system so far on the territory of Serbia Republic.*					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
University Library "Nikola Tesla"	*Nis, Serbia*	*1967*			http://www.ubnt.ni.ac.rs/english
Description: Nis University Library "Nikola Tesla" is located in the south part of the University building. It is a general–purpose scientific library designed to meet the learning, teaching and researching needs of the academic population. Furthermore, it has grown into a modern documentation-information center, the greatest in the southeast of Serbia, capable of providing comprehensive services to the widest public. The library was founded in 1967. Since 1978 it has been named after the great scientist Nikola Tesla. It provides the users with any information needed, including bibliographic search, inter-library loan services and user education. The library material can be used in one of the several reading rooms, with more than a hundred seats.					
Library of the Academy and Community of university libraries SANU	*Belgrade, Serbia*	*1841*			https://www.sanu.ac.rs/en/sasa-library/
Description: The SASA Library is one of the units of the Serbian Academy of Sciences and Arts. It is managed by a director appointed by the SASA Presidency from among the ranks of SASA members. The Library also has a Professional Council, comprised of representatives of all SASA departments and the Library Director. *The Library was established at the same time as the Society of Serbian Letters, on November 7, 1841. It started working on June 14, 1842, when it received its first books from Dimitrije Tirol. Its first librarian was Konstantin Bogdanović.* *The Library holdings contain around 1,500,000 books, periodicals and other printed and digital editions from all fields of science and art. Of all the libraries in Serbia, the SASA Library owns the largest collection of foreign books. By its holdings, the Library is believed to be the fourth largest in Serbia. Its holdings have mostly been expanded through exchange with foreign institutions. The Library does not have legal deposit, but exchanges publications with over 800 academies, universities and related institutions at home and abroad.* *The Library also expands its collections through purchases and donations; thus, its holdings are increased by around 8,000 publications annually.*					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
The State Statistical Office	*Skopje, North Macedonia*				http://www.stat.gov.mk/
Description: The State Statistical Office is specialised and independent organisation within the state administration in the Republic of North Macedonia. The basic functions of the institution are collecting, processing and disseminating statistical data about the demographic, social and economic situation of the Macedonian society. Besides that, the State Statistical Office is the primary bearer and coordinator of the statistical system of the country, the responsible institution for international cooperation in the field of statistics, for defining the statistical methodologies and standards, as well as for providing protection of the individual data collected from individual persons and legal entities. The State Statistical Office is realising its activity in accordance to the Law on State Statistics (1997, 2007, 2011, 2013, 2014, 2015, 2016, 2018) together with the other participants in the statistical system of the country defined in the Programme for Statistical Surveys (2018-2022). Official statistics is produced in accordance to the principles of impartiality, expert independence, objectivity, rationality and individual data protection. The strategic objectives and the basic values are defined in the Strategic Plan, 2018-2020 and according to this document the vision of the State Statistical Office is to be recognised as an institution that provides quality, timely and internationally comparable statistical data. The State Statistical Office is located in Skopje and 288 persons work in the institution (195 in the Central Office in Skopje and 93 persons in 8 regional offices).					
National and University Library	*Skopje, North Macedonia*	*1944*			https://www.cenl.org/library/national-and-university-library-st-kliment-ohridski/
Description: As an addition to its basic role as a National Library, the Library carries out scientific activities for the state university St. Cyril and Methodius and several private universities in Skopje. Also, it functions as a central library headquarters and educational centre, hence having the role of coordinator all the libraries within the territory of the Republic of North Macedonia. At the same time, it functions as a national bibliographic referral centre, r&d centre for librarianship, information sciences and it has a core role in developing the organisation's information system on a national level. In addition, it is the centre for restoration and conservation of library materials of the RNM, National centre for ISSN, National Agency for ISBN, International Agency for ISMN, Centre for international landing of library materials and E-CRIS. In line with the Law for culture of the Republic North Macedonia, the National and University Library is identified as institution that works on preservation, digitization and promotion of the national written cultural heritage.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Public university "Goce Delchev»	*Stip, North Macedonia*	*2007*		contact@ugd.edu.mk	https://www.ugd.edu.mk/index.php/en/
Description: Goce Delchev University in Shtip was established by the Assembly of the Republic of Macedonia on 27 March 2007. Its mission is to create and transfer knowledge for providing social and economic wellbeing and progress of the society, preparing students for professions in which the application of scientific discoveries and professional knowledge, cultural and language diversity, promotion of technological development, development of arts, technical culture and sport is required. Promoting and developing scientific disciplines present in the study programmes, in accordance with the requirements of the region and the country. Preserving and building up dignity of profession, developing and promoting moral values in the academic community, promoting knowledge as a value and sense of responsibility of the University as institution of the highest human values.					
The Macedonian academic research network (MARNET)	*Skopje, North Macedonia*	*2010*	*academic network*		http://marnet.mk/en/
Description: MARnet is a public institution that performs activities of public interest. It is established by passing of the Law of establishing the Macedonian academic research network – MARnet, which is adopted and published on 20.09.2010 in the Official Gazette br.124. With that MARnet acquired status of legal entity by registering in the Central Register of the Republic of Macedonia. With the appointment of the director MARnet officially starts with its work. MARnet mission is to provide services on a national level and international connectivity of Macedonian academic research network and educational community and support their research and educational activities; promoting and disseminating the use of information and communication technologies especially in the academic and research sector; maintenance and management of the national domain name system, international representation and membership; development of policy and development of the national academic network.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Nauka.mk	*Skopje, North Macedonia*				http://www.nauka.mon.gov.mk/en
The Human Rights Centre of the University of Sarajevo	*Sarajevo, Bosnia and Herzegovina*	*1996*			http://hrc.unsa.ba
Description: As the member of the University of Sarajevo, the Centre shares the vision provided in the text of the University of Sarajevo Institutional Development Plan. In the next decade we see University as: the main carrier of the life learning education system in society focusing on strengthening of post-graduate programmes (scientific and expert) relevant for social development as well as attractive and concurrent to European territory strong and recognisable centre of scientific and artistic work that will gather domestic and international teams on challenging and high-graded projects the key place in country for the development of evaluation model and ensuring quality in high-level education.					
Analitika – Center for Social Research	*Sarajevo, Bosnia and Herzegovina*	*2009*	*non-profit NGO*		http://analitika.ba
Description: Center for Social Research Analitika is a non-profit, non-governmental organization established in July 2009, and based in Sarajevo, Bosnia and Herzegovina. The mission of Analitika is to enhance the public policy process by conducting socially relevant, high quality research. In its research, the organization places great importance on the application of contemporary research methods, analytical capacities, competence and experience of its researchers, as well as rigorous external peer review procedures for its publications. Analitika's areas of research include rule of law, public administration reform with a focus on local self-government, and media and communication. SEEDS project (South-Eastern European Data Services, http://seedsproject.ch), which include FORS and ADP, two CESSDA ERIC service providers.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
PHAIDRA (Permanent Hosting, Archiving and Indexing of Digital Resources and Assets)	*Sarajevo, Bosnia and Herzegovina*		*institutional repository system for permanent archiving*	*support.phaidra@univie.ac.at*	*http://phaidra.ba*
The National and University Library of Bosnia and Herzegovina	*Sarajevo, Bosnia and Herzegovina*	*1945*	*Repository for scientific work*	*ured.direktora@nub.ba*	*http://nub.ba*
Description: One-stop access to libraries in Bosnia and Herzegovina. Searching for and reserving material in the shared catalogue of libraries Bosnia and Herzegovina and catalogues of individual libraries. Linked with the Slovenian Current Research Information System (SCIRIS), and LIBER – association of European Research Libraries					
National and University Library of the Republic of Srpska	*Banja Luka, Bosnia and Herzegovina*	*1936*	*Repository for scientific work*		*http://nub.rs*

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
The Agency for Statistics of Bosnia and Herzegovina	*Bosnia-Herzegovina*				http://bhas.ba
Description: Statistics of Bosnia and Herzegovina is statistics collected, processed and disseminated to implement statistical programs or other statistics required for Bosnia and Herzegovina. There are three statistical institutes within the Bosnia and Herzegovina. According to the law on statistics, the competent authorities for organizing, producing and disseminating statistics are: the Agency for statistics of Bosnia and Herzegovina at the level of the state, (BHAS), the Federal Office of Statistics for the Entity of Federation of Bosnia Herzegovina (FZS) and the Republika Srpska Institute of Statistics for the Entity of Republika Srpska (RZSRS). In addition to the three statistical institutions, the Central Bank of BIH compiles monetary and balance of payments and financial statistics for BIH (CBBiH).					
The Institute for Statistics of the Federation of BiH				*E-mail: fedstat@fzs.ba*	www.fzs.ba
The Institute for Statistics of the Republic of Srpska					http://rzs.rs.ba
Description: The Republika Srpska Institute of Statistics is a republic administrative unit of Republika Srpska whose main task is to produce official statistical data for all categories of users, from the Government and other bodies, business systems, institutions of science, to the general public and individuals. *MISSION - The mission of the Institute of Statistics is to provide reliable, high-quality, comprehensive, timely and internationally comparable statistical data, which meet the requirements of decision-makers, researchers and other domestic and international users, while at the same time presenting the situation and changes in the economic, demographic and social area, environment protection and natural resources.* *Collection, processing, analysis and dissemination of statistical data are carried out in accordance with statistical standards and modern technology, respecting the protection of statistical confidentiality, optimal use of resources and sensible burden on respondents.* *VISION - The Republika Srpska Institute of Statistics achieved complete harmonisation with international statistical standards and principles of the European Statistics Code of Practice, through the strengthening of its professional capacity and infrastructure and the adoption and application of the best statistical practices, respecting fundamental values such as professionalism, independence, impartiality and openness. Users are equally provided with relevant and high-quality statistical data and services, while the burden on respondents is moderate and proportional to the needs of users.*					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
Computer Center of the University of Sarajevo	*Sarajevo*	*1966*			http://utic.ba
Description: The UTIC University Tele-Information Center was founded in 1996 by an act of the University of Sarajevo. From day one, the Center actively contributes to raising the quality of education, both at the University of Sarajevo and across BiH, primarily through the implementation of modern information and communication technologies in the education system and facilitates the exchange of information and knowledge between the research and higher education community, its partners in world and environment. UTIC binds the members of the University of Sarajevo in a unique information and communication structure, thus fulfilling the role of a specific integrator of the University. We strive to encourage coordinated development of the education system in BiH by connecting universities, secondary and elementary schools. *UTIC was the first Internet service provider in BiH and is the only authorized name administrator. BA domain. In its 20 years of existence, UTIC has gained the trust of the academic community of the University of Sarajevo, as well as thousands of satisfied users across BiH and abroad. At the Center we cooperate daily with the educational institutions of the Cantons of Sarajevo and BiH. We have thousands of students, organizations, institutions and individuals at our disposal, determined to believe that everyone has the right to live in the information age.*					
Archives of Bosnia and Herzegovina	*Bosnia-Herzegovina*	*1947*			http://arhivbih.gov.ba
Description: The Archives of Bosnia-Herzegovina, the first modern archival institution in Bosnia-Herzegovina is established 1947. by decision of The Government of Peoples Republic of Bosnia-Herzegovina No. 1061 on December 12, 1947. Nowadays this date is known as Archives Day in Bosnia-Herzegovina. From 1965, by provision of Archives Act, name of this institution is changed into Archives of Bosnia-Herzegovina. Today, in the independent state of Bosnia-Herzegovina, Archives works under this name. Although archival service, as organised activity for preservation, protection and professional procession of archives in Bosnia-Herzegovina started in 1947, in Bosnia-Herzegovina there is significant tradition of preservation and keeping archives. In absence of archival institutions, a lot of archives have been kept by libraries, museums and other institutions, and also by particular persons. Many of B. H. Archives are raised from funds of libraries and museums. Although the number of these institutions in past was small, and they did not pay attention on records today known as public archives, without these institutions many of archives would not been saved.					

Identified International initiatives	*Location*	*Start of operations*	*Type of initiative*	*Contact (only if non-personal contact point found)*	*Website*
CESSI (Institute for comparative social research)	*Russia*				http://cessi.ru/
CESSI (Institute for comparative social research) is a marketing, public opinion and survey research organization in post Soviet region. They work in Russia, Ukraine, Belarus, Moldova, Kazakhstan, other Central Asia and Transcaucasian countries. CESSI offers field services in different survey modes and different samples (general population - national, regional, municipal samples, special groups of population – customers, stakeholders, government, media, business clients and providers, in hall testing).					

Table A8.2. Initiatives in countries not included in the regional approach employed and with which the European RIs and initiatives have ongoing links are also included

Country	*Name of initiative*	*Website*	*Links with European RI/initiative*
India	*LASI - The Longitudinal Aging Study in India*	*https://lasi.hsph.harvard.edu/*	*SHARE ERIC*
India	*Indian Institute of Management, Ahmedabad*	*https://www.iima.ac.in/web/iima*	*WageIndicator Survey*
Korea	*KLoSA - The Korean Longitudinal Study of Aging*	*https://www.nia.nih.gov/research/resource/korean-longitudinal-study-aging-klosa*	*SHARE ERIC*
Mexico	*MHAS - Mexican Health and Aging Study*	*http://www.mhasweb.org/*	*(SHARE E RIC)*
Mexico	*ITAM - Departemento Academico de Economia*	*http://departamentodeeconomia.itam.mx/*	*WageIndicator Survey*

APPENDIX 9 – HS-DH-L

Table A9.1. Selected Heritage Science (HS) and Digital Humanities (DH) centres around the world

Selected Heritage Science centres	Type	World Region	Country	Location
Canadian Conservation Institute, Ottawa	HS	North America	Canada	Ottawa
Parks Canada, Conservation Science, Heritage Conservation and Commemoration Directorate	HS	North America	Canada	Ottawa
Getty Conservation Institute (J. Paul Getty Trust), IPERION-CH project partner	HS	North America	USA	Los Angeles
Library of Congress, Preservation Research and Testing Division, Washington	HS	North America	USA	Washington, DC
National Gallery of Art, Washington	HS	North America	USA	Washington, DC
Metropolitan Museum of Art, Scientific Research Department, New York	HS	North America	USA	New York, NY
Northwestern University, Art Institute of Chicago Center for Scientific Studies in the Arts	HS	North America	USA	Chicago, OH
Pratt Institute, New York	HS	North America	USA	New York, NY
Stanford University, Stanford Archaeology Centre	HS	North America	USA	Stanford, CA
Smithsonian Institution, the world's largest heritage education, research and preservation complex representing 19 museums [mentioned as a collaboration partner on the E-RIHS website]	HS	North America	USA	Washington, DC
Lunder Conservation Center, Smithsonian American Art Museum, Washington	HS	North America	USA	Washington, DC
National Centre for Conservation, Restoration, and Museology (CENCREM), Havana	HS	Central America & the Caribbean	Cuba	Havana
Universidad Autónoma Nacional de Mexico (UNAM)	HS	Central America & the Caribbean	Mexico	Mexico City
Benemérita Universidad de Puebla	HS	Central America & the Caribbean	Mexico	Puebla
Centro de Investigaciones en Óptica de León	HS	Central America & the Caribbean	Mexico	León
Colegio de Michoacán A.C.	HS	Central America & the Caribbean	Mexico	
Universidad de Mérida - Cinvestav	HS	Central America & the Caribbean	Mexico	Mérida
Universidad Autónoma de Campeche	HS	Central America & the Caribbean	Mexico	Campeche

Selected Heritage Science centres	Type	World Region	Country	Location
Universidad Autónoma de San Luis Potosí	HS	Central America & the Caribbean	Mexico	San Luis Potosí
Universidad Autónoma de Yucatán	HS	Central America & the Caribbean	Mexico	
Universidad de San Nicolás de Hidalgo	HS	Central America & the Caribbean	Mexico	San Nicolás de Hidalgo
National Institute of Anthropology and History (INAH)	HS	Central America & the Caribbean	Mexico	Mexico City
Universidade Federal de Minas Gerais, Escola de Belas Artes, CECOR – Centro de Conservação e Restauração de Bens Culturais (Laboratório de Ciência da Conservação), Belo Horizonte	HS	South America	Brazil	Belo Horizonte
Universidade Federal do Pará, Instituto de Tecnologia, Laboratório de Conservação, Restauração e Reabilitação (LACORE), Belem	HS	South America	Brazil	Belem
Universidade de Campinas (UNICAMP), School of Civil Engineering, Architecture and Urban Design, Campinas	HS	South America	Brazil	Campinas
Universidad Nacional de San Antonio Abad del Cuzco, Cusco, Peru [	HS	South America	Peru	Cusco
University of Antofagasta, Faculty of Education and Human Sciences, Institute of Anthropological Investigation	HS	South America	Chile	Antofagasta
Laboratorio de Engenharia Civil de Cabo Verde (LNEC), Cidade da Praia	HS	West Africa	Cape Verde	Cidade da Praia
University Gaston Berger, Center for Research and Documentation of Senegal (research library, museum and conservation center)	HS	Sub-Saharan Africa	Senegal	Saint-Louis
CERDOTOLA, Yaounde, Cameroun; inter-state institution for research, documentation and preservation of African cultural heritage, languages and traditions	DH	Sub-Saharan Africa	Cameroon	Yaounde
Indian National Trust for Art and Cultural Heritage (INTACH), Centre for Conservation Training and Capacity Building	HS	South Asia	India	New Delhi
Chhatrapati Shivaji Maharaj Vastu Sangrahalaya (formerly Prince of Wales Museum of Western India), Art Conservation Centre, Mumbai	HS	South Asia	India	Mumbai
National Heritage Board, Heritage Conservation Centre	HS	South-East Asia	Singapore	Singapore
National Technical University, heritage conservation laboratory	HS	South-East Asia	Singapore	Singapore
Research Institute for Marine and Coastal Resources and Vulnerability, Jakarta	HS	South Asia	Indonesia	Jakarta
Chinese Academy of Cultural Heritage - Science and Technology Protection Laboratory of Underwater Cultural Relics	HS	South-East Asia	China	Bejing

Selected Heritage Science centres	Type	World Region	Country	Location
National Heritage Center at Tsinghua University (NHC-THU), Architectural Design and Research Institute, Cultural Relics and Architecture Protection Division	HS	South-East Asia	China	Bejing
Palace Museum, Conservation Department, Beijing	HS	South-East Asia	China	Beijing
Chinese Culture University, Taipei	HS	South-East Asia	Taiwan	Taipei
National Research Institute of Cultural Heritage, Cultural Heritage Administration, Republic of Korea	HS	South-East Asia	South Korea	Daejeon
National University of Cultural Heritage, Institute of Preventive Conservation for Cultural Property, Daejeon	HS	South-East Asia	South Korea	Daejeon
National Research Institute for Cultural Properties, Center for Conservation Science and Restoration Techniques, Tokyo, Japan	HS	Asia & Pacific	Japan	Tokyo
Australian Institute for the Conservation of Cultural Material, Canberra	HS	Asia & Pacific	Australia	Canberra
University of Wollongong, Centre of Excellence for Australian Biodiversity and Heritage	HS	Asia & Pacific	Australia	Wollongong
Center for History and New Media, George Mason University, USA	DH	North America	USA	Fairfax, VA
CESTA, Stanford University	DH	North America	USA	Stanford, CA
University of Toronto	DH	North America	Canada	Toronto
Canadiana	DH	North America	Canada	Ottawa
Research Center for Digital Humanities, National Taiwan University	DH	Asia	Taiwan	Taipei
School of Cultural Texts and Records at Jadavpur University, Kalkata	DH	Asia	India	Kalkata
Bibliotheca Alexandrina	DH	Africa	Egypt	Alexandria
Center for Documentation of Cultural and Natural Heritage (CULTNAT)	DH	Africa	Egypt	Cairo
American University of Beirut (AUB)	DH	Middle East	Lebanon	Beirut
South African Centre for Digital Language Resources (SADiLaR), North-West University	DH	Africa	South Africa	Potchefstroom
School of Arts and Sciences of the University of Pennsylvania	DH	North America	USA	Philadelphia, PA

Selected Heritage Science centres	Type	World Region	Country	Location
University of Alberta	DH	North America	Canada	Edmonton
Mc Gill University	DH	North America	Canada	Montreal
Mexicana	DH	Central America & the Caribbean	Mexico	Mexico City

Table 9.2. Distribution of subjects of 785 DH projects registered in the DHCommons database; extracted, analysed and grouped by PIN-VastLab.

Subjects	***Projects***		***%***
English Language & Literature (34) + other subjects (56)	90	153	19.05
Modern Languages (25) + History (18) + other subjects(13)	56		
19th century Literature (+ other subjects)	7		
History (77) + various other subjects (60)	137	145	18.05
American history (+ other subjects)	8		
Archaeology (35) + Archaeology and Classics & Ancient History (14) + other subjects (15)	64	115	14.06
Archaeology + History (9) + other subjects (18)	27		
Classics & Ancient History (10) + other subject (14)	24		
Drama & Theatre Studies (+ other subjects)	25	60	7.06
Music (+ other subjects)	23		
Dance Studies, Drama & Theatre Studies (+ other subjects)	12		
Visual Arts		23	2.09
Linguistics (+ other subjects)		21	2.07
Librarianship, Information & Museum Studies (+ other subjects)		20	2.05
Media (+ other subjects)		17	2.02
Digital Humanities (+ other subjects)		13	1.07
Theology, Divinity and Religious Studies		8	1.00
Architecture: History, Theory & Practice		6	0.08
		581	**74 %**
Various other specific subjects and combinations thereof		149	19 %
Subject/s not given		55	7 %
		785	**100 %**

APPENDIX 10 – E-infrastructures

Key initiatives mentioned

European e-Infrastructures

e-Infrastructure Reflection Group (e-IRG): http://e-irg.eu
GÉANT: https://www.geant.org/
PRACE: http://www.prace-ri.eu/
EuroHPC Joint Undertaking: https://eurohpc-ju.europa.eu/
EGI federation: https://www.egi.eu
The European Cloud Initiative: https://ec.europa.eu/digital-single-market/en/%20european-cloud-initiative
European Open Science Cloud portal: https://eosc-portal.eu
EUDAT: https://eudat.eu
OpenAIRE: http://openaire.eu
CoreTrustSeal data repository certification: https://www.coretrustseal.org/
Re3data – Registry of Research Data Repositories: https://www.re3data.org/
Platform of National eScience Centres in Europe (PLAN-E): https://plan-europe.eu/
Research Data Alliance: https://rd-alliance.org
WISE 'information security for IT infrastructures for research' community: https://wise-community.org/
HPC Centres of Excellence projects:
https://ec.europa.eu/programmes/horizon2020/en/news/overview-eu-funded-centres-excellence-computing-applications
EOSC-hub Competence Centres: https://wiki.eosc-hub.eu/display/EOSC/WP8+Competence+Centres

Networks

List of National research and education networks (NRENs): https://en.wikipedia.org/wiki/National_research_and_education_network
GÉANT Compendium: https://compendiumdatabase.geant.org/
AfricaConnect2 project: https://www.africaconnect2.net
CAREN project: http://caren.geant.org
EaPConnect project: https://www.eapconnect.eu/
EUMEDCONNECT3 project: http://www.eumedconnect3.net/Pages/Home.aspx
TANDEM project – "TransAfrican Network Development": https://www.tandem-wacren.eu/

MAGIC project – “Middleware for collaborative Applications and Global virtual Communities”: https://cordis.europa.eu/project/rcn/196897/factsheet/en

HPC

HPC Top500 list: https://www.top500.org/lists/
National Strategic Computing Initiative (USA): https://www.nitrd.gov/nsci/
Exascale Computing Project (USA): https://www.exascaleproject.org/
Flagship 2020 Project (Japan): https://www.r-ccs.riken.jp/en/overview/exascalepj
XSEDE programme: https://www.xsede.org/
Supercomputing Consortium of Russian Universities: http://hpc.msu.ru/node/136

Grids and clouds

Open Research Cloud Alliance (ORCA): http://www.openresearchcloud.org
Open Science Grid (USA): https://opensciencegrid.org/
JetStream Cloud (USA): https://jetstream-cloud.org
CyVerse: http://www.cyverse.org/about
NET+ Cloud Services Program: https://www.internet2.edu/vision-initiatives/initiatives/internet2-netplus/
CSTCloud federation (China): http://cstcloud.net/
Indian Centre for Development of Advanced Computing: https://www.cdac.in/index.aspx?id=hgc
DiCOS - operating system for the distributed Cloud environment: https://dicos.grid.sinica.edu.tw/
Nectar cloud (Australia): https://nectar.org.au/research-cloud/
New Zealand eScience Infrastructure (NeSI): https://www.nesi.org.nz/
South African National Integrated Cyber Infrastructure System (NICIS):
https://www.csir.co.za/national-integrated-cyber-infrastructure-system

Data

CODATA: http://www.codata.org
Dryad digital repository (US): http://datadryad.org/
figshare (US): http://figshare.com/
Harvard Dataverse (US): http://dataverse.harvard.edu/

Open Science Framework (US): http://osf.io/
Mendeley Data (US): https://data.mendeley.com/
National Data Service (US): http://www.nationaldataservice.org/

ScienceOpen (US): https://www.scienceopen.com/
Unpaywall (US): https://unpaywall.org
CyVerse (US): http://www.cyverse.org/about
Google Dataset Search (US): https://toolbox.google.com/datasetsearch
Federated Research Data Repository (Canada): https://www.frdr.ca
LA Referencia: http://www.lareferencia.info/en/
Australian National Data Service: https://www.ands.org.au
Research Data Australia discovery portal: https://www.ands.org.au/online-services/research-data-australia
NCI National Research Data Collection (Australia): https://nci.org.au/services/nci-national-research-data-collection/
African Open Science Platform initiative: http://africanopenscience.org.za/
Fudan University Social Science Data Repository: https://dataverse.org/blog/featured-dataverse-repository-fudan-university

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