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

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INTERNATIONAL RESEARCH INFRASTRUCTURE LANDSCAPE 2019

A European Perspective
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Additional appendices including contact information of the identified RIs are available at https://riscape.eu/riscape-report/
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 RIs. 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 landscaping 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 G50. 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.

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1. FRAMING AND SCOPE OF THE REPORT

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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?

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.

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.
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.

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

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.
FRAMING AND SCOPE

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

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.
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.

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.

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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

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3.1 Domain Overview

In the ESFRI 2018 Roadmap¹ (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

<table>
<thead>
<tr>
<th>Short name</th>
<th>Name</th>
<th>Subdomain*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACTRIS</td>
<td>Aerosols, Clouds and Trace Gases Research Infrastructure</td>
<td>A</td>
</tr>
<tr>
<td>AnaEE</td>
<td>Infrastructure for Analysis and Experimentation on Ecosystems</td>
<td>B</td>
</tr>
<tr>
<td>AQUACOSM</td>
<td>Network of Leading European Aquatic Mesocosm Facilities Connecting Mountains to Oceans from the Arctic to the Mediterranean</td>
<td>H</td>
</tr>
<tr>
<td>ARISE</td>
<td>Atmospheric Dynamics Research Infrastructure in Europe</td>
<td>A</td>
</tr>
<tr>
<td>DANUBIUS</td>
<td>International Centre for Advanced Studies on River-Sea Systems</td>
<td>H</td>
</tr>
<tr>
<td>DiSSCo</td>
<td>Distributed System of Scientific Collections</td>
<td>X</td>
</tr>
<tr>
<td>EISCAT_3D</td>
<td>Next Generation European Incoherent Scatter Radar Network</td>
<td>A</td>
</tr>
<tr>
<td>eTER</td>
<td>Integrated European Long-term Ecosystem Research Network</td>
<td>B</td>
</tr>
<tr>
<td>EMSO</td>
<td>European Multidisciplinary Seafloor and Water-Column Observatory</td>
<td>H</td>
</tr>
<tr>
<td>EPIC</td>
<td>European Plate Observing System</td>
<td>G</td>
</tr>
<tr>
<td>EUROFLEETS</td>
<td>European Contribution to the International Argo Programme</td>
<td>H</td>
</tr>
<tr>
<td>EuroGOOS</td>
<td>European Global Ocean Observing System</td>
<td>H</td>
</tr>
<tr>
<td>GROOM</td>
<td>Gliders for Research, Ocean Observation and Management</td>
<td>H</td>
</tr>
<tr>
<td>IGOS</td>
<td>In service Aircraft for a Global Observing System</td>
<td>A</td>
</tr>
<tr>
<td>ICOS</td>
<td>Integrated Carbon Observation System</td>
<td>X</td>
</tr>
<tr>
<td>INTERACT</td>
<td>International Network for Terrestrial Research and Monitoring in the Arctic</td>
<td>B</td>
</tr>
<tr>
<td>IS-ENES2</td>
<td>Infrastructure for the European Network for Earth System Modelling</td>
<td>X</td>
</tr>
<tr>
<td>JERICO</td>
<td>Joint European Research Infrastructure Network for Coastal Observatories</td>
<td>H</td>
</tr>
<tr>
<td>LifeWatch</td>
<td>e-Science and Technology European Infrastructure for Biodiversity and Ecosystem Research</td>
<td>B</td>
</tr>
<tr>
<td>SIOS</td>
<td>Svalbard Integrated Arctic Earth Observing System</td>
<td>X</td>
</tr>
</tbody>
</table>

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, internationally 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”[1]. 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 / Equatoral 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 (JAPAN) of Indonesia. The EMU facility is co-located with an upcoming facility with 10 times the sensitivity of EAR. This is an equatorially geographic complementary to the high latitude EISCAT_3D system in Europe. However, no formalised agreements

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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 Seismic Sounding 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, MLT 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-instruments 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, calibration 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 Eulenrian 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 organisation 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 in their 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
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 99 countries and 29 international organisations 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 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 data 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, Nunavut. 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, 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.

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 sever-al 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 respective 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 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, like Japan where earthquakes and other natural disasters can be 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.

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

There is a constant pressure to be relevant.
Rarely, RIs mentioned that they (or their funders) seek a diversification of funding mechanisms. For instance, MIED 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 benefit 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 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 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 Understanding, 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 SEACRIFOS). 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 understand 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.

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2. www.gem.uno
3. www.saucifos.eu
4. www.saucifos.eu
5. www.seacrifog.eu

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of Biodiversity Surveys for Assessments. 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.
4. HEALTH AND FOOD RESEARCH INFRASTRUCTURES

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This report and its contents are provided as a contribution to the ongoing investigation of the global research infrastructure landscape. Every effort has been made to ensure the accuracy of the material contained in this publication; however complete accuracy cannot be guaranteed. The views in, and contents of, this report do not necessarily represent those of RISCAPE partner organisations or the European Commission. No responsibility is accepted for the consequences of any action, or refraining for action, as a result of material contained in this publication.

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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

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

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.

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...
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 licensing.

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 CORDR 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, cardiology 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 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 Human and Animal Health scope 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 EMBRC (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 IOMCR), 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...
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 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 (A AHL), 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, 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](image_url)

**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 78% 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 as 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.
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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 €60 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:

- 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.

(Ris did not respond to the survey)
(Ris under construction)

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

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 RI 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 have been 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 landscape. Although, in the appendix one can find a list of all the RIs considered in the 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 (3 GeV, 10+7 planned)
- UVX LNLS Laboratorio Nacional de Luz Sincrotrão, Brazil (1.37 GeV, 17)
- CLS Canadian Light Source (2.9 GeV, 19+2 at APS)
- PF Photon Factory High Energy Accelerator Research Organization, KEK, Japan (PF: 2.5 GeV, PAF: 6.5 GeV, 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 (2.2 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, 32)
- 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 (2.5 GeV, 14)
- SSRF Shanghai Synchrotron Radiation Facility, China (3.5 GeV, 14)
- PLS-II Pohang Light Source-II, S. Korea (3.0 GeV, 36)
- KRSR Kurchatov Synchrotron Radiation Source, Russia (2.5 GeV, 14)
- SSTRC Siberian Synchrotron Terahertz Radiation Centre, Russia (2.2 GeV, 12)
- SLSL Singapore Synchrotron Light Source National University of Singapore (0.7 GeV, 7)

In addition, LNLS - SIRIUS PROJECT Laboratorio Nacional de Luz Sincrotrão, 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)
- **BARI** Karlsruhe Research Reactor, Germany (18 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 1100 kW; 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 (ICUHL) 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 24 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 Magnétiques Intenses units 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, 4 responded to the survey

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

- **IUCN** 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 fulfill 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.

<table>
<thead>
<tr>
<th>PP/ NP</th>
<th>ARI (NS, SR, FEL)</th>
<th>HPL, HMF</th>
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<td><strong>OPERATION</strong></td>
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<tr>
<td><strong>ACCESS</strong></td>
<td>Few / large collaborations / Experiments lasting years</td>
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<tr>
<td><strong>Challenges &amp; Impact</strong></td>
<td>Big fundamental questions (e.g. standard model)</td>
<td>Grand challenges in general / technical and scientific support</td>
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**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).

- Budker Institute of Nuclear Physics, Russia
- TJNAF - Jefferson Lab Thomas Jefferson National Accelerator Facility, USA
- 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.
5.4.2 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 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 are the most important indicators to funding bodies and partner organisations, and hence to the RI itself. Many of the RIs acknowledged 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 thesis expensive facilities.

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 thesis 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.
6. ENERGY RESEARCH INFRASTRUCTURES

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This report and its contents are provided as a contribution to the ongoing investigation of the global research infrastructure landscape. Every effort has been made to ensure the accuracy of the material contained in this publication; however, complete accuracy cannot be guaranteed. The views in, and contents of, this report do not necessarily represent those of RISCAPE partner organisations or the European Commission. No responsibility is accepted for the consequences of any action, or refraining for action, as a result of material contained in this publication.

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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 CO₂ emissions. For the EU, the goal of reducing CO₂ 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. 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 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...
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 energy 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 (ECSCOL) 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. ECSCOL 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.

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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.

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.

![Figure 6.1 European research infrastructures identified and contacted](image)

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

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*For the purpose of clarity these organisations are also listed at the end of Appendix 6.*
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.
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.

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 EESCEL 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) is the oldest and largest 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 Dimitrovgrad (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 for 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 radiotherapy, 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 – UPVR, 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 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, nano-electronics, 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.

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, IMIF-DONES, MYRHYHA 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.

<table>
<thead>
<tr>
<th>Construction costs</th>
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<tr>
<td>Renewables: $5–$50 million</td>
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<tr>
<td>Specific nuclear facilities (e.g. synchrotrons): $300m–$1800 million</td>
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<tr>
<td>Carbon Capture, Storage and Utilization: €1 billion</td>
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<tr>
<td>Nuclear, large-scale: $5–$100 billion</td>
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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, Japan 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 organisation3. In Brazil, all three organisations contacted are included in the Federal Government Plan4. 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. Australian Nuclear Science and Technology Organization (ANSTO), with its major facility – OPAL reactor – is mentioned in Australian National Research Infrastructure Roadmap 20165. 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 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

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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 research projects. However, the 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 online. 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 Dmitrovgrad 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.

Another interesting example is EME, Canada, which claims that some of its programmes have certain targeted parameters set on the planning stage 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).

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 EURATOM 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. 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 inspecting 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”.

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1 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.riar.ru/sites/default/files/annual_report_nar_2018_pdf.pdf


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 does 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](image-url)
7. ASTRONOMY AND ASTROPARTICLE RESEARCH INFRASTRUCTURES

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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.
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.

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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.

7.3 Overview of the International landscape

The field of astronomy is 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.

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.

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 Magellanic 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,
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 (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.
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 astrophysics 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

ESF RIs 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 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, a 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

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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).

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.

- **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.

<table>
<thead>
<tr>
<th>Full name</th>
<th>ESFRI status</th>
</tr>
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<tbody>
<tr>
<td>ESS ERIC</td>
<td>European Social Survey</td>
</tr>
<tr>
<td>SHARE ERIC</td>
<td>The Survey of Health, Ageing and Retirement in Europe</td>
</tr>
<tr>
<td>CESSDA ERIC</td>
<td>Consortium of European Social Science Data Archives</td>
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<tr>
<td>E-RIHS</td>
<td>European Research Infrastructure for Heritage Science</td>
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<tr>
<td>GGP</td>
<td>The Generations and Gender Programme</td>
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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...
Advice for the INFRA-DEV 3 Cluster Project, Synergies for Europe’s Research Infrastructures in the Social Sciences (SERISS) included representatives from the EU’s European Agency for Fundamental Rights and European Foundation for the Improvement of Living and Working Conditions. 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-RHIS, 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.

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1 [www.seriss.eu](http://www.seriss.eu)
2 [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 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.

* http://www.worldsocialscience.org/resources/survey-surveys/

Figure 8.1 Social Science infrastructures and initiatives interviewed and total number of found SS initiatives in the area
The Group of Senior Officials assessment of global Research Infrastructures recognizes 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) (ISPUR), 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 Análise 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, (this new 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. It’s 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, University of Cape Town, SA). Latinobarómetro conducts an annual survey in 18 Spanish and Portuguese speaking countries, using representative samples. Arab Barometer is a public opinion poll conducted in 2005 and conducted in the 12 Middle Eastern countries Algeria, Bahrain, Egypt, Iraq, Jordan, Kuwait, Lebanon, Libya, Morocco, Pakistan, 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 (EESAS) 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 organizes 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 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: economies, 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 **Colderidge Initiative** is aiming to use data to transform the way governments access and use data for the social good. The Initiative itself serves as a remote access facility, which provides access to and use of confidential microdata, and associated training programs Colderidge 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. The 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 Análise 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 Brazilian government. The **Chinese Panel Survey Data Archive** is a national, longitudinal, cross-sectional 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 2010. **Survey Data Archive** is a Core Trust Seal certified national repository, providing access to the academic community, a vast archive of social science data (quantitative data obtained from surveys) for secondary analyses. 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 Economic, 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 social science data and environmental information, and dissemination and mapping services. DICESE, 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 DICESE. 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** (INEOD, 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 2010. **Survey Data Archive** is a Core Trust Seal certified national repository, providing access to the academic community, a vast archive of social science data (quantitative data obtained from 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 1961 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 generalizable 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 documents the 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 changes in 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 (ISPRJ) in Skopje, North Macedonia, was founded in 1965 with the decision of the Council of the University “St. Cyril and Methodius”. Since then, the ISPRJ 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 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.

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 initiatives). In general, constructions 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%).

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.

8.4.5 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.
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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 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 RI’s 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 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.

* https://ec.europa.eu/research/scrip/index.rtf?p=ricountries
9. CULTURAL HERITAGE, DIGITAL HUMANITIES AND LANGUAGES RESEARCH INFRASTRUCTURES

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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.
E-RIHS is a distributed RI on the ESFRI Roadmap currently in the preparatory phase (2017–2020), and an RI for heritage science research including analysis, documentation, 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 2018: 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 2018: 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 EHRI 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, stylometry, 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 ESFRI 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, FPT-Infrastructure, Integrating Activity, 2/2013-1/2017). 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.

ECHI - 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). 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; 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 Cultural Heritage the digital infrastructures outside Europe seem 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 (CRIN, Italy), identified networks of centres, documentation of the ICCROM forum on heritage science (Heritage & Gofomitsu 2015), and other sources consulted.

9.3.1.1 Holocaust research

RI comparable to EHRI: EHRI 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 EHRI. The EHRI initiative includes, as a core element, an e-infrastructure providing access to a catalogue
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) and 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

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).
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 Panjib 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 Qings 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.

9.3.3 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.

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-INFRASTRUCTURES

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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 einfrastructures, the line between ‘being an infrastructure or being a project’ is blurry, as many e-infrastructure initiatives mostly reusing content from their Guide to e-infrastructure requirements for European Research Infrastructures1. The following subsections present a brief introduction of the major pan-European e-infrastructure initiatives mostly


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.
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-infrastructure. 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-infrastructure. 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-infrastructure. 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-infrastructure. 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-infrastructure. 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-infrastructure. Data is a key component of Research Infrastructures, a fundamental scientific product offered for scientific and commercial exploitation.

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 and 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.
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 depends upon their mandates may extend also to private R&D firms.

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, as well as candidates 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.
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 petalopf 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 petalopf 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 service 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 (LPI= 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 NIREN, 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.
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 are 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, 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 Data 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. In the government decree of December 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

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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 cooperation. 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 support 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 intendeded 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
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 number 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 a more 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. 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 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. Although 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 such long time development can be impossible afterwards.
CONCLUSIONS & GENERAL FINDINGS

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 managers 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 also be 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 community. Embargo is typically stated in metrics for usage. Some RIs have experimented 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.

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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. 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 facilities 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.
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