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Terminological and strategical analysis of the concept of research infrastructure

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Terminological and strategical analysis of the concept of research infrastructure

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1. Main findings

- The research infrastructure (RI) concept is by its nature composite and complex – given the large differences in how research is performed by scholarly communities and in its relationships to society that also translate into differences in the kind of 'infrastructure' these communities need.
- Core elements of RIs are a) the reference to a research community managing the RI and willing to use it by sharing facilities and tools, b) the presence of a large enough community to justify their existence, c) the notion of open or conditional access to all researchers in a field, and d) the fact that in RIs what is shared is some kind of 'material' entity including tools, instruments, data and software codes that enable research
- It is important to distinguish between a broad scholarly definition of RIs and the process of political prioritisation through which RIs become labelled and, eventually, funded by specific channels. These processes should comprise a) the broad identification of those RIs needed in a specific field, as related to a long-term research programme, b) the labelling of RIs as fulfilling the basic criteria for RI funding and their level of priority in terms of funding, and c) funding decisions by different funders, such as the European Union, countries, research institutions.
- The current Swiss RI process shares many characteristics with other countries, such as the broad definition of RIs, the establishment of sectoral roadmaps for specific fields, and a distributed and multi-actor process of prioritisation.
- However, the Swiss RI process simply refers to a 'European' definition of RIs while 'implicit' (and somewhat incoherent) definitional elements can be found in legal texts (such as the Research and Innovation Promotion Act RIPA), official documents and actors' statements.
- Unlike the European Strategy Forum on Research Infrastructures ESFRI and most roadmaps in other countries, the Swiss RI roadmap is actually a funding roadmap, in the sense that it identifies directly the way (and extent) individual RIs will be funded. This setting does not allow for long-term strategic planning and leads to fragmentation and coordination issues.
- It is therefore suggested that a more open and explicit debate on the RI definition should take place to help understand the different dimensions of RIs (such as physical vs. virtual, differences in scale and scope, and differences between fields) and articulate the discourses and interests of different actors more openly.
- Further, the report suggests separating the definition and identification of RIs of (potential) national importance from funding decisions. The Swiss RI roadmap process should be managed through an organisational setting which is independent of funding responsibilities.
- Finally, sectoral roadmaps are a convenient way to reach a level of prioritisation by the communities themselves inside smaller domains. It is therefore suggested that this practice is progressively extended to all domains where the respective community is able and willing to invest in such a process.

Contents

List of abbreviations

BMBF	German Federal Ministry of Education and Research
EOSC	European Open Science Cloud
ESFRI	European Strategic Forum for Research Infrastructures
EU	European Union
FIT	Federal Institutes of Technology
HedA	Higher Education Act
MERIL	Mapping of the European Research Infrastructure Landscape
MESRI	French Ministry for higher education, research, and innovation
MINT	Mathematics, informatics, natural science, and technology
NSTC	United States National Science and Technology Council
RI	Research Infrastructure
RIPA	Federal Act on the Promotion of Research and Innovation
RIPO	Research and Innovation Promotion Ordinance
SCNAT	Swiss Academy of Natural Sciences
SERI	State Secretariat for Education, Research, and Innovation
SNSF	Swiss National Science Foundation
SSH	Social Sciences and Humanities

1 Introduction

Since the beginning of the 21st century, the concept of *Research Infrastructure* (RI) has gained popularity in the research policy literature (Hallonsten & Cramer 2020), and in the political discussion about research funding (Franssen 2020). While the emergence of the concept has been promoted by the European Union (EU) through the establishment of the European Strategic Forum for Research Infrastructures (ESFRI), most developed countries have now integrated RIs and their funding within their set of research policy instruments and establish roadmapping processes to decide which RIs should receive dedicated funding (Bolliger & Hallonsten 2020).

A similar evolution has been observed in Switzerland where, since 2011, the Swiss Roadmap for Research Infrastructures has been elaborated every four years as an instrument for identifying RIs of national importance and the Swiss participation in international RIs. Some of these RIs are then funded in different ways through the Education, Research, and Innovation dispatch.

Despite its prominence, the notion of RI remains relatively ambiguous and subject to debate. Frequently, definitions are of operational nature and are driven by the interests of actors to receive funding for their own infrastructure. Some scholars even argue that the RI concept represents a purely political construct to fund initiatives that have little in common besides being awarded the RI label (Hallonsten 2020). While struggles over resources are an unavoidable and even necessary dimension of research funding policies, the lack of clarity about the concept and its different extensions makes an informed discussion and prioritisation more difficult and might affect the legitimacy and accountability of funding decisions.

To contribute to the debate on RIs, the Swiss Science Council has commissioned the Institute of Communication and Public Policy of the Università della Svizzera italiana to investigate the different definitions and usages of the term 'research infrastructure' in the scholarly literature (section 2) and in the political process at the European level and in selected countries (section 3). The goal is therefore to compare existing definitions in terms of a set of dimensions, including terminology, criteria for inclusion, categories of RIs and possible examples; further, we aim at observing to which (groups of) entities the concept of RIs is attributed, as this will implicitly reveal the content (and extension) of the definition.

Finally, we contrast our findings from the international (scholarly and political) debate with a comparative analysis of the RIs definitions by official documents and actors in the Swiss research policy (section 4). We conclude with some suggestions to improve the clarity of the debate on RIs in the Swiss research policy (section 5).

2 Research infrastructures: a review of the scholarly literature

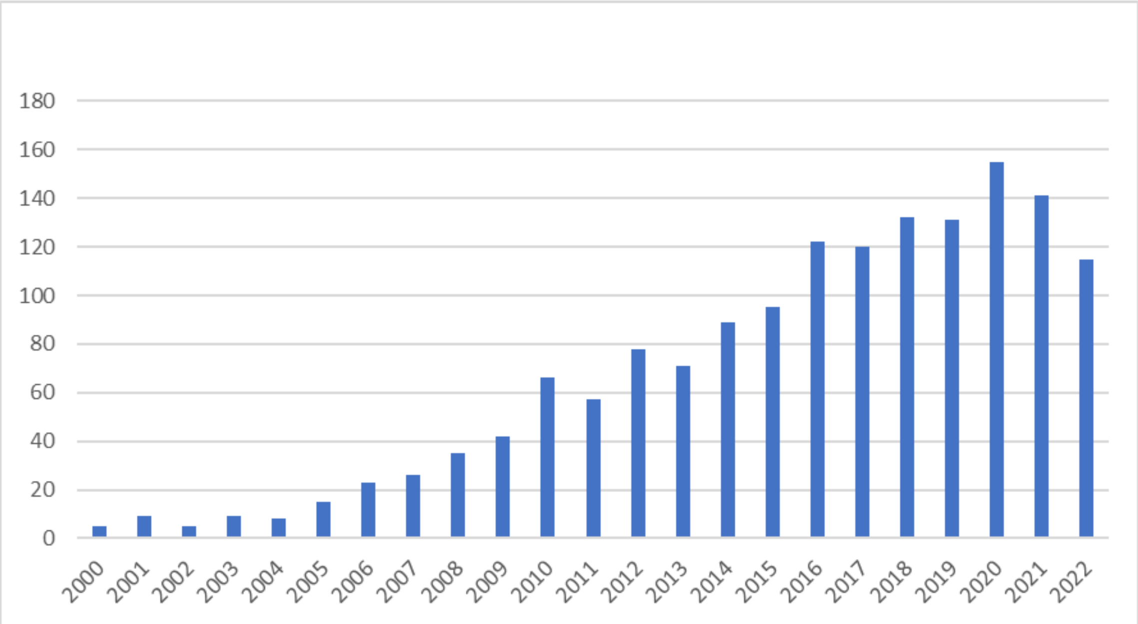
In the following, we first provide a quantitative analysis of the scholarly literature using the term 'research infrastructures', and then we focus more specifically on the smaller body of literature dealing with definitional issues.

2.1 The use of the term in the scholarly literature

A search query made in November 2022 on the Scopus database (www.scopus.com) for the publications including the sentence 'research infrastructure' in the title or the keywords retrieved 1,578 documents, most of them being journal papers (655) or conference papers (650). As shown in Figure 1, the term was very rarely used before 2005, while the number of documents exceeded 150 in 2020 (data for the years 2021 and 2022 are still incomplete). The introduction of the term in European research policy, with the foundation of ESFRI in 2002, therefore pre-dates its scholarly usage, which started with Papon's paper on European research cooperation (Papon 2004).

Of course, several works analysed the establishment of entities which are today included among research infrastructures, such as CERN or EURATOM. However, they were usually subsumed under concepts such as 'big science' or 'megascience' (Cramer & Hallonsten 2020), i.e., with the idea that some forms of scientific inquiry required a large scale of investments (in terms of funding, personnel and political process), which required coordinated action at the country and/or international level. As we shall discuss later in this report, this original idea of 'big science' (and related criteria of scale and uniqueness) is still present in many political definitions of RIs, but hardly fits the current RI landscape.

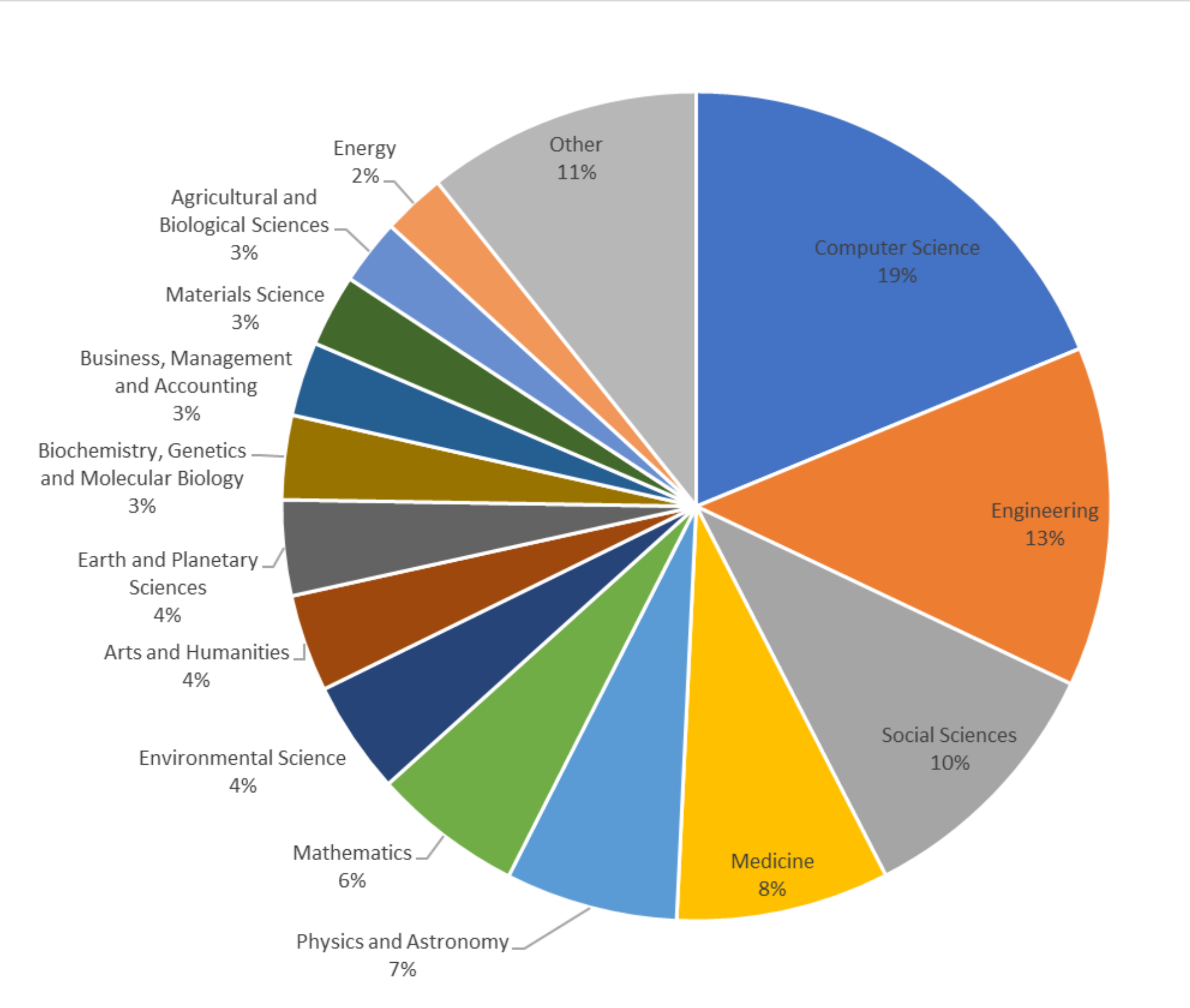
Figure 1. Publications in Scopus using the word 'research infrastructure'



As shown by Figure 2, retrieved publications are distributed over all research areas, with the largest numbers in computer science (19%), engineering (13%), social sciences (10%), medicine (8%), physics and astronomy (7%). While the term 'big science' was mostly used for facilities in natural sciences and engineering, the term 'research infrastructure' has therefore become widespread in all subject domains. Given the differences between scientific domains in how research is conducted and in the type of facilities required, this is expected to translate into high heterogeneity of the entities labelled as RIs, as we shall see later in this report.

Figure 2. Scopus publications by subject categories

Based on the journal's classification



A more fine-grained view of the concepts associated with the RI term is provided by the analysis of the words used in the title and abstract of the publications, grouped by co-occurrences. In this analysis, neighbouring words in the map occur together frequently in the publications, and, accordingly, clusters of words identify specific sets of meanings associated with RIs. The analysis was performed using the VoS viewer software (Van Eck and Waltman 2010).

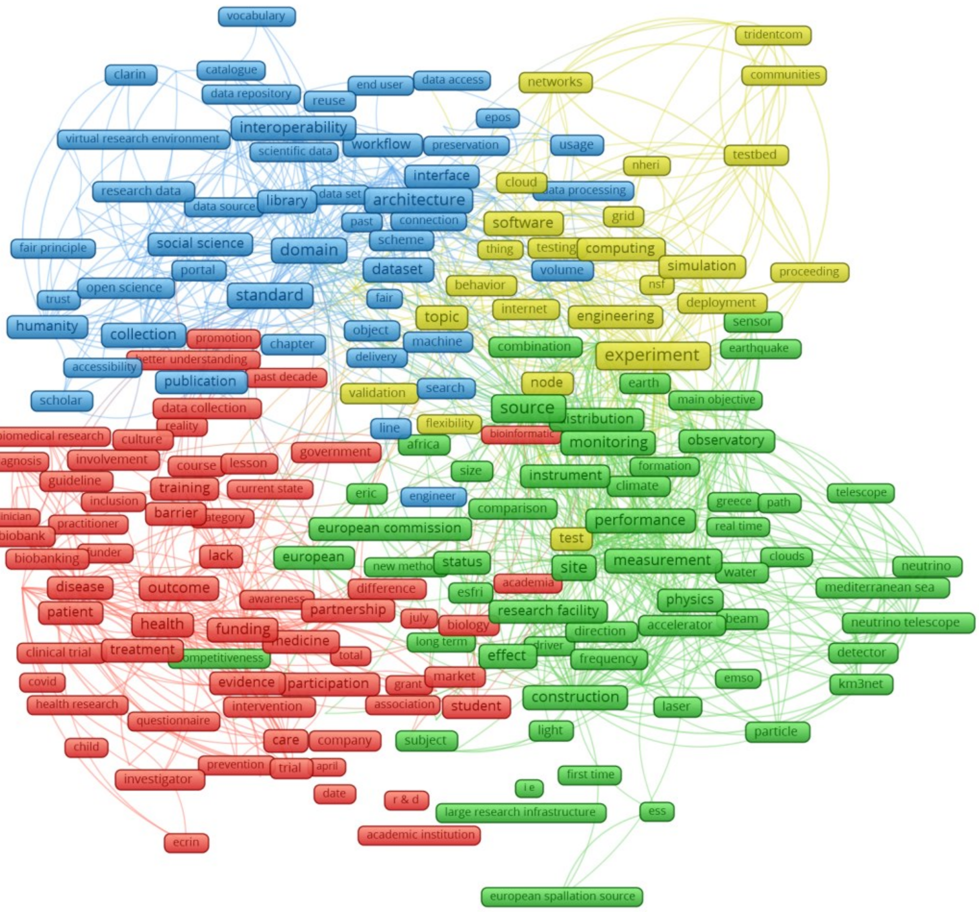
As a result, four main clusters can be identified (Figure 3); their main feature is their association with specific disciplinary contexts, suggesting indeed that RI definitions are largely discipline-specific. More specifically, we distinguish between:

- A *research data* cluster, where the focus is on repositories, data architecture, ontologies and open data. Expectedly, this cluster is also associated with social sciences and humanities.
- An *IT* cluster, including advanced computing facilities, but also software platforms and testbeds.

- A cluster dealing with facilities and research instruments in physics, engineering and environmental sciences, such as telescopes and accelerators; expectedly, this cluster includes also the sentence 'large research infrastructure', as well as the terms associated with European policies such as ESFRI.
- A *health-related cluster*, which can be broadly divided into two dimensions: on the one hand, clinical medicine such as clinical trials and patients' data, and on the other hand (basic and translational) medical research, such as biobanks.

Figure 3. Words associated with research infrastructures

Source: Scopus, visualisation based on VOS viewer



A cursory look at the most cited papers in this sample shows that they deal with the presentation of examples of entities labelled as 'research infrastructure' without questioning the RI definition itself. To provide some examples from the most cited papers, these include the US XSEDE/ACCESS computing infrastructure (https://access-ci.org/), the open-source and collaborative online platform for computational metabolomics (W4M; https://workflow4metabolomics.org/), a review paper on biobanking for biomedical research, the Global Earth Observation System digital infrastructure (GEOSS; https://www.earthobservations.org/geoss.php), the Human Brain Project (https://www.humanbrainproject.eu/en/), and the Australian Industrial Ecology Virtual Laboratory (IELab; https://ielab.info/).

This preliminary analysis leads to some remarks.

a) The extension in the scholarly literature of the usage of the term 'research infrastructure' is much broader than traditional RIs such as observatories or large facilities. The examples proposed, however, suggest that there is a common core constituted by the fact that RIs are tools to organise and manage collective research by offering to scholarly communities a sharing of tools, experimental facilities and/or data. In other words, RIs are created around scholarly communities organising themselves but involve a 'material' (in the broadest sense) dimension, which distinguishes them from networks of institutions and/or people. Beyond this (sociological) core understanding, the nature of RIs (and their main types) is essentially discipline-based, reflecting underlying differences in how scientific communities are organised and the type of facilities and/or services that need to be shared.

b) Second, most RIs are distributed or of virtual nature, being composed of virtual platforms gathering data and services from different providers. The digital and big data revolution has therefore largely transformed the landscape of RIs, which however still comprises several traditional (large-scale, single site) instrumentation. A second factor extending the scope of RIs has been changes in the organisation of science with the emergence of fields, such as biomedicine, which rely to a stronger extent on the cooperation between multiple actors and, therefore, also require sharing facilities beyond the traditional boundaries of laboratories or research institutions (Bonaccorsi 2008).

c) Third, there is considerable variety in the organisation and funding form, ranging from RIs supported and hosted by research labs, to networks where partners provide a share of services and national initiatives. In a number of cases, such as the Human Brain Project, the platforms are integrated within broader research initiatives to which they provide data and services and through which they are funded. This also emphasises the close connection between RIs and research programmes developed by specific communities.

c) Fourth, the number of entities is very large and most of these entities are not included in international or national roadmaps – as we shall see below in chapter 3, the number of entities listed in inventories of European RIs such as MERIL (https://portal.meril.eu/meril/) is in the range of thousands, while most roadmaps include only some dozens of entities. Moreover, while RIs are mostly distributed and cover all scientific domains, most roadmaps (still) focus on large-scale physical infrastructures in the sciences. As we discuss below in chapters 3 and 4, national and European roadmaps are tools to label those RIs that, because of their characteristics, cannot be maintained by the research actors themselves but require dedicated state intervention.

2.2 Defining research infrastructures

As presented in the previous section, a large number of (disciplinary) papers deal with specific instances of RIs; most of these studies take for granted the label of 'research infrastructure' without attempting to elaborate on its definition. There is, however, a small number of works dealing specifically with the origin of the concept, showing how it was linked to the emergence of European research policy and its goal of coordinating national initiatives (Ulnicane 2020).

This literature emphasises the political and processual nature of the RI definition. As put forward by Hallonsten (Hallonsten 2020), the criteria proposed in the ESFRI definition of RIs as 'facilities, resources or services of a unique nature that have been identified by European research communities to conduct top-level activities in all fields' (ESFRI Forum 2018) are not easily applicable to the European

RI landscape. No RI included in the ESFRI roadmap is unique worldwide, and most of them have 'competitors' even at the national level, and the criterion of top-level activities hardly applies to most of them. The core of the definition is in fact the identification of a process through which RIs are, first, identified by research communities and, second, prioritised in a political process involving countries which are in principle willing to commit resources to their establishment and maintenance. The RI concept as used in the political process of roadmapping represents therefore a way of labelling and prioritising some initiatives to channel them European and national funding. Accordingly, the (political) RI definition is closely associated with the establishment of roadmaps and related funding instruments (Bolliger and Hallonsten 2020).

The labelling of RIs is, therefore, by and large a tool for the governance and funding of research by public authorities (Franssen 2020). Its emergence can be seen as a response by public authorities to two arising issues. On the one hand, structural changes in public research funding implied a reduction of baseline funding to universities and public research organisations, through which many RIs were funded in the past (Lepori, Jongbloed and Hicks 2023). This generated the need for a specific funding channel for RIs beyond the few very large infrastructures, which always required specific arrangements because of their size. On the other hand, current research policy increasingly emphasises the need for coordination, achieving a critical mass and avoiding duplications (Elzinga 2012); accordingly, it has become less acceptable to finance, in parallel, similar initiatives in a decentralised way. As shown by the case of digital humanities in the Netherlands, funding for RIs can be used as an incentive for scholarly communities, particularly in traditionally fragmented fields such as social sciences and humanities, to develop stronger forms of cooperation (Franssen 2020). Conversely, success in putting RIs on national and European roadmaps largely depends on the ability of the related communities to organise their activities jointly.

2.3 Types of research infrastructures

The heterogeneity of RIs has led to efforts to develop typologies or classifications of RIs to create some order and to identify common patterns. Already ESFRI distinguishes between three RI types depending on their spatial structure, i.e., single-sited, multiple-sited and virtual RIs (ESFRI Forum 2018), but this classification is not coherently applied even to RIs in the ESFRI roadmap, specifically, the distinction between multiple-sited and virtual RIs is not always straightforward.

A second classification common to most roadmaps is by the RIs scientific field; while the broad domains, such as social sciences and humanities, are used in most classifications, there are some differences at the level of fields. As compared with the broad distribution of RIs in all scientific fields, a prevalence in the ESFRI roadmap of RIs in sciences has been noted.

A third classification used by ESFRI is between single-purpose RIs, designated for a specific research area, such as particle accelerators, and multiple-purpose RIs, that can be mobilised for different research programmes, such as light sources.

In a study of RIs in China, Qiao, Mu and Chen (2016) distinguish between three RI types, i.e., *dedicated RIs*, developed to address the major science and technology objectives of a specific discipline, *public experimental platforms (PEPs)*, that serve basic research, applied fundamental research and applied research for multiple disciplines, and *public infrastructures (PIs),* designed to provide scientific data and information for national development.

A more refined typology in terms of the RIs' functions has been proposed by Hallonsten (2020). He distinguished between systems to perform measurements (*instruments*), facilities to observe the real world (*observatories*), collections of data to be used in research (*repositories*) and, finally, support that allows research at remote sites, such as aircraft (*vessels*).

Applying these classifications to the 60 RIs included in the ESFRI roadmaps, he was able to identify some patterns. Expectedly, the single-sited RIs are mostly instruments and observatories and concentrated in sciences (astronomy, physics, material sciences, engineering). In contrast, the multiple-site category is very heterogeneous in terms of functions and organisation; this applies particularly to the multiple-sited and multiple-purpose RIs, where it is hardly possible to find any commonalities – some of them being simple collections of national facilities. In Hallonsten's view, this shows how flexible the RI concept is, but also questions whether overstretching it to this extent makes the concept useless. From a slightly different perspective, this analysis suggests that the concept of RIs might still be rather clear when dealing with specific and localised infrastructures, where concentrating facilities in one place allows the construction of more powerful telescopes, accelerators or test facilities; as soon as the single-sited constraint is lifted, it becomes more and more difficult to distinguish in practice between RIs and networks of laboratories or researchers sharing some facilities.

2.4 Final remarks

The analysis shows that the scholarly literature identifies two distinct usages of the term 'research infrastructure'.

On the one hand, the term RI is generically used for entities or facilities, or tools shared by a research community to organise joint research activities. The nature of these entities varies between scientific fields, but they have in common two basic ideas: the existence of research communities sharing them and the fact that what is shared is not just research ideas or people, but some kind of material (or electronic) artefact. In practice, it might be sometimes difficult to distinguish between research cooperation and RIs.

On the other hand, the term RI is used in the research policy process (at the national and international level) to designate entities that are awarded a certain label and, by this, are facilitated in the search for research funding from different sources. In such a perspective, RIs are a tool in the governance and funding of research, which allows for prioritising scientific programmes and structuring research communities around a specific stream of resources. By its nature, the subset of RIs in this second meaning is much smaller than in the first; and some labelled RIs do not fully correspond to the first definition as they are more collections of independent activities than shared facilities.

3 European and international definitions of RI

Despite an increasing number of initiatives aiming to improve understanding and governance of RIs at both global and European levels (ESFRI 2017; GSO 2019; OECD 2010, 2017; Science Europe 2017), most RIs are still funded, managed, and operated at a national level, and mostly target national research communities (OECD 2020). Since researchers and policy needs can vary across countries, we expect a diversity in the understanding and support of RIs throughout Europe and beyond. Countries were selected based on the size of their research ecosystem – including some of the largest European countries, as well as middle-size advanced countries more similar to Switzerland − and on available information through InRoad reports and national roadmap.

3.1 RI definition within and beyond Europe

As Hallonsten (2020) puts it, the term RIs remains vague and can be used for a wide variety of entities from the Large Hadron Collider at CERN to the Digital Research Infrastructure for the Arts and Humanities, a virtual network enabling researchers in the Arts and Humanities to share knowledge and research material.

In its Regulation (EU) 2021/695 establishing Horizon Europe, the ninth EU Framework Programme for Research and Innovation, RIs are defined as *"facilities that provide resources and services for the research communities to conduct research and foster innovation in their fields, including the associated human resources, major equipment or sets of instruments; knowledge-related facilities such as collections, archives or scientific data infrastructures; computing systems, communication networks and any other infrastructure of a unique nature and open to external users, essential to achieve excellence in R&I; they may, where relevant, be used beyond research, for example for education or public services and they may be single sited, virtual or distributed."*

This definition considers several aspects linked to RIs, such as their purpose ("achieve excellence in RI", "use beyond research"), their form (single-sited, virtual, or distributed), and some wide categories and examples. Although this definition serves as a reference for EU Member States in their effort to define RIs, the set of national definitions collected within the InRoad project (https://www.inroad.eu/) shows variations across national contexts.

For example, the Austrian, French, Dutch, and Spanish definitions, among others, state that, to be considered as such, RIs must offer "unique capabilities". Some countries defined specific threshold values, e.g., at least € 50 million in construction costs and ten years of service life in Germany, the range of € 3-14 million for the construction and/or implementation of RIs in Denmark, or the minimum of five years of service life in the Netherlands. In Germany, the use of RIs is regulated based on scientific quality standards, while in Sweden, RIs must be easily accessible to researchers, industry, and other stakeholders (InRoad 2018).

Differences can also be found in the RIs' target groups. While most countries largely consider researchers as their main target groups, some countries emphasised the industry relevance of the RIs. This includes the UK, which, in its last roadmap to date, sees RIs as enablers for the development, demonstration, and delivery of new "innovative processes, products, and services" (UKRI 2020a). The evaluation of Spanish potential RIs takes into account the potential industrial return and cooperation with other types of stakeholders.

In most cases, RIs are defined in the national roadmaps by the responsible ministries (Austria, Denmark, France, Germany), research council (Sweden) or established committee for RIs (Finland, the Netherlands). In Belgium, where RIs are regulated in their different entities, there is no roadmap yet, but RIs are for example defined in Art. 3 of the Flemish Research Foundation's regulation on the participation in and/or funding of international research infrastructure. In Czechia, RIs are defined in the Act on Support of Research, Experimental Development. and Innovation (Paragraph 2, Article 2, Letter (d) of the Act No 130/2002).

Table 1 shows an overview of aspects covered in national definitions of RIs, based on the InRoad country reports and national roadmaps.

	AT	DE	DK	EU	FI	FR	IL	NL	SE	UK	CH
Costs and size	•	•		•			•	•		•	•
Governance		•				•		•			•
Industry relevance			•						•	•	
International	•		•		•	•				•	•
National interest		•	•		•	•			•	•	•
Open Access policy		•	•		•	•	•	•	•	•	•
Scientific excellence				•	•	•	•	•	•	•	
Service life, sustainability		•	•		•	•		•	•	•	•
Societal relevance	•		•								
Uniqueness	•			•		•		•			

Table 1. Aspects covered in national definitions of RIs. Sources: InRoad country sheets (2018), national roadmaps.

3.2 RI governance

While many countries have clear processes to identify and support RIs, we note critical cross-country differences in terms of RIs' roadmap governance, RI identification mechanisms, the content of roadmaps, and support mechanisms.

RI roadmaps may be led by one national ministry responsible for research, a combination of national ministries, an agency or research council acting with or on behalf of the ministry, or involve multiple actors at different levels, notably in federal systems (OECD 2020). Scientific communities are involved to diverse extents, with countries following more or less top-down or bottom-up mechanisms for the identification of RIs.

In France, the Ministry for higher education, research and innovation (MESRI) is coordinating the roadmapping with input from research alliances, CNRS and CEA in the planning phase. MESRI and research alliances are responsible for the science-driven evaluation, and the final decision is taken by the Cabinet of MESRI. In Germany, the Federal Ministry of Education and Research (BMBF) is responsible for the roadmapping procedure, while funding decisions can be taken by BMBF, Federal Ministries, and Federal States. In South Korea, the ministry leads the roadmapping process and decisions are taken by experts recommended by the scientific community (OECD 2020).

In the United States, each agency, such as the Department of Defense or NASA, has its own priority-setting process, while the National Science and Technology Council (NSTC) facilitates efforts for coordinated Federal R&D investments (NSTC 2021). Community input and planning are managed at the discipline level (OECD 2020). This is notably done through decadal surveys, which set the broad vision for scientific discovery for the coming decade in a given discipline, including the RIs needed to reach that vision (NSTC 2021). The collection of decadal surveys is managed by the National Academies of Sciences, Engineering, and Medicine, in coordination with agencies and research communities.

Roadmap governance model	**Countries**
Ministry alone	Australia, South Korea
Agencies alone	USA
Ministry and agency	Denmark, France, Ireland, the Netherlands, Norway, Sweden, UK
Ministry, agency and regional authority	Austria, Canada, Germany, Japan, Spain

Table 2. Governance of RI roadmaps. Sources: InRoad country sheets (2018), OECD (2020).

The InRoad data collection on RI practices showed that the purpose and content of RI roadmaps also vary across European countries. Most national roadmaps cover strategic RI priorities, the preparation for the negotiations at European (ESFRI) and international levels, and the identification of scientific needs and existing gaps. National roadmaps in Ireland and Israel also include a list of RIs desired by the scientific community. Some roadmaps (e.g., in Austria, France, Ireland, and Spain) include an inventory of existing RIs. The French, Irish, and Italian roadmaps address the differentiation between institutional/regional RIs and RIs of national importance.

	AT	DE	DK	ES	FR	IL	IT	NL	NO	UK	CH
Scientific needs identification	•	•	•			•			•	•	•
List of desired RI by scientific community						•					
Strategic RI priorities	•	•	•	•	•	•	•	•	•	•	•
Inventory of RIs	•		•	•	•			•			
Input for funding decisions	•	•		•		•	•	•	•		•
Planning instrument for ESFRI	•	•			•	•	•			•	
Differentiation institutional/regional vs. national RIs					•		•				
Monitoring RI implementation				•	•	•		•	•		

Table 3. Purpose of national RI roadmaps. Source: InRoad country sheets (2018).

3.3 Types of RI funded

The EU-funded MERIL project (Mapping of the European Research Infrastructure Landscape, https://portal.meril.eu/meril/) produced and maintained an inventory of RIs across Europe from 2010 to 2020. A total of 1,042 RIs were included in their database. To be included, RIs must provide access to users outside of the country in which they are located, clear access rules, a website in English, and have received national, regional, or European public funding. Their database is therefore not exhaustive but can nevertheless provide an overview of what types of RIs are supported and prioritised by national and regional authorities in Europe.

One of the key outcomes of this project is the rather comprehensive categorisation of RIs by discipline and type of RIs (MERIL-2 n.d.). Their categories and sub-categories are notably used as references in national RI inventories in Austria and Germany. To illustrate the diversity of supported RIs per coordinating country across Europe, we use this categorisation and the MERIL database in Table 4.

At the disciplinary level, we observe that RIs in “Biological and Medical Sciences” is the category with the highest number of RIs (341). “Earth and Environmental Sciences” and “Physics, Astronomy, Astrophysics and Mathematics” follow with 267 and 265. “Social Sciences” is the category with the lowest number of RIs (107).

At the country level, we notice for example that France and the UK have the highest coverage of RI types. This may be related to the size of research systems. We can however observe that the UK only covers one out of the six categories in “Engineering and Energy”. While Germany covers most categories in “Biological and Medical Sciences” and “Chemistry and Material Sciences”, their coverage of “Earth and Environmental Sciences” and “Engineering and Energy” is relatively low.

Aside from illustrating differences in terms of national priorities, the MERIL database also questions the relevance of “uniqueness”, often a criterion for the allocation of public RI funding. Most RIs are in fact not unique at a European level, and sometimes not even at the national level.

	AT	BE	DE	DK	EU	FR	IT	NL	NO	SE	UK	CH
Biological & Medical Sciences												
Agronomy, Forestry, Plant Breeding Centres	•		•			•				•	•	
Animal Facilities	•	•	•			•		•		•	•	
Collection of biological resources	•	•	•	•		•	•	•			•	•
Bioinformatics facilities		•	•			•	•	•	•	•	•	•
Biological/Biomedical Engineering and Biotechnology/Nanotechnology Research Facilities		•				•		•	•		•	
Biomedical Imaging Facilities	•	•	•			•		•	•		•	•
Cell Culture Facilities	•	•	•			•	•	•			•	•
Clinical Research Centres	•		•			•		•			•	•
Environmental health research facilities		•		•		•		•		•	•	
Genomic, Transcriptomic, Proteomics and Metabolomics Facilities	•	•	•	•		•	•	•	•	•	•	•
Structural Biology Facilities	•	•				•	•	•	•	•	•	•
Systems Biology/Computational Biology Facilities	•		•	•		•	•				•	•
Telemedicine Laboratories and E-Health Technologies	•											
Translational Research Centres	•		•			•		•			•	•
Chemistry and Material Sciences												
Analytical Facilities	•	•	•			•	•	•	•	•	•	•
Chemical Libraries and Screening Facilities	•	•	•			•			•			
Intense Light Sources	•	•	•			•	•	•		•	•	•
Intense Neutron Sources	•		•		•	•				•	•	•
Materials Synthesis or Testing Facilities	•	•	•			•		•		•	•	•
Pilot Plants for Process Testing	•											•
Reference Material Repositories		•				•		•			•	

	AT	BE	DE	DK	EU	FR	IT	NL	NO	SE	UK	CH
Earth and Environmental Sciences												
Acoustic Monitoring Stations								•		•	•	
Atmospheric Measurement Facilities	•	•	•			•	•	•	•	•	•	•
Earth Observation Satellites	•	•				•	•		•		•	
Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres		•				•	•	•	•		•	•
Earthquake Simulation Laboratories		•				•						
Environmental Management Infrastructures		•				•		•	•	•	•	
Geothermal Research Facilities												
In Situ Earth Observatories	•	•		•		•	•		•		•	•
In Situ Marine/Freshwater Observatories	•	•	•			•	•	•	•	•	•	
Natural History Collections		•		•		•		•			•	
Polar and Cryospheric Research Infrastructures		•		•		•	•		•	•	•	
Research Aircraft						•		•			•	
Solid Earth Observatories, incl. Seismological Monitoring Stations				•		•	•		•	•		•
Engineering & Energy												
Aerospace and Aerodynamics Research Facilities	•	•	•			•		•				
Civil Engineering Research Infrastructures					•	•		•				•
Electrical and Optical Engineering Facilities	•					•				•		
Energy Engineering Facilities (non-nuclear)	•	•		•		•		•	•		•	
Marine & Maritime Engineering Facilities						•	•	•	•	•		
Mechanical Engineering Facilities	•	•				•		•		•		
Humanities & Arts												
Collections	•	•	•			•		•	•		•	
Repositories	•	•	•			•		•	•		•	
Databases		•				•	•	•	•		•	•
Conceptual Models						•					•	
Research Archives	•	•	•			•		•	•		•	•
Research Libraries		•	•	•		•		•	•		•	•
Research Bibliographies	•	•				•			•		•	

	AT	BE	DE	DK	EU	FR	IT	NL	NO	SE	UK	CH
Information Science & Technology												
Centralised Computing Facilities	•		•			•	•	•			•	•
Communication Networks						•		•		•		
Complex Data Facilities		•				•	•	•	•	•	•	•
Distributed Computing Facilities		•				•	•	•		•		•
Software Service Facilities			•			•		•	•		•	•
Physics, Astronomy, Astrophysics and Mathematics												
Astro-Particle and Neutrino Detectors and Observatories	•			•			•					
Centres for Advanced Research in Mathematics										•	•	
Centres for Development of Industrial Mathematics											•	
Cross-Disciplinary Centres in Mathematics											•	
Extreme Conditions Facilities	•	•	•		•	•	•	•	•	•		•
Gravitational Wave Detectors and Observatories	•						•					
High Energy Physics Facilities	•		•	•		•	•	•				•
Mathematics Centres of Competence	•										•	•
Micro and Nanotechnology Facilities	•	•	•	•	•	•	•	•	•	•	•	•
Nuclear Research Facilities	•		•		•	•	•	•			•	•
Safety Handling Facilities						•		•			•	•
Space Environment Test Facilities			•					•			•	
Telescopes	•		•	•		•	•	•		•	•	•
Underground Laboratories					•	•	•					
Social Sciences												
Data Archives, Data Repositories and Collections	•	•	•			•	•	•	•	•	•	•
Data mining and Analysis Centres, including statistical analysis		•	•			•		•			•	
National Statistical Facilities (offices)											•	
Registers and Survey-led Studies/Databases			•					•			•	•
Research Data Service Facilities		•	•	•		•	•	•	•	•	•	•

Table 4. Types of RIs coordinated per country.

Sources: MERIL database (2020); BMBWF RI database for Austria (https://forschungsinfrastruktur.bmbwf.gv.at/ 2022); DFG portal for RIs for Germany (https://risources.dfg.de/ 2022).

4 The research infrastructures concept in Swiss research policy

In this chapter, we first summarise the definitions and criteria for RIs provided in Swiss research policy official documents and by other actors involved in the roadmap process. We then compare definitions and criteria among them and with the previous analysis of the scholarly literature and the international definitions.

4.1 RI definitions in the Swiss legal basis

The legal basis for the RI planning process in Switzerland is set by the Research and Innovation Promotion Act (National Science and Technology Council) and, more specifically, the Research and Innovation Promotion Ordonnance (RIPO). Art. 41 RIPA allows the Confederation to coordinate research and innovation in a subsidiary role in the domains where cooperation cannot be achieved through the autonomous coordination of research actors. Art. 41, lit. 2 mentions explicitly in this context the “cost-intensive” research infrastructure, where coordination is required between international research activities, planning of the Federal Institutes of Technology (FIT) and coordination of cost-intensive domains in higher education as defined by the Higher Education Act (HedA).

The RIPA mentions explicitly RIs and their funding at other places:

- Art. 10, lit. 3 allows the SNSF to support research infrastructures, which are at the service of the development of scientific domains in Switzerland.
- Art. 11, lit. 6 foresees that Swiss Scientific Academies can support data collections, documentation systems, scientific journals and editions, which have a function as research infrastructures in specific domains.
- Art. 15, lit 3. foresees that the Confederation can support non-commercial RIs outside higher education institutions, and specifically scientific and support services in the domain of scientific and technical information and documentation. The focus of this support is on RIs (and other institutions) performing tasks of national importance, which cannot be fulfilled by other actors such as HEIs.
- Art. 28, lit. 2. allows the Confederation to support the Swiss participation in international RIs.

The RIPA ordonnance provides in its Art. 55 a detailed description of the planning process for RIs, which foresees that the State Secretariat for Education, Research, and Innovation (SERI) establishes a period report on the development of RIs, with a special focus on large international RIs with Swiss participation. The planning process should take into account international treaties, European developments in the domain of RIs, the priorities of scientific domains and disciplines, as well as the development plans of the FIT sector and higher education. The Swiss Science Council could be consulted and is directly involved in evaluating the RIs funded through Art. 15 RIPA.

While there is no explicit definition of RIs in these legal documents, some implicit content can be inferred. First, there is a notion that RIs are tools or entities which have a national significance and therefore require coordination at the Swiss level; this applies particularly to cases where costs are particularly high. Second, coordination with European and international initiatives is central to the RI planning and development in Switzerland. Third, RIs should serve the development of scientific disciplines and domains, and hence it is recognised that most HEIs are domain-specific. Fourth, the RIPA explicitly mentions some categories of RIs, including data collection, documentation and information systems and scholarly publications. As discussed earlier, in this report, these all belong to ‘new’ RIs related to digitalisation and open data.

4.2 RI definitions in the Swiss roadmap and ERI dispatch

The guidelines for the Swiss RI roadmap 2023, currently in preparation, do not provide their own definition of RIs but refer to the definition given in the Horizon 2020 programme[1] (see above in section 3.1).

The guidelines further specify four main criteria for evaluation:

- *Scientific added value*. The RI has the potential to contribute significantly to the development of a scientific and research domain.
- *National significance*. The RI has the potential for a significant usage by the Swiss research community.
- *Access*. Access for national and international researchers is provided.
- *Location*. The RI can be either located at a single place or in multiple places, but with a central management.

The 2019 roadmap[2] also refers generically to a 'European definition' and includes the four criteria above plus the criterion that an RI does not primarily perform research on its own but is open for researchers to execute their own projects. Additionally, three criteria for inclusion in the roadmap are added, i.e., the RI should be either new or substantially upgraded, the maturity level should be very advanced, and total costs for the period 2021−2024 should exceed 5 million CHF.

Finally, the ERI dispatch 2021−2024 provides some definition of RIs at two places[3]. When speaking of national RIs funded through Art. 15 RIPA, the dispatch states that these are an important basis for the development of research in specific scientific domains, as these collect and make available complex data and provide services to research, the public and the private sector. Further, the dispatch highlights the importance of digitalisation and, accordingly, of digital RIs for research and innovation and reiterates that a condition for support is open access to data. When dealing with international RIs, the dispatch seems to adopt a more traditional definition as laboratories or observatories that provide instruments for scientific research.

To summarise, the Swiss roadmap process does not build on a specific RI definition but generically refers to the broad European definition and few general criteria for inclusion. There is an emphasis on the digital dimension of RIs and a clear understanding that RIs to be included in the roadmap process should reach some minimal scale, even if the threshold defined in the 2019 guidelines is quite small compared with large observatories or instruments at the European level. We also observe some variation in the understanding of the RI concept within these documents.

4.3 The 2019 roadmap

An analysis of the 2019 roadmap provides some more insights into how these definitions and criteria are employed in practice.

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[1] SBFI, Schweizer Roadmap für Infrastrukturen 2023 (im Hinblick auf die BFI-Planung 2025−2028) Zielsetzung, Prozess und Kriterien: ein Leitfaden, 15.04.2021, available at https://www.sbfi.admin.ch/sbfi/de/home/forschung-und-innovation/forschung-und-innovation-in-der-schweiz/uebersicht-forschungsinfrastrukturen.html.

[2] SBFI, Schweizer Roadmap für Forschungsinfrastrukturen im Hinblick auf die BFI-Botschaft 2021–2024, 17.04.2019, available at https://www.sbfi.admin.ch/sbfi/de/home/forschung-und-innovation/forschung-und-innovation-in-der-schweiz/uebersicht-forschungsinfrastrukturen.html.

[3] Bundesrat, Botschaft zur Förderung von Bildung, Forschung und Innovation in den Jahren 2021–2024, 26.02.2020, available at https://www.sbfi.admin.ch/sbfi/de/home/bfi-politik/bfi-2021-2024.html.

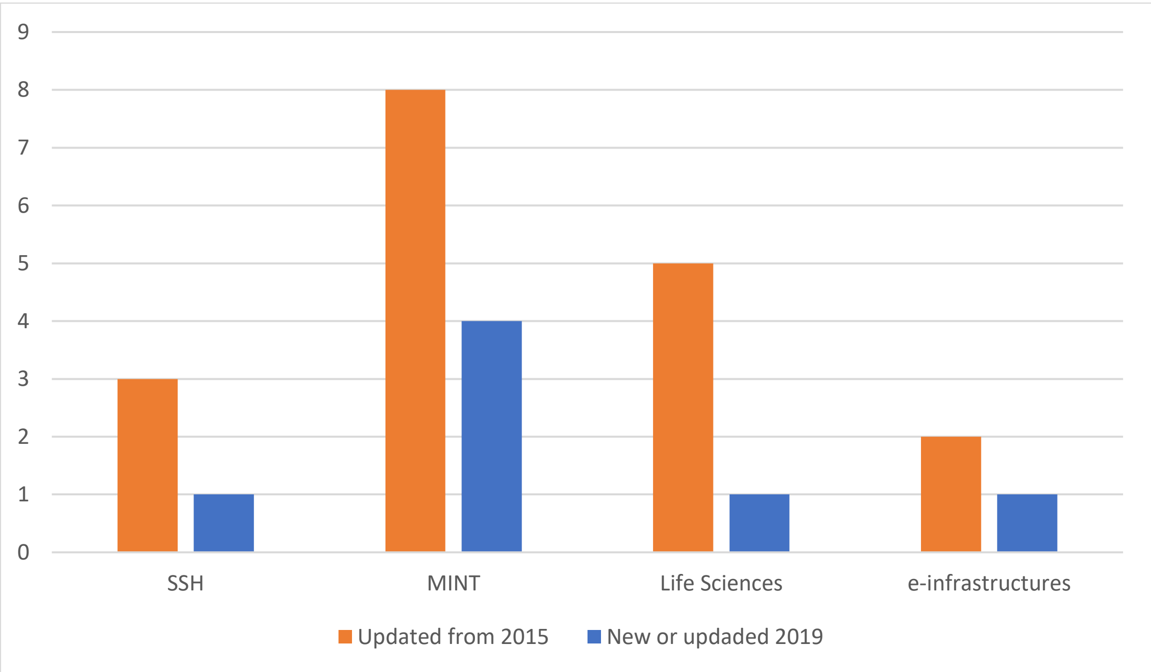
Structurally, the roadmaps are not organised by scientific fields, as ESFRI or most roadmaps in other countries, but by funding responsibilities. Therefore, the roadmap deals in a separate chapter with RIs supported through the different provisions of RIPA:

- RIs funded based on Art. 41 RIPA through the domain of Federal Institutes of Technology or the cantonal universities.
- RIs funded by SNSF and by the scientific academies.
- Swiss participation in international RIs either included in ESFRI or established through international treaties.
- National RIS funded through Art. 15 RIPA that are of national importance and cannot be managed through other research institutes and HEIs.

From a reading of the roadmap, it is fairly clear that RIs in each category are selected based on different criteria, i.e., the need for national coordination and size for the first category, support to scientific research through instrumentation and data services for SNSF and academies; the added value of Swiss participation for ESFRI RIs; and, finally, national importance for Art. 15 RIs.

Moreover, we observe differences in the type of RIs and their disciplinary orientation. The first category is dominated by natural sciences (4 out of 7 new RIs), while the largest initiative in financial terms is the high-performance computing and networking infrastructure project; the presence of Social Sciences and Humanities (SSH) RIs is quite limited. This applies also to the RIs already included in the 2015 roadmap (see Figure 4).

Figure 4. RIs in the Swiss roadmap



On the contrary, support by the Swiss National Science Foundation (SNSF) and academies have a different focus. Besides a programme for small RIs within universities (R'EQUIP), SNSF support essentially data services in SSH, such as FORS and DASCH, as well as in medical and life sciences, such as Clinical Cohorts and the Swiss Biobank Platform. The academies support editions in SSH, collections in natural sciences and a large initiative in clinical data, i.e., the Swiss Personalized Health Network.

A cursory look at the listed infrastructure shows the same kind of heterogeneity as observed internationally, as the roadmap includes observatories and instruments, but also distributed infrastructures and research networks involving the sharing of existing infrastructures, as well as parts of the informatics network and authentication services of Swiss higher education.

The main distinguishing character of the Swiss roadmap, as compared with ESFRI and other roadmaps abroad, is to be directly associated with specific funding streams – i.e., being more a collection of different roadmaps of the project that can be funded by different actors and streams than the attempt to identify, first, those RIs that are of strategic importance for Swiss research overall. This also implies that the nature of RIs and the criteria for inclusion differ by actor and funding stream.

4.4 SNF, academies, swissuniversities

The SNSF is in charge of the scientific evaluation of national RIs to be included in the roadmap, which is submitted through a call for proposals. It builds on the same definition as the roadmap, but provides a more specific delineation by stating that "RIs are *facilities, resources and services*, including major scientific equipment (or sets of instruments), knowledge-based resources such as collections, archives and scientific data and e-infrastructures, such as data and computing systems and communication networks."[4] It adopts the same criteria as in the roadmap 2023, but adding an emphasis to RIs driving "fundamental research and technological innovations**"** and "developing specialised fields and/or open new scientific frontiers" that is coherent with the main SNSF mandate of promoting excellent science.

swissuniversities is in charge of the evaluation of the RIs to be funded through the higher education act (HEdA, Art. 47, lit 3.). These RIs are subject to three additional criteria already specified in the roadmap, i.e., national coordination in a high-cost domain, costs for the funding period 2025−2028 exceeding ten million CHF and inclusion in the higher education strategic coordination. Accordingly, the (implicit) understanding of RIs focuses more on institutional coordination than on scientific missions.

Finally, the Swiss Academy of Natural Sciences (SCNAT) was involved in the process by establishing sectoral roadmaps in specific scientific domains; these roadmaps have been mandated by the State Secretariat for Education and Research as a contribution to the national roadmap, even if the connection between the two processes is not very explicit.

Interestingly, the SCNAT website speaks explicitly of 'large' RIs[5], even if some of the sectoral roadmaps, such as the astronomy one, also endorse support for 'medium-size' RIs. The seven disciplinary roadmaps in natural sciences do not provide a formal definition of RIs in their field but build catalogues that also allow the understanding of the implicit definition adopted in the field. All of them have in common a strong link between leading science questions and RI needs, i.e., emphasising the scientific added value as the key criterion for inclusion in the roadmaps. Most of them also share a broad perspective on RIs, including also instruments that allow the use of international RIs (such as detectors) and a general focus on the need for computing and data infrastructure. The type of infrastructure differs widely between domains and broadly matches the categories identified in the literature analysis. These roadmaps, therefore, provide a broader characterisation of RIs as a scientific field; most of them also provide recommendations for funding but do not explicitly prioritise RIs in terms of their inclusion in a funding list.

[4] SNSF, Factsheet on the Swiss National Roadmap for Research Infrastructures 2023 for national projects, 2022, available at https://www.snf.ch/en/fvnejfErYvg7ShsD/funding/infrastructures/roadmap.

[5] SCNAT, Welche Grossanlagen braucht die Schweizer Forschung?, 2019, available at https://scnat.ch/de/for_a_solid_science/networks_and_infrastructures/research_infrastructures/uuid/i/ad5186af-09b8-59aa-b014-64526723cf7c-Welche_Grossanlagen_braucht_die_Schweizer_Forschung

While no similar roadmaps exist in social sciences and humanities, a position paper was published in 2022 by a group of representatives of RIs in SSH[6] that sheds some light on the understanding of RIs in SSH. The paper focuses on the digital dimension and mentions research outputs such as collections and editions, as well as digital data infrastructure and, in general, open data services, such as the European Open Science Cloud (EOSC) initiative.

To summarise, while not providing different definitions of RIs, other actors involved in the process specify the generic definition based on their role and key objectives, such as promoting excellent science (SNSF) and fostering coordination in higher education (swissuniversities). As for disciplinary communities, their understanding of RIs is largely domain-specific and reflects their own research needs; the selection of RIs is more driven by leading scientific questions rather than formal criteria.

4.5 Comparing definitions and criteria

Against the goal of this mandate to analyse and compare RI definitions in Swiss research policy with those abroad, our finding is that none of the documents dealing with Swiss RIs provides an explicit definition of RIs; the 'European' definition is generically referred to but is not made explicit nor discussed in terms of its content. While, as shown in our literature review, no definition of RIs will be fully coherent and, at the same time, operational, the lack of engagement with the concept represents in our view a weakness of the process, as it does not allow to make the different actors' positions and interests explicit.

Further, the legal basis for federal support of RIs is fragmented and obeys different rationales and slightly different definitions; noticeably, these are related to the different actors and to their mandate in Swiss Research Policy (such as in the case of SNSF) rather than to an overall policy of supporting RIs. As in the European landscape, we also highlighted the coexistence between a 'traditional' model of RIs as large facilities and instruments and the emphasis on digital sciences and their specific needs for data services and platforms.

In terms of criteria, those mentioned by Swiss documents are largely the same as found in other countries, such as open access, scientific added value, scale, and internationality; it seems however that criteria of social and economic relevance are less prominent than in some other countries; RIs in Switzerland are (still) strongly associated with scientific added value and disciplinary cultures. Expectedly because of the lack of a definition layer, individual actors include their weighting of the criteria (based on their missing and/or interest) directly within the roadmapping process, such as the SNSF (emphasising scientific added value) and swissuniversities (need for national coordination and minimal scale).

Finally, our analysis highlighted the composite nature of the Swiss roadmap process, which is composed of different and largely independent subprocesses (in terms of prioritisation and funding) and the fact that, unlike ESFRI, the Swiss roadmap is not a labelling process of RIs, which could be funded by different sources, but it is rather a direct financial prioritisation process. The sectoral roadmaps prepared by SCNAT provide a broader perspective, which is less directly associated with funding; however, these are currently limited to some domains in natural sciences.

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[6] Position paper: Social sciences and humanities research infrastructures in Switzerland, 24.08.2022, available on the FORS website, https://www.google.com/search?client=firefox-b-d&q=Position+paper%3A+Social+sciences+and+humanities+research+infrastructures+in+Switzerland.

5 Conclusions and recommendations

We summarise our main findings, as well as a few remarks on the Swiss roadmapping process, as follows.

Firstly, the research infrastructure concept is by its nature composite and complex – given large differences in how research is performed by scholarly communities and in its relationships to society that also translate into differences in the kind of 'infrastructure' these communities need, in terms of their physical and geographical characteristics, as well as how these can be managed and funded. Accordingly, an RI definition must be flexible and open to accommodate such differences, the definition adopted by ESFRI being a good example in that respect.

Nevertheless, we also found out that there are a few elements, which belong to the (semantic and pragmatic) core of an acceptable RI definition; in our view these are:

- The reference to a research community managing the RI and willing to use it by sharing facilities and tools; such a community might also include private actors as well as social actors in some domains.
- The notion of interinstitutional coordination and scale. RIs might not be unique but have to be shared across a large enough community to justify their existence; scale is therefore defined more by the size of the potential user community than by costs, as the latter strongly vary by field.
- The notion of open or conditional access to all researchers in a field. While access might be subject to some rules or contributions by the user, RIs belong to the public domain and are not managed based on private interest.
- The fact that in RIs what is shared is some kind of 'material' entity including tools, instruments, data, and software codes that enable research; forms of collaborations where researchers work together without sharing any 'material' entities, such as research networks, are not RIs.

Secondly, it is important to distinguish between a broad scholarly definition of RIs and the process through which RIs become labelled and, eventually, funded by specific channels, including dedicated RI funding. As presented in this report, this is essentially a process of political prioritisation, which is driven by strategic considerations, the engagement of specific actors, including subject communities, and financial considerations.

Our analysis suggests that this process should comprise three connected steps (managed by different actors), i.e.:

- The broad identification of those RIs needed in a specific field, as related to scholarly (or policy) questions and to long-term research programmes.
- The labelling of RIs as fulfilling the basic criteria for RI funding and their level of priority in terms of funding.
- Funding decisions by different funders, notably the European Union, countries, and research institutions.

Third, when compared with the RI literature and with practices abroad, the current Swiss RI process shares many characteristics, such as the broad definition of RIs, the establishment of specific roadmaps for specific fields, and a distributed and multi-actor process of prioritisation.

However, Switzerland stands out for two peculiarities, i.e., the lack of direct engagement with the RI definition and the close connection between roadmapping and funding decisions.

On the first peculiarity, we have found out that the Swiss RI process simply refers to a 'European' definition of RIs without engaging directly with it. At the same time, 'implicit' (and somewhat incoherent) definitional elements can be found in legal texts (such as the RIPA), official documents and actors' statements. We suggest that a more open and explicit debate on the RI definition would be important: while it cannot be expected that this would lead to a precise and clear-cut RI definition, it would help in understanding the different dimensions (such as physical vs. virtual, differences in scale and scope, differences between fields) and articulating the discourses and interests of different actors more openly. This debate could take place in the first phase of the roadmapping process and would benefit from the explicit identification of RIs (and their prioritisation) as a constitutive part of the Swiss research policy process.

On the second one, we found out that, unlike ESFRI and most roadmaps in other countries, the Swiss RI roadmap is a funding roadmap, in the sense that it directly identifies the way (and extent) individual RIs will be funded. This setting has some advantages as it allows translating directly the inclusion in the roadmap into funding decisions. However, it does not allow for long-term strategic planning: some RIs might still be in the planning phase and, therefore, not require large amounts of funding currently, but still benefit from an explicit label to acquire preparatory funds, as it happens with some RIs included in the ESFRI roadmap. Moreover, RIs in Switzerland can be funded through different streams: this is a useful feature, as it allows accounting for the diversity of RIs and their financial needs; however, organising the roadmapping exercise by funding streams leads to fragmentation and coordination issues.

We therefore strongly suggest separating the labelling aspects – i.e., defining and identifying RIs of (potential) national importance – from the competence and funding aspects, i.e., which actor is responsible for managing and funding RIs. This would generate a similar model as at the European level, where ESFRI is responsible for roadmapping and labelling, while funding is provided by the European Union and individual countries through their regular funding instruments (including specific instruments dedicated to RIs' funding). The roadmap would therefore require a specific organisational setting, which is distinct and independent from funding responsibilities, while the latter could be dealt with within the prioritising process of funding programmes and consolidated into the ERI dispatch as it is now.

Finally, since RIs identification is, by and large, subject-specific, we consider that sectoral roadmaps are a convenient way to start the process and to reach a first level of prioritisation by the communities themselves inside smaller domains. In this sense, the existing roadmaps mandated by SERI to SCNAT represent an important and useful contribution to the process. We therefore suggest that this approach is progressively extended to all domains, where the respective community is able and willing to invest in such a process. One could think of proceeding in batches, mandating a few additional roadmaps per planning cycle, and updating the existing ones. Of course, in some fields, the delimitation of domains could be difficult and not always be based on disciplinary borders, and some sectoral roadmaps might focus on specific types of RIs and/or need to also involve actors from the economy and society.

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