

Research Infrastructures in Europe: The Hype and the Field

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Research Infrastructures (RIs) are tools for scientific research that have received increased attention in science policy in Europe in recent years, including the launch of specific governance bodies and a structured process of prioritization and organization of RI projects in the making. But there is no commonly accepted definition of what RIs are, and the category is both very varied and lacks historical roots. This article provides a historical contextualization of this policy area and discusses, in some detail, different ways of categorizing the 60 RIs identified by EU-level governance bodies as strategically important for Europe as a whole. Showing that the concept of RIs is a political construct with little analytical value for assessing the role and function of RIs in science and innovation systems, the article paves the way for more conceptually and analytically stringent studies of the politics of RIs in Europe.

Introduction

Research Infrastructures (RIs) are resources that enable scientific research or development work. They can be mission-oriented and devoted to single disciplines, or multidisciplinary and open-ended in their use, and they can take a variety of technological shapes and forms including instruments and tools for discovery and experimentation, repositories of data and materials, and vessels for exploration. In recent years, RIs have attracted increased policy attention, most notably on the level of European Union (EU) innovation and economic growth policy. RIs have been declared a ‘pillar’ of the Europe 2020 strategy and ‘engines’ that shall drive the research- and innovation-based growth of the EU economy (European Commission 2008). In 2002 a special EU counsellor body was formed, the *European Strategy Forum for Research Infrastructures* (ESFRI), and in 2008 the European Commission also invented a new organizational form – the *European*

Research Infrastructure Consortium (ERIC). Several European countries have made similar, but national, policymaking efforts to strengthen their domestic RIs.

This political hype around RIs has, however, not been matched by any comprehensive definitional or categorization work – the term *Research Infrastructures* (RIs) remains very vague and can be used to designate entities as diverse as the gargantuan Large Hadron Collider (LHC) at CERN, where in 2012 the Higgs particle was discovered, and the digital humanities project DARIAH (Digital Research Infrastructure for the Arts and Humanities), which consists of a network, without a central physical site, that allows scholars and organizations to connect and share research material. In the category of RIs there are also icebreaker ships for polar expeditions, fleets of aircraft that enable atmospheric observations for climate research, research reactors for various fusion energy-related technology development, and networks of clinical trial research centres and biotherapy facilities, among many other things.

In this article, we make an effort to bring some analytical and taxonomical clarity to the diverse organizational field of RIs in Europe, and to contextualize the *policy hype* historically. The article has three parts: a historical literature review, a discussion about the workability of the RI concept and what it corresponds to empirically, and an attempt to categorize and identify functions and traits that can help systematize and categorize RIs and contribute to a better understanding of what ‘RIs’ means. While the category of RIs in Europe is potentially enormous, including also RIs of national and local interest, the article delimits itself empirically to the 60 RIs that have been identified and prioritized by ESFRI, and thus listed in one or more of its four consecutive *Roadmap* documents (issued 2006, 2008, 2010, and 2016), and/or been granted ERIC status by the European Commission (as of December 2017).

The aim of the article is thus to demonstrate the complexity of the field of RIs in Europe and discuss what its variety means for the prospects of ‘RIs’ as a workable category in research policy and in studies of research policy. While we suggest some taxonomies and put these to use, the key conclusion is that the 60 RIs in the sample do not constitute an organizational field or a category of any analytical relevance, but that instead the concept has an exclusively political origin and that the 60 RIs have little in common besides having been identified by ESFRI and/or the European Commission as vital to European science. Research into the politics of the underlying processes is therefore urgently needed and encouraged, and this article can hopefully serve as groundwork for such studies.

History of Pan-European RIs

The 60 RIs in the sample used for analysis in this article have all been identified as important in an international context, as well as relevant for the EU to monitor through ESFRI and its *Roadmap* documents. Globally speaking, the sample of course only covers a tiny minority: most RIs around the world are planned, funded,

and operated on national or local levels, also in very small countries. Very large RIs are routinely funded, built and operated nationally, in larger industrialized or newly-industrialized countries (e.g. the United States, France, Germany, Japan, China, the UK). The most expensive RI among the 60 in the sample, the European Spallation Source (ESS) (with an estimated construction cost of €1843 million), is funded jointly by 15 European countries sharing the costs, but its main competitors on the global stage are facilities of similar size and cost that were nationally planned, funded, and built in Japan and the United States.

Therefore, it is clear that the reasons for European collaboration in the area of RIs go beyond the sheer need to share costs. Although the term RIs most certainly was not used in the 1940s, it can be argued that RIs rose to an important status as assets for research and development during the Second World War, when nuclear reactors and particle accelerators were built to produce fissile material for atomic weapons programmes in Nazi Germany and the USA (Hiltzik 2015). Reactors and particle accelerators are a kind of archetypal RIs, very costly and technologically advanced, and they had a special status in the post-war mobilization of science and technology for military-strategic purposes (including weapons R&D) and economic competitiveness, on both sides of the Iron Curtain (Galison and Hevly 1992).

Europe, largely in ruins after the war, began its arduous reconstruction process under the threat of brain drain to, and a looming technological gap with, North America. Western European intergovernmental collaboration in science and technology, under US superintendence, became a natural means of simultaneously catching up, healing wounds, and subsuming Western Germany in institutions and organizations under the control of the three Western World War II victors (Krige 2006). CERN, the European Laboratory of Nuclear Research (originally *Conseil Européen pour la Recherche Nucléaire*), was founded in 1954 and embodied all these ideals (Hermann *et al.* 1987). CERN was a relatively small-scale complement to national nuclear R&D programmes in Europe, and so the motivation for creating an international treaty organization in Geneva was most of all political and symbolic (Krige and Pestre 1992). Later in the same decade, the Joint Research Centre (JRC) was established in Ispra (Italy) with nuclear physics RIs in operation for joint use by European researchers, within the framework of the European Atomic Energy Community (EURATOM) (Papon 2004). The motivation was likewise political, namely to tie up the nuclear R&D resources of European countries (including, crucially, Western Germany) in a peaceful programme that could be in part controlled by the United States (Krige 2008). In the early 1960s, the European Southern Observatory (ESO) was founded as perhaps the first collaborative European RI entirely motivated by scientific ambitions and necessitating collaboration to share the costs: while some of the larger countries in Europe could probably have born the full investment of a major ground-based astronomical observatory, it was agreed that a collaborative European facility would be the most efficient use of funds for the benefit of the whole continent (Krige 2003).

The same decade, the size and cost of accelerators needed to make further advances in particle physics grew to a level where it no longer made sense for large

countries to duplicate efforts. In Europe, CERN embarked on a major upgrade that would keep the organization globally competitive but increase the investments by member states dramatically. An arduous debate ensued, the traces of which are still seen in the policy field of European collaboration in Big Science: faced with dramatic membership-fee increases, most countries hesitated and many placed demands that the new CERN lab be built on their soil, so that they could reap the socio-economic benefits of the investment (Krige 2003). The new lab was eventually housed with the original CERN in Geneva, but it drained the resources from most national particle physics programmes in Europe. Only the United Kingdom and the Federal Republic of Germany kept constructing new and bigger accelerators for particle physics (Hallonsten 2016, 88–89).

Since then, the costliest RIs in Europe have been funded and built through intergovernmental collaborations, but while most of these collaborations have been very successful, they have also all been plagued by the tendency of (prospective) member countries to try to maximize their own profit from collaborating – European scientific collaboration is ‘the pursuit of one’s interests by other means’ (Krige 2003, 900). Processes towards reaching deals for funding, localization and governance are characterized by political horse-trading and secrecy, and, interestingly, because the policy field has been unregulated and left to *ad hoc* solutions, the cycles of European mainstream politics usually influence the decision-making processes, although formally these processes are entirely detached (Hallonsten 2014).

Or not so entirely: while the mainstream political integration process of (Western) Europe through the treaties that founded the European Coal and Steel Community (ECSC) and the European Economic Community (EEC) never included any mandate in science (other than in some applied sciences, such as nuclear R&D within Euratom) (Middlemas 1995, 21–22), efforts to include science and technology policy in the work of the European Communities began in the late 1970s (Grande and Peschke 1999, 45; Papon 2004, 69–70). In the early 1980s, the EEC launched several programmes on the applied R&D side (Sharp 1994), and RIs got some attention in the Second Framework Programme for Research and Technological Development (FP2, 1987–1991), when €30 million was earmarked for facilitating access to RIs for researchers across the continent, thus enabling the scientific communities of smaller countries to use the RIs run by larger ones. In the third and fourth Framework Programmes, the fund was expanded (Papon 2004, 69–70).

Yet the real breakthrough for RIs in EU policymaking came with the launch of the *European Research Area* (ERA) policy in the early 2000s. The early Framework Programmes had been mostly geared to technological development, but in the mid-to late-1990s EU research policy experienced a shift of focus to *innovation*, which meant a broadening in scope (Borrás 2003). The ERA initiative, consequently, was aimed at providing favourable conditions for all steps of the innovation process and all elements of the innovation system (Ulnicane 2015), and the document that launched ERA noted that RIs ‘play a central role in the progress and application of knowledge in Europe’ and that it was now time ‘to go a step further and develop a European approach to infrastructures, covering both the creation of new

installations, the functioning of existing ones and access to them' (European Commission 2000, 10–11).

The practical implementation of the RI policies within ERA began with the launch of the European Strategy Forum on Research Infrastructures (ESFRI) in 2002, an initiative by the European Council and with representatives from all EU member states (appointed by their governments) plus the European Commission. ESFRI is most of all a discussion forum (Papon 2009, 40) but was given the specific task by the Competitiveness Council in November 2004 to develop 'a strategic roadmap for Europe' concerning RIs (ESFRI 2006, 5). This roadmap, issued in 2006 and updated in 2008, 2010 and 2016, contains the result of an EU-wide inventory of new RIs (and upgrades to existing ones) 'of pan-European interest and of scientific excellence' but having 'reached different degrees of maturity' (ESFRI 2006, 10). A total of 58 RIs have been listed in the four roadmap iterations.

Upon request by ESFRI, the Commission also included special funds within the Seventh Framework Programme for the 'preparatory phases' of the 34 RIs listed in the 2006 ESFRI roadmap. Thus, €142.6 million was spent on the preparatory phases of 33 projects, including all except four listed in the 2006 ESFRI roadmap plus the preparatory phases of two projects not listed in the roadmap (CORDIS 2017). This use of funds, and the urging of ESFRI chair Carlo Rizzuto in 2010 that the Eighth Framework Programme (which became Horizon 2020) should spend billions of euros in the same way (Jiménez 2010), was criticized by the director-general of the European XFEL (X-Ray Free-Electron Laser), Massimo Altarelli (2010), who argued that 'it would be better to concentrate this on a few essential facilities, rather than using the money to subsidize the running costs of hundreds of different ones' and also called the ESFRI roadmap an 'impossible wish list' that too weakly mirrors the political reality of RIs in Europe and not sufficiently differentiates between large and small projects, i.e. projects in need of multinational political mobilization and projects small enough to be possible to achieve without it (Springfellow 2016).

In 2008, ESFRI had identified 'a lack of appropriate legal instruments' for setting up European RIs (ESFRI 2008, 9), which it communicated to the European Commission. The viewpoint echoes much of what was discussed above regarding the lack of a policy framework for scientific collaboration, and especially Big Science, in Europe (Papon 2004; Krige 2003; Hallonsten 2014). In response, the commission presented a proposal for a new legal framework for *ERIC* (*European Research Infrastructure Consortium*), which was approved and confirmed in amended version by the European Council in 2009, whereby this entirely new organizational construct saw the light of day (European Council 2009). In 2011 and 2012, two databases in the area of health and linguistics were granted ERIC status by the commission after the mandatory application procedure, and in 2013–2019, an additional eighteen RIs have received ERIC status (Moskovko *et al.* 2019).

In conclusion, a large amount of European Union policymaking, committee work, and also funding, has gone into strengthening RIs, which thus can be identified as a category denoting an organizational field apparently in need of strong political backing from the European Union, and with strong strategic importance for the

achievement of the goals set forth in the ERA strategy (Ulnicane 2015; Chou 2014; Ryan 2015). It is fair to conclude that there is a policy *hype* around RIs on EU level. But the term and category itself, and the organizational field it denotes, have only been rudimentarily defined, if at all, and it is still both very varied and imprecise.

The Field

The group of 60 RIs listed in one or several ESFRI roadmaps and/or granted ERIC status by the European Commission should, presumably, fit the definition of an organizational field as launched by DiMaggio and Powell, namely a set of ‘organizations that, in the aggregate, constitute a recognized area of institutional life’ (DiMaggio and Powell 1983, 148). EU policymaking is, arguably, one of the most palpable examples available of ‘a recognized area of institutional life’, and the 60 RIs in the sample all have in common that they have been highlighted by ESFRI and/or the European Commission as ‘of pan-European interest and of scientific excellence’ (ESFRI 2006, 10). But DiMaggio and Powell also stipulate that ‘the structure of an organizational field cannot be determined a priori but must be defined on the basis of empirical investigation’ (DiMaggio and Powell 1983, 148). When approaching the sample of 60 RIs thusly, several things emerge to suggest that the organizational field is not very clearly demarcated or defined. First of all, it is unclear where the term ‘research infrastructures’ comes from. It is of course intuitively clear and concise. The *Oxford English Dictionary* defines ‘infrastructure’ as ‘the basic physical and organizational structures and facilities [...] needed for the operation of a society or enterprise’. This would mean that a ‘research infrastructure’ simply is a resource utilized to do research, which, however, does not point in the direction of a specific organizational field.

The 2010 ESFRI roadmap provides a 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 2010, 7, emphasis added). Clearly, the definition is political rather than analytical. First of all, hardly any of the RIs of the roadmaps are ‘unique’, given that most of them have direct competitors in, for example, the United States and Japan, and across Europe. Second, the definition makes clear that a political process of prioritization lies behind the ESFRI list, rather than an evaluation of performance or potential according to specific criteria or functions, sizes, or reaches in use, of RIs. Examples are also given by ESFRI to add clarity. RIs are ‘major equipment or sets of instruments, in addition to knowledge-containing resources such as collections, archives and data banks’ (ESFRI 2010, 7). But unless ‘equipment’ is very widely interpreted, as covering also observatories and vessels, for instance for polar exploration, these examples do not cover the full range of RIs listed in the roadmaps, which is a very varied category, as the next section will reveal in greater detail.

In some of the key works in the history of twentieth-century science in Europe, the term ‘research infrastructure’ is either completely absent or used in a much broader,

descriptive sense (Hermann *et al.* 1987, 1990; Galison and Hevly 1992; Capshew and Rader 1992; Krige 1996, 2003, 2008; Krige and Guzzetti 1997; Misa and Schot 2005). The first use of the term in the academic literature to denote a category of resources for scientific research of interest to a pan-European community is probably by Papon (2004). The concept has become more frequently used in recent work in research policy studies and research evaluation studies (Lozano *et al.* 2014; Deák and Szabó 2016; Del Bo 2016; Qiao *et al.* 2016; Larsson *et al.* 2018), and in particular RIs for the social sciences have been the topic of some major works (Kleiner *et al.* 2013; Duşa *et al.* 2014). However, none of these provide any definitions other than citing those of policymaking bodies such as ESFRI (above) or similar non-scholarly origins. Papon's historical exposé shows that Big Science or 'megascience' are much more relevant categories (and these do not overlap completely with RIs, see below) and that RIs started to encompass, for example, distributed resources and services in the 1990s, most notably with the 'access to research infrastructures' programme within the Fifth Framework Programme (FP5, 1999–2000) where 'medium-size facilities, data banks, museums, and industrial facilities with a European dimension' were included in the category of RIs (Papon 2004, 69–70).

A significantly more popular concept in the history and sociology of science is *Big Science*, and it should overlap (in part) with RIs given that the most physically imposing (and expensive) RIs, accelerators and reactors, are also archetypal examples of Big Science (Galison and Hevly 1992; Hallonsten 2016). But a closer look at the sample of 60 RIs yields that these categories overlap only in small part. First of all, many RIs are not very big: while some of the RIs in the sample cost over a billion euros to build, the list also contains several projects with an investment cost of less than a tenth of this, and operations costs that are dwarfed by most universities and corporate R&D labs. Second, some things that have been convincingly designated Big Science in scholarly studies are not RIs, such as the *Human Genome Project* (HGP) which was a project that made use of RI (advanced and costly instrumentation) (Kevles 1997), the large corporate R&D divisions of the 1970s (Hounshell 1992), or the nineteenth-century naturalist explorer missions to Latin America (Knight 1977).

Returning to the concept of organizational fields, it can be noted that 'RI' does not point to a specific type of organization. The sample of 60 contains resources that are hosted and run by organizations of almost any kind: universities, governmental agencies, associations, limited liability companies, ERIC, and in rare cases international treaty organizations. Some of these have been structured and created to launch and operate a particular RI, but some RIs in the sample are hosted by organizations set up and operating with different and/or broader mandates, such as the ELIXIR (nowadays called EMBL-EBI), which is part of the European Molecular Biology Laboratory (EMBL), an international treaty organization founded in 1973 (Krige 2003). Moreover, some of the 60 RIs in the sample studied here may, with time, develop organizational ambiguity: The *European XFEL* and the *European Spallation Source* (ESS) are big facilities operated by big organizations (one German limited liability company with the member countries as shareholders,

and one ERIC with 16 members, to date). Many such big organizations have historically been launched with the purpose of building and operating specific RIs, but outlived their original missions and purposes and developed new RIs, sometimes with new uses, and thus remained in place for several decades, occasionally even retaining the name of the original RI as the name on the organization (Hallonsten and Heinze 2012, 2016).

Doubts can therefore rightly be raised whether the 60 RIs in the sample really constitute an organizational field. Although, as argued above, they quite clearly ‘constitute a recognized area of institutional life’ (DiMaggio and Powell 1983, 148), they are not primarily defined by being organizations. Accepting, for the moment, that we are dealing with a field of entities (although not organizational), what seems to remain, again, is an empirical investigation to determine what kind of a field the 60 RIs make up, and how it can be better understood.

Taxonomies

Looking closer at the information available in the ESFRI roadmaps and the ERIC website, there are a number of ways that the 60 RIs in the sample can be categorized and differentiated as a step towards a better understanding of the field. The scope and length of a journal article does not permit a deeper categorization with notice taken of each and every RI and what it is and does – in the following, therefore, some generalizations are necessary and many of the specific RIs in the sample go unmentioned. First of all, it must be noted that the 60 RIs vary greatly in estimated investment costs – from €9 million to €1.1 billion in the 2006 roadmap, and from €1.5 million to €1.8 billion in the 2016 roadmap. Consequently, one should expect a considerable variety in the sample on most accounts: sizes, time frames, scientific areas served, technological complexity, heterogeneity and size of user communities, and so on.

To our knowledge, the categorization by Xu *et al.*, proposing three main types of RIs – ‘dedicated’, ‘public experimental’ and ‘public interest’ RIs – is the only available scholarly work that systematizes and defines different types of RIs under that headline (Xu *et al.* 2017). We will therefore return to it at various points in the discussion below, and thus assess the validity and workability of these three categories.

To begin with, ESFRI notes three types of RIs in the roadmaps – ‘single-sited’, ‘distributed’ and ‘virtual’ (ESFRI 2006, 16; ESFRI 2010, 7), which refers only to physical location (or lack thereof, in the case of virtual RIs), but this is not much use here since none of the four roadmap documents explicitly identifies the listed RIs as any of these. Separating single-sited RIs from the distributed or virtual is a relatively simple task, whereas the difference between distributed and virtual is unclear and not explicated in any of the roadmaps. For the purposes of this article, therefore, as a start, we will instead separate single-sited and multiple-sited RIs.

Table 1. Cross-tabulation of single-sited/multiple-sited and single-purpose/multi-purpose pairs, and counts of RIs from the sample in each quadrant.

		Purpose	
		Single	Multiple
Site	Single	11	10
	Multiple	18	21

Table 2. The 60 RIs sorted according to ESFRI working groups and scientific categories.

	2006	2008	2010	2016
Social Sciences and Humanities	6	5	2	
Social and Cultural Innovation				1
Environmental Sciences	7	10 (3)	9	
Environment				6 (2)
Energy	3	4	6 (3)	4
Biomedical and Life Sciences	6			
Biological and Medical Sciences		10 (4)	13 (3)	
Health and Food				8 (1)
Material Sciences	7			
Materials and Analytical Facilities		6 (1)	3	
Astronomy, Astrophysics, Nuclear and Particle Physics	5			
Physical Sciences and Engineering		8 (1)	5	3 (2)
Computer and Data Treatment	1			
e-Infrastructures		1		

Note: Categories change names between reports but correspond and are thusly grouped in the table. Numbers in parentheses denote newly added RIs in the respective roadmaps.

Another straightforward and simple categorization is to separate those RIs that are built and operated for a single scientific purpose (such as particle physics or astronomy) from those built and operated for a broader set of scientific uses. Cross-tabulating single-sited and multiple-sited with single-purpose and multiple-purpose renders four types of RIs. The result is shown in Table 1, where also the 60 RIs in the sample are categorized and the number of RIs in each quadrant noted.

This classification, of course, says little about which scientific areas the RIs serve. All the four ESFRI roadmaps are structured according to chapters or sections where RIs are grouped together in different areas, corresponding to the working groups that have made the prioritization and worked to compile the roadmaps. Table 2 shows these, and the number of RIs in each area, in each roadmap report. The distribution over the areas is rather even. The areas give a rough indication of the scientific areas served by the RIs, although of course the categories are very broad: in 2016, for example, the *Materials and Analytical Facilities* category has been merged into the *Physical Sciences and Engineering* category, which means that the latter spans a

great compass: astronomical observatories, nuclear and particle physics labs, and synchrotron radiation facilities, whose user communities in no small part are made up of non-physicists and non-engineers (e.g. biologists, chemists, environmental scientists).

Looking instead at the *functions* of the RIs, another categorization is possible. In the sample are four different types of RIs. First, there are those made up of technological systems or setups that are used in experimentation or measurement and hence can be classified as *instruments*. Among them are synchrotron radiation facilities and high-performing computer resources, but also structural biology labs and laser equipment for energy research. Second, there are those that are made up of technologies for studying real-world phenomena, these can be named *observatories* and consist not only of astronomical observatories but also, for example, seafloor or atmosphere observation and measurement technology. Third, there are databases, biobanks and the like, i.e. collections of material or data that can be used in research, these can be classified as *repositories*. Fourth, there are icebreaker ships and aircraft that enable research work at remote locations (polar regions) or in the atmosphere/stratosphere; these can be named *vessels*.

These four functional types are shown in Table 3, cross-tabulated with the ESFRI categories (from Table 2). It should be noted that categories change, and some RIs appear in several roadmap reports, sometimes even in different categories, so some have been merged to improve readability. This also means that the numbers in Table 3 do not exactly add up, but nevertheless give a general impression of how the categorizations correlate. Table 4 contains the same cross-tabulation as Table 1, but with the distribution in the four functional types in each. In Table 5, the ESFRI functional types are cross-tabulated with the four categories from Table 1 (single-sited/multiple-sited and single-purpose/multiple-purpose).

Some patterns are discernible. Among the four quadrants of Table 1, the single-sited and single-purpose RIs is the simplest: all are either instruments or observatories, and all fall either in the category *Energy* or *Astronomy, Astrophysics, Nuclear and Particle Physics* or *Physical Sciences and Engineering*. Unsurprisingly, these single-sited and single-purpose RIs are also quite homogeneous when it comes to what they actually do and how: the 11 RIs are either particle accelerators, reactors, observatories, or neutrino observatories (consisting of huge water tanks below the ground). These 11 RIs also correspond very well to the category ‘dedicated’ RIs as proposed by Xu *et al.* (2017, 399), which they describe as single-sited and single-purpose and exemplify with particle physics facilities and astronomical telescopes.

The group of ten single-sited and multiple-purpose RIs (Table 1) is more heterogeneous but still dominated by instruments and by the materials science category. This means that it partly corresponds to the ‘public experimental’ RIs category proposed by Xu *et al.* (2017, 399) and defined as ‘platforms for multidisciplinary and interdisciplinary research and support for various kinds of studies’ – this is true for all of the ten single-sited and multiple-purpose RIs, not only the five materials science user facilities (neutron, synchrotron radiation, and laser facilities) but also

Table 3. Cross-tabulation of ESFRI categories and RI functional types.

	Instrument	Observatory	Repository	Vessel
Materials Sciences (2006), Materials and Analytical Facilities (2008, 2010) or Physical Sciences and Engineering (2008, 2010), Physical Sciences and Engineering (2016)	8	0	0	0
Energy (2006, 2008, 2010, 2016)	6	1	0	0
Biomedical and Life Sciences (2006), Biological and Medical Sciences (2008, 2010), Health and food (2016)	7	2	6	0
Astronomy, Astrophysics, Nuclear and Particle Physics (2006), Physical Sciences and Engineering (2008, 2010, 2016)	3	3	0	0
CDT (2006), e-Infrastructures (2008, 2010), e-RI (2016)	1	0	0	0
Environmental Sciences (2006, 2008, 2010), Environment (2016)	2	9	0	3
Physical Sciences and Engineering (2008, 2010, 2016)	0	3	0	0
Social sciences and humanities (2006, 2008, 2010), Social and Cultural Innovation (2016)	0	0	7	0
Total	27	18	13	3

Table 4. Cross-tabulation of single-sited/multiple-sited and single-purpose/multi-purpose pairs, with numbers of each functional type noted.

		Purpose	
		Single	Multiple
Site	Single	Instrument: 6 Observatory: 5 Repository: 0 Vessel: 0	Instrument: 6 Observatory: 2 Repository: 1 Vessel: 1
	Multiple	Instrument: 6* Observatory: 8* Repository: 4 Vessel: 1	Instrument: 10* Observatory: 4* Repository: 8 Vessel: 1

*Three RIs in the sample are classified as both instrument and observatory.

the others (two observatories, one repository, and one vessel) which are all multidisciplinary and physically centralized resources. It should be noted that one of the single-sited and multiple-purpose RIs is an instrument in the ESFRI category *energy*, and could very well have been branded single-purpose since it is primarily built and operated to support R&D efforts in nuclear fusion research, but it has a number of auxiliary uses in several sciences which means that it is multiple-purpose. The remaining four facilities in this group are one icebreaker ship for polar expeditions, supporting multidisciplinary environmental sciences (in principle single-sited although mobile); the upgrade of the EISCAT facility for multidisciplinary ionospheric and space weather research; the upgrade of the ELIXIR databank that collects, stores and makes available biological data from all over the world; and the upgrade of SIAEOS (later SIOS), an arctic earth observatory for multidisciplinary environmental sciences.

When it comes to the multiple-site RIs (both bottom quadrants in Tables 1 and 4), the complexity is greater and the exceptions many. First of all, it can be concluded that these 39 RIs are not all what Xu *et al.* (2017, 399) call ‘public interest’ RIs, ‘aiming at providing scientific data and service for the public’. Several of the 39 – for example the European Magnetic Field Laboratory (EMFL), the European Multidisciplinary Seafloor Observation (EMSO), or the Integrated Carbon Observation System (ICOS) – are such that this definition does not particularly apply to them any more than it applies to every one of the 60 RIs in the sample.

Eighteen of these 39 are single purpose, whereof 15 belong to the two ESFRI categories *Biomedical and Life Sciences* (2006)/*Biological and Medical Sciences* (2008, 2010)/*Health & Food* (2016), and *Environmental Sciences* (2006, 2008, 2010)/*Environment* (2010). They range from networks of structural biology labs and centres for clinical trials, over networked marine biology data repositories and biobanks, to tectonic plate observing systems. The remaining three multiple-site, single-purpose RIs are a so-called wind scanner facility and a solar power research facility, both

Table 5. Single-sited/multiple-sited and single-purpose/multi-purpose categories cross-tabulated with functional types.

	Single-sited single-purpose	Single-sited multiple- purpose	Multiple-sited single-purpose	Multiple-sited multiple-purpose
Materials Sciences (2006), Materials and Analytical Facilities (2008, 2010) or Physical Sciences and Engineering (2008, 2010), Physical Sciences and Engineering (2016)	0	5	0	3
Energy (2006, 2008, 2010, 2016)	3	1	2	1
Biomedical and Life Sciences (2006), Biological and Medical Sciences (2008, 2010), Health and Food (2016)	0	1	9	4
Astronomy, Astrophysics, Nuclear and Particle Physics (2006), Physical Sciences and Engineering (2008, 2010, 2016)	5	0	0	0
CDT (2006), e-Infrastructures (2008, 2010), e-RI (2016)	0	0		1
Environmental Sciences (2006, 2008, 2010), Environment (2016)	0	3	5	4
Physical Sciences and Engineering (2008, 2010, 2016)	3	0	1	0
Social sciences and humanities (2006, 2008, 2010), Social and Cultural Innovation (2016)	0	0	0	7

belonging to the category *Energy*, and an array of telescopes for astronomy that belongs to the category *Physical Sciences and Engineering*. In the latter case, the classification multiple-site is of course accurate but the relevance of the taxonomy can be questioned, given that little separates this telescope array, in any other meaning, from the single-sited, single-disciplinary telescopes in the upper left quadrant of Table 2.

Finally, the 21 RIs in the sample that are multiple-sited and multiple-purpose vary even more. Every ESFRI category is represented among the 21 except *Astronomy*, *Astrophysics*, *Nuclear and Particle Physics* and *Physical Sciences and Engineering*. The variation within the group means it makes little sense to go through all 21, but there are two that stand out and demonstrate quite clearly the problem of pinpointing what exactly the multiple-sited and multiple-purpose RIs in the sample have in common. The Central European Research Infrastructure Consortium (CERIC), never part of an ESFRI roadmap but granted ERIC status by the commission in 2014, and the Pan-European Research Infrastructure for Nano-Structures (PRINS), are both collections of instruments for materials sciences, and consist of eight and three facilities, respectively, that all would qualify as single-sited multi-purpose RIs if viewed individually, and that each were (and are) national RIs in their own right.

Just like the telescope array mentioned above, the identification of CERIC and PRINS as multiple-site, multiple-purpose raises objections to the usefulness of the taxonomy. But most of all, these two cases demonstrate very clearly how the concept of RI is very flexible, on the verge of diluted and meaningless, because it is used to denote something that quite evidently is a collection of RIs (at best) or perhaps really a collection of scientific *instruments*. The question remains: what is gained by using the concept RIs?

Concluding Reflections

The final sentences of the last section reveal quite blatantly the problem that this article set out to identify and discuss: there is a policy hype around RIs in Europe but the hype is not matched by any substance on the side of what qualifies as a RI and not, and why.

The section entitled ‘The field’, relying on official ESFRI documentation and secondary literature, did not manage to achieve a definition of RIs that matched the sample of 60. We will have to revert to repeating what other authors have stated: there is ‘no single accepted definition’ of RIs (Larsson et al. 2018; Farago 2014). The problem is, we contend, that while a politically viable definition seems to be either already in place (the ESFRI definition, see the section ‘The field’) or unneeded, an analytically workable definition is out of reach unless the scope is limited and the aim of the definition is made more precise. We build this conclusion on the following main points that reiterate the findings in the preceding sections.

The attempts at categorizing in the previous section led to mixed results: those 11 single-site, single-purpose RIs that were identified as instruments or observatories ('dedicated' RIs in the taxonomy of Xu *et al.* 2017) and that all belong to either the physics or energy research categories of ESFRI are probably best described as 'Big Science' in a rather traditional meaning – in other words, large-scale technical installations serving clearly-defined needs and operated by big teams of scientists and engineers. It is confusing to lump them together with the other 49 and label them all RIs. Analogously, the ten single-site, multiple-purpose RIs are large-scale technical installations with open-ended use in a variety of sciences ('public experimental' RIs in the taxonomy of Xu *et al.* 2017). They can, possibly with the exception of the one vessel and the one repository among them, be rewardingly described as examples of 'transformed Big Science', a concept that was developed on the basis of vast empirical material and significant analytical work (Hallonsten 2016). It is once again doubtful whether it serves any scholarly purpose to group these together with the other 50 RIs. As shown in the second half of the last section, the group of 39 RIs that are multiple-site is varied enough to make it close to impossible to make any sense of, without a case-by-case discussion that surpasses the ambition of this article and has questionable use.

Put differently, the 60 RIs in the sample do not constitute an organizational field, and given the variety in sizes, reach, purposes, and governance structures that they represent, it is reasonable to assume that RIs generally is a category just as amorphous. Also, the 60 RIs in the sample do not constitute a coherent set of resources for science. They represent almost the full breadth of the disciplinary spectrum of contemporary science and reach from the most fundamental topics of investigation (particle physics) all the way up to applied-science observatories and repositories. When it comes to the roles and functions of these 60 RIs in science and society it can therefore be argued that there is as much variety within the field as outside it.

What remains, in other words, is political meaning. We have already demonstrated that the concept of RIs has a political origin and apparent political usefulness, and that it was most likely invented by EU policymakers for political purposes. Why, then, is such a highly politicized category of entities/organizations so ill-defined? Part of the answer probably lies in the fact that decision-makers are unaware of how RIs function and what RIs are, compared with other infrastructures such as roads, bridges, power plants, and so on. But this only reinvigorates the need for further studies of the politics of RIs, on EU and national levels.

Our contribution is critical, in identifying the seeming lack of stringency and substance behind the concept of RIs, but also constructive, in adding nuance and detail by identifying different ways of categorizing and identifying subsets of RIs. As a scholarly contribution, this is arguably additive, but only as one contribution to a greater project of providing insight into the works of politics and the organization of society.

Fortunately, a shift from the category itself and the question of whether or to what degree it corresponds to an organizational field or an analytically useful category, to the political process(es) by which it came into being and then started to be

used, gives rise to many interesting research questions. Why and how did specific RIs become included in the ESFRI roadmaps? Given that size or cost is not the issue (see the second section), what were the criteria? How did the work procedures of creating the roadmap spread to individual countries? Why does a RI choose to apply for ERIC status? Those are but some of the issues that can, and should, be explored in future studies. Such future studies will also yield significant clues to whether the apparent political value of the concept also translates into value for society in the way that has so far been claimed in policymaking: are 'RIs' critical for science, innovation, and the solving of grand challenges? Or would these urgent tasks perhaps be better served by the use of more fine-tuned and/or adequate concepts?

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