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Foreword

Research infrastructures have been a major topic for analysis and discussion since the creation of the OECD Megascience Forum in 1992, which was renamed Global Science Forum (GSF) in 1999 after the broadening of its mandate.

Following publications on "Large Research Infrastructures" (2011), which dealt primarily with policies for the establishment and management of large single site facilities, and on "International Distributed Research Infrastructures" (2014), addressing the challenges associated with a growing type of infrastructures that are distributed geographically, this new report is identifying policies and procedures that can strengthen the sustainability and the effectiveness of the functioning of research infrastructures during their entire life cycle.

As the number and complexity of research infrastructures (RIs) is increasing, managers, funders and research performing organisations have to find solutions that can ensure the long-term operation of their RIs, which represent very important strategic investments in research within rapidly evolving financial and political contexts.

This report presents findings, analyses and conclusions from an OECD GSF Expert Group regarding the challenges faced by research infrastructure funders, managers and operators for the long-term sustainability of these facilities. The objective was not to carry out an exhaustive analysis but rather, based upon an in-depth survey of the various stakeholders, to provide useful information and advice to funders, managers and policymakers who are faced with very practical challenges. This OECD report therefore analyses key issues that were identified all along the various phases of the research infrastructure life-cycle, presents solutions that have been found to be applicable in certain cases, and proposes a series of policy recommendations which could be implemented to increase the sustainability of research infrastructures. We sincerely hope that it will be informative and useful. Naturally, we would be interested in receiving comments from readers. The GSF staff can be reached at gsforum@oecd.org.

This report was co-written by the GSF Expert Group Co-chair Professor Hans Rudolf Ott and the GSF secretariat with extensive input from the Expert Group members.

The Swiss Academies of Arts and Sciences provided support to Co-Chair Hans Rudolf Ott in the form of a science officer (Roger Pfister) who was generously funded through the Swiss State Secretariat for Education, Research and Innovation.

Table of contents

Abstract

Research infrastructures are long-term enterprises. They are increasingly diverse in nature, may operate under very different models of governance and financing, and within diverse and evolving financial and political contexts. They represent strategic investments which are indispensable for enabling and developing research in all scientific domains and also often have broader socio-economic impacts. This report identifies the challenges faced by research infrastructure funders, managers and operators all along the various phases of the research infrastructures life-cycle, presents practical solutions that have been found to be applicable in certain cases, and proposes a series of policy recommendations which could be implemented to increase their effectiveness and sustainability.

Keywords: research infrastructures, effectiveness, sustainability.

Executive summary

Research infrastructures (RIs) are long-term enterprises, often being operational for several decades. They represent long term strategic investments which are indispensable for enabling and developing research in all scientific domains and also often have broader socio-economic impacts. They require careful planning and continuous and stable support, which is not limited to financial considerations.

Developing and maintaining the sustainability and efficiency of research infrastructures is a complex endeavour as they are increasingly diverse in nature, may operate under very different models of governance and financing, and within diverse and evolving financial and political contexts.

As research funders and organisations have to manage increasingly large and complex portfolios of research infrastructures, they have to develop together with RI managements and administrators financing and operating models that can ensure the successful operation of RIs beyond their establishment phase, taking into account the evolving needs of the different scientific communities.

This work was designed to identify policies and procedures that can strengthen the sustainability and the effectiveness of the functioning of RIs during their entire life cycle, and was structured to address two general questions:

- What are the main challenges faced by RI management, their funders and their host and participating institutions to design and operate sustainable RIs all along their life cycle?
- What are the current practices that could be adapted and shared to improve sustainability and efficiency?

The study was overseen by an international Expert Group co-chaired by Professor Hans-Rudolf Ott (ETH Zurich, Switzerland) and Professor Satoru Iguchi (National Astronomical Observatory, Japan). 37 interviews were conducted to gather information from selected individuals covering a large diversity of RI types and disciplines, funding and decision bodies, with a broad geographical distribution. The preliminary results were considered during an international workshop in Geneva, which included scientific users, infrastructure managers, research funders and policy makers.

Challenges to be addressed to ensure the sustainability of RIs

There are various definitions of "sustainability", encompassing different criteria. In this report, the definition of RI sustainability which was adopted is "*the capacity for a research infrastructure to remain operative, effective and competitive over its expected lifetime*".

Effectiveness and sustainability are dependent on a number of elements which are interconnected. The practices and policies which are required to promote them depend upon a variety of factors including the nature of the RI (single-site, distributed…), its role and user base, its membership, its financial arrangement, the national or international funding bodies supporting it, and its host (if any). There is therefore clearly no "one size fits all" sustainability model. However, the numerous reports and experts consulted and interviewed during this study identified a series of common challenges which research managers and funders have to address:

- Maintaining a high level of competitiveness.

  Being and remaining at the cutting edge of science is always a priority for RIs, as they operate in a competitive environment and need to demonstrate their capacity to deliver the quality of scientific output they were developed for. This includes the need to keep pace with developments to provide updated, cutting-edge installations and instrumentation that allow maintaining international scientific competitiveness and performance. It also means ensuring reliability in terms of access and services, and assistance to users, notably regarding technical support and data management.

- Managing data throughout the research infrastructure life time

  RIs produce, store, process and make available increasingly large amounts of data, and this is not just true for "data infrastructures" or "data repositories". They have to respond to larger and more diverse communities of users and acknowledge "open access" policies which are adopted by a large number of countries and institutions. The cost and manpower required to manage these data and make them accessible has often been underestimated by RI promoters and funders and requires advanced planning and organisation as well as adequate resources.

- Setting up and securing funding with long-term commitment based on a solid business case.

  Whatever their nature, RIs are most often long-term enterprises which require adequate, and sometimes very substantial, financial effort. Funding has to be adapted to the RI needs during the various phases of its life cycle. This also means proper cost control and effectiveness for both construction and operation phases, resources streams for upgrades, and proper risk assessment and contingency planning as many unforeseen events may adversely affect RIs during their life-cycle. For many RIs, the transition between the establishment/construction phase and the operation/running phase is especially challenging: new funding streams often need to be secured since initial/traditional funders have to support increasingly large portfolio of RIs. Finding adequate resources for their operation phase was found to be a challenge for many RIs and a real threat to their capacity for medium to long-term strategic planning.

- Attracting and retaining leading scientists and qualified personnel with necessary skills and expertise.

  Although a number of RIs are embedded within existing research organisations, many of them are specific entities with complex institutional arrangements which can make it more difficult to recruit and keep the right staff. Adequate human resources policies (to attract and retain efficient staff as well as ensure good management) can be a particular challenge if the legal status and internal organisation of the RI are not properly tailored.

- Responding to more general strategic objectives of host and member countries, particularly for socio-economic returns.

  While the quality of scientific output is the primary objectives of most RIs, most decision-makers and RI partners also expect additional value from their investments in such important and often expensive undertakings. Socio-economic added value often needs to be demonstrated both when the initial project is developed as well as when the RI is in operation. The role of RIs in training and education as well as local direct economic impact linked to construction and public procurements (for large facilities) is usually well documented but the inherently long-term nature of the transition from research to innovation or to public policies have often created difficulties for RIs to fully assess and communicate on their actual socio-economic impact.

- Planning for the phasing out and termination of the RI.

  Discussing the possible termination of a RI is always a sensitive topic. Although RI managements always strive to update their facilities to maintain state-of-the-art services, the emergence of new and possibly better competitors as well as the need for funders and host institutions to rationalise their portfolio means that some RIs will need to be either re-structured for other uses or closed down and dismantled. For some facilities that harbour specific and sometimes hazardous equipment, dismantling may mobilise significant resources and time, something which appears to be rarely planned in advance. And whatever the RI, data and sometimes physical elements or specimens will have to be preserved and transferred to new homes and the RI staff managed in appropriate ways to avoid losing unique information, knowledge and experience.

Policy recommendations

The following policy recommendations are aimed at science policy makers, research performing institutions, governmental and private funding organisations and agencies at national or regional levels as well as RI planners and administrators, wishing to improve the efficiency and effectiveness of their facilities.

1. A comprehensive business plan should be created early in the development stage of any new RI.

This should be based on a clear business model and describe how science, technical, financial data-management and technology transfer issues will be addressed during the lifetime of the RI. The business plan should also describe the decision-making process for progressing from one stage of RI development to the next and set out financial responsibilities of funders and host during the operational phase.

2. Risk assessment processes and contingency arrangements should be put in place during the early stages of the RI development.

The risk assessment process should outline the steps to be taken to identify, mitigate and manage the risks associated with changing resources, costs, memberships, scientific, technological or political context. The initial risk assessment carried out alongside the science and development cases should be reviewed and revised periodically on a timescale appropriate to the relevant fiscal and financial planning cycle. It should also describe the arrangements for accessing contingency funding which should be developed by funders and RI management.

3. Appropriate data management policies and procedures should be developed and supported by both RI management and funders.

They should respond to the needs for a coherent and user-friendly data access system, for supporting data processing and storage, for conforming with open-access and open-data mandates and policies and for preserving data after termination. They should also foster synergies and links with (cyber) infrastructures whenever applicable to optimise resources and cost and increase data availability.

4. A robust staffing policy should be developed by the governing body and management (and by the host institution of any RI if it is also the RI staff employer).

Such a policy will need to be updated throughout the RI life-cycle and should allow for attracting and retaining scientists (particularly young scientists) and engineers, provide for the training and development of RI staff at all levels and foster the mobility of staff among RIs as well as between academic and private sectors. An “International Mobility Charter” could be developed to facilitate the development of adapted employment conditions.

5. Medium to long-term funding mechanisms should be set up by funders to provide support to RIs during their operational phase.

Various options may be developed for such schemes depending on national contexts, and allocation of such funds should be done on the basis of appropriate scientific, technical and management criteria without being administratively burdensome or complex. Cost recovery from users (“user fees”) should however be considered only when the access mechanism is such that it does not discriminate on the basis of the sole capacity of the user to pay such a fee.

6. Cost optimisation procedures should be co-developed by funders and RI management for an efficient and effective use of resources.

RI management should have a clear understanding of their income streams, cost lines and related outputs, to identify where costs might be reduced without significantly affecting the RI performance. At the same time, funders should provide incentives for RIs to implement cost saving measures that do not affect their effectiveness and funding should be flexible to allow for some re-allocation to priorities or later time periods.

7. RIs should develop appropriate innovation policies and procedures in order to remain at the cutting edge.

RI management should develop their internal development capacity and co-operation with public or private organisations wherever appropriate while funders should provide incentives and support commercialisation and knowledge exchange efforts.

8. RIs should develop appropriate strategies and policies to maximise their socio-economic value.

Although the socio-economic added value is specific to each RI, activities aiming at contributing to understanding and addressing grand challenges, transferring technologies to society, providing knowledge for regulatory purposes or policy decisions or to enhancing public engagement in science can be an important part of their mission. This requires a clear vision of the socio-economic objectives and a regular monitoring and impact assessment, knowledge and technology-transfer policy enabling the RI to optimise the potential use of innovations developed in-house, and a public outreach and communication strategy.

9. Funders and RI governing structures should co-develop appropriate plans for an RI's terminal phase.

These plans should be developed whenever reviewing mechanisms indicate that a particular RI is unlikely to be able to provide a valuable user service in the foreseeable future. They should provide information on the process and possible timing and close down scenario (termination/decommissioning, reuse, transformation…) and should include appropriate data (and/or specimen) archiving and transmission policies as well as staffing transition plans.

Definitions

Business model: abstract representation of an organisation, which includes all core interrelated architectural, co-operational and financial arrangements designed and developed by an organisation (presently and in the future), as well as core products or services the organisation offers or will offer to achieve its strategic goals.

Business plan: Concrete, operational and budgeted translation of the business model. Formal document, which should describe the organisation strategy and vision, how the business model will be implemented, and expectations regarding the development of the organisation’s activities and finances.

Competitiveness: research infrastructure competitiveness is understood as their capacity to become and remain attractive to users vis-à-vis other similar facilities, and therefore includes scientific performances, access policy, added value for users etc.

Life-cycle: The life-cycle of a RI consists of different phases which are each characterised by specific funding and decision-making processes. According to the definition proposed by the G7 Group of Senior Officials on research infrastructures[1], there are five RI life-cycle stages:

1. Conceptual development stage
2. Design stage
3. Implementation stage
4. Operations stage
5. Termination stage

For the sake of simplicity, the first three stages (development, design and implementation) were regrouped into a single phase (pre-operation) in this report.

Research infrastructure: although there is no single definition of a research infrastructure, it is understood in this report as an organisational structure dedicated to deliver data or services for basic or applied research. This report is focused on addressing sustainability and effectiveness of two main types of RIs:

- Single site RIs which are either nationally owned with an internationally-based user groups or international with a correspondingly broad user community
- Distributed RIs composed of geographically distributed (national or internationally owned) facilities which are open to international user groups

Smaller/local or national RIs with a local/national focus were not included in the study.

Sustainability: the definition of RI sustainability, which was adopted for this report, is understood as the capacity for a research infrastructure to remain operative, effective and competitive over its expected lifetime.

1. Introduction

1.1. Rationale

The issue of research infrastructure (RI) sustainability has taken on growing importance in recent years[2]. This is due, among other factors, to the increasing number and diversity of RIs, including not just single-site facilities but also a variety of distributed infrastructures, which operate under very different models of governance and financing. These RIs represent a substantial amount of the total public investment in research (in France for instance, this cost is estimated to about 10%).

A number of major and very successful RIs have been established on the basis of international treaties, which provides some long-term stability. However, this approach has been increasingly questioned by governments and funding agencies due to its lack of flexibility and to the length of the negotiation processes required between planning and implementation. More flexible organisational frameworks which do not include mandated financial commitments are now often preferred but these can have drawbacks (or uncertainties) in terms of medium to long-term financial visibility and security.

The sustainability challenges for RIs go beyond funding. Difficulties in training, recruiting and maintaining key personnel have in several instances been identified as a particular issue. Other common challenges include unexpected events such as extended length of the establishment phase of RIs or requirements for upgrades and/or new operations for existing infrastructures associated with rapid developments in science and technology. The latter can be essential in order for an RI to stay attractive for users. More recently, the exponential growth of data produced, and the need for them to be curated and distributed by RIs has also been identified as an emerging and complex issue to be addressed. Indeed, although longer-term financial sustainability and human resources are often considered as central elements, sustainability and effectiveness are dependent on a number of factors, which are interconnected.

1.2. Background

The Global Science Forum (GSF) has carried out extensive work on RIs over the years. Indeed, facilitating co-operation on large-scale international RIs was the original purpose for the creation of the Megascience Forum, the precursor of the GSF. Two reports on Large Research Infrastructures[3] and on Distributed Research Infrastructures[4] were published in 2011 and 2013, which dealt with the challenges associated with the launching and managing these facilities. This was followed in 2014 by a case study work looking at the impact of CERN infrastructures on economic innovation and on society[5].

The GSF then decided at its 30th meeting in April 2014 to set up a Scoping Group which produced a list of issues related to RIs policy that should be addressed as priorities at the international (global) level. The first topic on this list was the sustainability of RIs. There are various definitions of “sustainability”, encompassing different criteria (see for example the EIROforum discussion paper on long-term sustainability of Research Infrastructures[6]). The need to address the long-term sustainability of RIs had been highlighted previously by many stakeholders, who have focused either on specific topics (typically on cost and financing[7,8]), or specific types of RI (biobanks[9], e-RIs[10]…). The definition of RI sustainability, which was adopted for this report, was understood as **the**

capacity for a research infrastructure to remain operative, effective and competitive over its expected lifetime.

Following the report of the scoping group (DSTI/STP/MS(2015)2), the Global Science Forum authorised an activity on "Strengthening the sustainability and effectiveness of International Research Infrastructures" at its 32nd meeting in April 2015. The objectives of this activity were to identify policies and procedures that can strengthen the sustainability and the effectiveness of the functioning of RIs during their entire life cycle (including their dismantling or potential reuse). The RIs considered are those which are publically funded and which primary objective is to produce data and services for research purposes, with a focus on international RIs or national RIs which have an international user community.

1.3. Methodology

The activity was supervised by an Expert Group (see Appendix 1), co-chaired by Professor Hans Rudolf Ott (ETH Zurich, Switzerland) and Professor Satoru Iguchi (National Astronomical Observatory, Japan), and whose members were nominated by national OECD GSF delegations. Experts from international organisations interested in RI policy were also invited.

The Terms of Reference of the work which were proposed by the Expert Group and approved by the Global Science Forum Bureau, included the definitions and scope of the activity, and the rules for selecting infrastructures for detailed study. Based on an earlier report of the GSF Scoping Group, it was proposed to focus initially on funding models and human resource factors that can help secure the sustainability of RIs during their life cycle. An initial list of topics, to be later completed by feedback from the various stakeholder communities, served as a guideline for framing the work and included issues such as financial/operating models most appropriate for different types of RIs, adapting and combining funding policies (particularly for the operating phase) to allow for good medium to long-term planning, searching for solutions that can help reduce costs for construction, implementation and operation, identifying risk management strategies that can help mitigate unforeseen cost escalation, identifying promising human-resource policies and practices for attracting and retaining the necessary staff, covering the costs for upgrades or defining how to plan for the financial costs and management of human resources and of the accumulated data for the termination phase.

A preliminary fact-finding exercise and discussion was conducted by the Expert Group and the Secretariat to identify the main sustainability issues and criteria. A more in-depth survey was then carried out among a set of representatives of RIs, funding institutions and decision-making structures through interviews with key individuals (typically the RI Manager/Director, Directors or equivalent of funding agencies involved in supporting RIs, and senior research policy officials). The facilities analysed encompassed single site and distributed site RIs; they were national, multinational or global in terms of geographic spread; and they covered a broad variety of scientific disciplines, from medicine to engineering to the social sciences and humanities. These interviews were structured around a set of issues and challenges identified as important for RI sustainability and effectiveness, adapted in function of the different stakeholder groups. The interviews were conducted mainly via skype and telephone by Co-Chair Prof. Ott and the GSF Secretariat during the period February to November 2016. A total of 37 persons were interviewed. The respective questionnaires and the list of individuals interviewed are presented in Appendices 2 and 3. The results from the interviews were summarised in a findings document and made available to the Expert Group for discussion and analysis. Efforts were made to reach a global coverage of feedback.

The Expert Group held several meetings, and the preliminary results from the interviews were also discussed during an international workshop, which took place on 17 May 2016 in Geneva. There were 67 participants, including members of the Expert Group, persons nominated by GSF delegations, invited experts, GSF Delegates and members of the GSF Secretariat, which represented the scientific users, infrastructure managers, research funders and policy maker communities (the list of participants is provided as Appendix 4). The Expert Group's preliminary findings were also presented and discussed during the session organised on the sustainability of RIs at the International Conference on Research Infrastructures (ICRI) held in Cape Town (South Africa) on 3-5 October 2016.

1.4. Report structure

Following the introduction, this report is structured in five different chapters.

Chapters two to five provide findings gathered through the comprehensive information-gathering exercise and an analysis of these findings.

In addition to the information from the literature and that directly provided by the members of the Expert Group, chapter 2 contains a summary of the key elements related to the sustainability and effectiveness of RIs which were obtained from interviews conducted with decision makers and funders of facilities as well as with research facility managers and user group representatives.

Chapters three to five are organised in line with the RI life cycle: pre-operation (conceptual development, design, decision process, implementation), operation and termination. A strict separation is not always possible because necessary actions intended to lend support to sustainability and effectiveness during these periods may influence each other or overlap. These chapters provide additional detailed information obtained from the survey and a variety of additional sources on major challenges identified by the different stakeholders as well as an analysis of various practices and policies that were implemented to address those challenges. However, it should be understood that the international RI landscape is hugely complex with many complicated interactions and relationships and with a huge diversity across RIs in terms of funding models, organisational structures and ongoing support arrangements. The objective is not to provide a complete and detailed picture of the RI landscape but rather to illustrate the key challenges identified by representative examples, and help to identify the broad policy areas where further attention needs to be applied.

Short conclusions with practical relevance are highlighted in italic format and interesting cases are described in boxes in these chapters.

In chapter 6, the document offers policy recommendations that were drawn from the analysis of the findings and good practices, supporting sustainability throughout the whole RI life-cycle alongside a set of major criteria identified earlier.

2. Major elements of research infrastructure sustainability

The initial literature review carried out by the Expert Group underlined how RI sustainability had been an increasing concern over the recent years, and highlighted several of the main challenges faced by today's RIs:

- To maintain a high level of competitiveness (scientific excellence and attractiveness for users)
- Funding policy (robustness, long-term support for operation, resources streams for upgrades…)
- Cost control and effectiveness (for both construction and operation)
- Human resources (to attract and retain efficient staff as well as ensure good management)
- Governance and legal structure (for improving efficiency)

However, information in the literature was very limited with regards to effective practices and policies to address these issues. The Expert Group therefore identified a detailed list of potential issues that required a more in-depth analysis, and which was used to frame the follow up interviews.

A number of RI managers interviewed mentioned that they had included in their overall strategy the need to address a number of sustainability criteria over the whole lifetime of their facility. These criteria are primarily related to their strategic objective which is usually to reach and maintain the scientific excellence of their facility. In some cases, a comprehensive independent review system to assess the RI on a regular basis (3-6 years) had been established, to ensure that it could continue to operate under satisfactory conditions over the expected time frame. Nevertheless, very little consideration for long-term sustainability was still apparent for more than half of the surveyed RIs.

Decision makers and funding agencies usually concur with RI managers and users that a facility's scientific excellence and potential remain the primary criteria for the sustainability of RIs, related to which is the attractiveness for users. However, additional elements such as business plans and adequate funding are also highlighted and often considered as equally important by facility managers or users. This being said, it is often difficult to assess the robustness of business plans and to have an overview of the complete costs due to the lack of tools and models for evaluating medium to long-term costs and of the potential changes of policies by funders. Although valuable experience has been acquired from traditional RIs (e.g. single site facilities in physics), much less is available from more recent types of distributed RIs. National funders may gain experience by participating in transnational projects involving single-site or distributed-site RIs. To ensure medium to long-term funding for research facilities, many countries are trying to set up new funding schemes to cover needs beyond the establishment phase. This can be done for example by increasing flexibility in funding mechanisms within dedicated funds and between earmarked and more general research funds, or by implementing user fees when access costs can be considered as eligible costs in research project funding.

Sustainability elements identified by RI managers

- Keep pace with developments to provide updated, cutting-edge installation technology and instrumentation that allow maintaining international scientific competitiveness and performance;
- Ensure relevance to user needs, for example through high-quality samples in a biotechnology research infrastructure, with pro-active customer consultation and involvement;
- Attract, train and retain leading scientists and qualified personnel with necessary skills and expertise;
- Ensure the reliability of the research infrastructure in terms of access (number of hours of operation offered to users) and services;
- Provide services and assistance to scientific users, notably regarding technical support and data management;
- Secure core funding with commitment to establishing mechanisms for long-term operational support and establish a solid business case;
- Open infrastructures for collaboration with industry partners;
- Stakeholder and financial support from an adequate number of member organisations.

Sustainability elements identified by funders/decision makers

- Robust governance;
- Uniqueness or complementarity with other facilities;
- Capacity to raise additional funds/support, including from the host institution;
- Education and training capacity;
- International dimension;
- Matching more general strategic objectives of the host country;
- Potential socio-economic returns are becoming increasingly important to varying degrees in different countries according to their priorities so there is often a need for demonstrating return.

Absence of or lack of substance in any of these elements can affect the overall effectiveness of research infrastructures and consequently their sustainability

Specific challenges for the sustainability of RIs were also mentioned by decision makers and funding agencies:

- The flexibility for funding new RI opportunities decreases when funders need to curb costs under financial pressure, have large RI portfolios and many international engagements which do not allow flexibility;
- The diversity of funding and access mechanisms in multi-stakeholder facilities and between different funding sources in different phases of the life cycle is difficult to manage;
- The shortage of candidates with the right management skills required to hold leading positions in RIs.

3. Pre-operation period

The term pre-operational phase relates to the time that elapses between the first conceptual proposals and planning steps for a new RI and the beginning of its actual operation, thus including the planning, design and construction of the facility. RIs relying on large/high-technology installations and instrumentation will typically need more time for construction and commissioning than other RIs that are developed from pre-existing facilities. Multinational RIs will also usually require extra time for this phase due to the need for co-ordination and management between the various partners from different countries or continents.

There is no doubt that the basis for the later sustainability of an RI originates in the pre-operation period. Independently of the scientific discipline, various critical elements (e.g. the choice of RI's scientific mission, its location, its design and instrumentation, its organisation and construction…) have to be determined during this phase.

This subchapter summarises the study's findings and analysis regarding the most important issues related to sustainability for this part of RI life-cycle.

3.1. Decision process, design and planning

The establishment of most facilities results from bottom up initiatives with the following motivations:

- Gap in the current facility portfolio and hence the need for a new facility to serve the need of a sizeable scientific community or in recognition of a newly emerging research field;
- Develop synergies and facilitate exchange of research materials and data by combining individual infrastructures into an organised conglomerate of institutions serving the same purpose.

In some cases, bottom up initiatives are matched with support from decision-making bodies, e.g. funding agencies or government agencies, with the ambition to better serve a research community with a joint facility or to raise the profile of the hosting country in a given research area. Political considerations can also be important with considerable regional/national prestige attached to hosting large science facilities.

The effectiveness of planning is greatly enhanced if structured and transparent mechanisms for the eventual decision-taking exist.

A diversity of decision taking-processes were identified in the pre-operation phase, depending on the facility's size, its geographic domain of influence, its strategic priority and the relevant approaches of national research funding organisations. This being said, a case-by-case decision process, linked to a well-organised scientific community able to start lobbying political decision-making rather than through a more structured and transparent decision-making mechanism, was reported as being problematic. Strategic planning at the national level is therefore increasingly used. This can help countries to manage a large portfolio of RIs, providing some vision on future needs. Road-mapping exercises are a major feature in Europe, where many roadmaps are set up at the national level, and these are normally (but not necessarily) complementary to the roadmap set up at the European level through the European Strategy Forum on Research Infrastructures (ESFRI). Similarly, Australia has established a national strategic roadmap for its RIs which is strongly correlated to government funding. There is no overall national road-mapping exercise in the US, as funding/operating agencies have a considerable autonomy and develop their own strategic planning, although there is exchange of information at interagency level. Similarly Canada does not organise a national road-mapping exercise. In other countries such as Japan or Korea, decision-making process is more of a mix of bottom up lobbying and top-down strategic decision-making that often encompasses more than just RIs.

The timespan from planning to construction can vary from 3 to 15+ years for RIs at the national or international level, reflecting the range in the number of participating partners as well as of the complexity of legal and organisational obstacles to be surmounted. Including construction time, that period can even extend over 20 years for complex projects requiring an extended discussion and negotiation phase such as was the case for the neutron facility European Spallation Source (ESS) in Lund, Sweden. A timeframe of some 20 years also applies to the Square Kilometre Array (SKA) project that can be considered as global in its ambition with main facility sites situated in Australia and South Africa. Additional elements that influence both the complexity and duration of the pre-operation period are the level of sophistication and quality required for building, infrastructure and instrumentation, as well as political issues, as illustrated by the International Thermonuclear Experimental Reactor (ITER), probably the largest and most complex international project undertaken, for which construction in still ongoing more than 30 years after original plans were formulated.

Site decisions are simple if an existing infrastructure offers or, by consensus, is found to be suitable to provide the desired service. In particular cases, national governments can compete for hosting RIs. In order to avoid later complications or deficits at chosen sites that seriously affect the desired sustainability or effectiveness later in the life-cycle, the decision should be based on detailed planning that should absolutely respond to the sustainability challenges highlighted in chapter 2.

The interviews with RI managers highlighted the importance of personal leadership in terms of dedication, scientific expertise and political sensitivity. Individual champions are often critical during the initial phases of planning and developing a new RI.

The wide involvement of the scientific communities in the conceptual and design phases should always be verified and stimulated, before moving to the implementation phase.

The initial phase consisting of developing the concept and reaching a consensus for decision is normally initiated through a bottom-up process involving research communities and is driven by a scientific need and/or significant new technological developments. Alternatively, it can sometimes originate in administrative or scientific institutions when opportunities to perform advanced research coincide with the research strategy at the national level (e.g. United States, South Africa, Japan, Australia).

In most cases, the scientific communities become involved when their opinion-leading members reach an understanding that a new scientific need/opportunity cannot be met within a closed circle or an academic institution (University), or inside the resources available to a single country but, instead, requires overcoming the “proprietary” approach to the instruments and facilities, which tends to be the prevailing “reflex” in academic science. This collaborative approach is different in different areas and disciplines. Some areas (e.g. Astronomy or Humanities depending on access to extensive collections/libraries) are very “open” to the joint ownership of facilities, while other areas (e.g. some Medical or Juridical Sciences) are less accustomed to a shared use of the same resources.

The purpose of a RI is embedded in its scientific community to which it must offer the necessary tools to meet a new or increased scientific community demand. To fulfill this primary goal, a RI can compete and/or collaborate with other RIs depending on the overall requirements. This usually friendly competition pushes the advancement of science and related technologies. The creation of a new RI can also sometimes be linked to specific socio-economic factors, such as science and technology education, which can typically contribute to the advancement of science at a competitive global level for emerging countries.

The desire on the part of funders for flexible agreements that respond to changing circumstances needs to be balanced by the desire on the part of operators for longer-term guarantees for core-funding. Therefore, an adequate business plan has to be developed for each case.

With respect to finances and funding, it must be recognised that the RI funding landscape is very diverse, responding to different national needs and strategies and adapted to the needs of different scientific communities. The many different approaches to funding new RIs range from single government sources via one-off project funding, through to multi-partner arrangements that can be a combination of government or government/private sources, over varying timescales (a few years to 30+ years) and consist of cash or a combination of cash/in-kind contributions. Funding arrangements tend to be debated and agreed most intensively during the preparatory and implementation stages and agreements drawn up at these stages are likely to identify how the partners intend to share the financial burden of establishing the RI, particularly for large physical infrastructures where the cost of construction and operation is too great for one country or region alone to afford. Such agreements may also address how the partners will share the benefits. In some cases, longer-term operational costs are considered alongside the cost of capital construction. In others, there is an expectation that operations will become self-sustaining in later years (through the provision of services, user fees or other financial resources). The latter option depends very much on the scientific discipline to which the RI is linked and cannot be generalised[11].

The Diamond Light Source Ltd (United Kingdom) business case

The Diamond Light Source was set-up as a (not-for-profit) Private Limited Company following the signing of a joint venture agreement (JVA) between CCLRC (subsequently STFC) – on behalf of the United Kingdom government, and the Wellcome Trust. Diamond is funded the following basis: STFC: 86% and The Wellcome Trust: 14%. This funding is applicable to both the capital costs of construction, and for Diamond's ongoing operations costs. The JVA also regulates the governance of Diamond (Chair, Board and executive directorship of the company).

The key objective of the Shareholders was to provide a cost-effective synchrotron facility for both the life/bio-sciences and physical sciences research.

The guiding principles in achieving this objective were that:

- the methods chosen to procure and operate the facility should achieve the best possible long-term value for money;
- the facility should meet the needs of both the life science and physical sciences research communities, and should also permit mutually beneficial international collaborations;
- the facility should be built to international standards and provide a comparable level of service;
- the facility should provide access to industrially funded users and access for commercial exploitation of science;
- the operation of the facility should be flexible in terms of scientific developments and access.

As a Private Limited Company, Diamond must meet all of the legal obligations of any company, with a Board of Directors and annual reporting to Companies House etc. However, as the majority of Diamond's funding is by public/government funds, it also has to complete the regular reporting that any other publicly funded United Kingdom body would, and indeed it is bound by many of the same rules as government agencies.

One advantage seen of creating Diamond as a separate legal entity was that it is very clear what Diamond costs. If Diamond were to be part of a larger institute, then the exact costs of running the facility might have been less transparent as many functions would be centralised.

After a 5 year pre-operation phase (Phase I), Diamond started operations in 2007. Phase II design and construction (which spanned nine financial years) started in 2003/04 during which another 15 beamlines were added. Phase III construction began in 2008/09, with the addition of further 10 beamlines, the last of which becomes operational in 2018.

Funding consists of capital funding and operational funding, respectively, running in parallel since operations started.

Business Plans for each capital funding of Phases I to III were put together by Diamond and submitted to the United Kingdom Goverment and to The Wellcome Trust for approval. The corresponding budgets including a spend/budget profile for each year were submitted to the Shareholders (and Government) for consideration. The finally approved budgets and the available funding directly affect which beamlines could be built and when.

One-year operations budgets, approved by the Board, are submitted to the Shareholders for consideration each year on the background of a 5-year budget plan. Depending on the Shareholder's verdict, the budgets may have to be modified to match the actually available funding. The above mentioned funding ratio (86:14) is strictly obeyed also in reduced budgets.

At present both capital and operations budgets run in parallel. With respect to staff budgets, part of the staff are funded from the capital budget, and other staff from the operations budget. The increase in instrumentation (beamlines) has been reflected as an increase in the operational budget.

Diamond expects to reach a steady state in the number of beamlines in 2020. Diamond is also currently preparing a case for an upgrade of the ring lattice in approximately 2024/25. If funded this upgrade would also necessitate a partial upgrade of some beamlines in order to benefit from the new opportunities of the revised ring lattice. A case for the upgrade has not yet been submitted to the funders.

The financial case for a RI should be assessed in parallel with the scientific/technical case to ensure that the scientific objectives can be delivered at a cost that is affordable.

Matters of financial sustainability need to be considered as early as possible in the planning process and address, as far as possible, the whole lifecycle of the RI.

One element that is not often well appreciated is that the resources needed and the specific expenditure required for a successful design phase are typically around 10% of the final implementation cost. This preliminary expenditure is often hidden in the "normal" budget of the institutions and/or academic groups collaborating in the designing and proposing of the RI, but is a strong motivating factor in building a coherent effort.

The design phase is also critical in preparing the conditions for the longer-term support and success in the operational phase. For large and more expensive RIs (of the order of EUR or USD 1 billion) the discussion and agreement on a shared concept and the joint development of a design, in which several different researchers and research groups are, via open calls, allowed to contribute (also involving the industrial (and the political) stakeholders), is often a precondition to ensure enough continuity to the funding stream between the implementation and the operation phases.

Very often, the construction phase of a new infrastructure is based on "extra" funding (additional to the general annual research budgets of the participating institutions) while the operation falls squarely within the usual research budget which tends to be stable and can even be "compressed" by additional needs from other existing or new infrastructures.

Vital to ensuring long term sustainability, a rigorous cost evaluation and assessment during the phases of planning and, later, implementation (construction) is a major undertaking. Nevertheless, survey feedback shows that cost evaluation and assessment is not always carried out at the same time as the scientific assessment. Although it can be difficult to predict and analyse longer-term costs in the absence of effective analysis tools, such assessment is now increasingly required by governments and funders across all RI types. In Europe for instance, the ESFRI process has established a robust process whereby independent scientific and financial/governance assessments are carried out in parallel throughout the life cycle of RIs; New RIs are now encouraged to develop a business case and to show a proof of financial commitment as part of the application process, which are taken into account during the assessment process.

Data-management will account for a significant proportion of operating costs across many types of RIs, not limited to e-infrastructures, and the technical and human resources required for this need to be considered within the context of policy mandates, e.g. for open science, that may go beyond the primary mission of the RI .

Data management costs and the availability of suitably qualified support people are not always fully taken into account during the initial planning and evaluation processes for RIs. Many RIs generate and/or collect massive amounts of data that have to be shared with the expert user community for analysis. Increasingly, research funders are mandating Open data, i.e. making research data publically accessible as soon as possible. This has significant additional resource implications in terms of long-term data stewardship and if a carefully considered data management plan (including the relevant human resources and their cost) is not developed early in the process, the necessary resources may not be incorporated into business cases and financial planning (issues related to data management during the operational phase of the RI life-cycle are considered in more detail in section 4.6).

3.2. Legal status and governance

Solid legal forms and corresponding statutes help in securing RI sustainability. Practical solutions should be adapted to the agreed needs of a RI.

Because legal status has implications on most of the operations of a RI (management, funding, human resources, access policies), partners involved in any new RI project need to carefully consider the options available. In this context, it should be noted that some interviews exposed evidence of misunderstandings about existing funding and legal arrangements and how they work

Several of the facilities surveyed (in Japan, in the United Kingdom and in the United States for example) are part of an academic institution with all staff being employed by the organisation's terms of engagement. Although such an arrangement can provide some practical advantages, a possible drawback can be the difficulty to enter into legal arrangements with other organisations, including the private sector. To remove this barrier, RIs may seek to have their own independent legal status. As an example, a United Kingdom facility confronted with this situation is striving to become an independent legal entity in form of a Company Limited with Guarantee.

Several of the European RIs that were analysed during this study are organised as a European Research Infrastructure Consortium (ERIC). This legal framework was created with the purpose to facilitate the establishment and operation of RIs at the European level, with members being countries or intergovernmental organisations. Although this legal structure provides some interesting advantages to the RIs (such as a possible VAT exemption), it does not provide for detailed provisions on the basis of which the entity will be set up. These must therefore be carefully negotiated among the different prospective members, as reports indicated that they can sometimes conflict with national legal or administrative requirements, leading to important delays in the establishment phase. An alternative legal form, which can sometimes pave the way for ERIC status and has been adopted by some facilities is that of "International association without lucrative purpose" (Association Internationale Sans But Lucratif AISBL) under Belgian law. Various other national legal forms are also used by RIs, such as the GmbH in Germany or the Société Civile in France, while at international level, different organisational set-ups may also be used such as being part of a national research funding institution under the relevant legislation and rules, being part of a multilateral organisation or as a node in a global network, or the use of lighter agreement forms such as a Memorandum of Understanding.

Partners in new RI projects usually strive for a governance structure that is simple, transparent and flexible. However, this needs to be balanced with the various partners' requirements, elements of accountability towards the funders and administrative efficiency.

RIs (and in particular those which are membership-based) commonly entail a series of generic governing instances:

- General Assembly / Assembly of Members / Council: highest authority with decisions on financial matters and long-term strategy;
- Executive Committee: reports to the General Assembly / Assembly of Members / Council; composed of Board of Directors (usually country representatives), Head of Scientific Advisory Board / Steering Committee and Director

- Advisory/Steering Boards or Committees (Scientific, Industrial, Administrative/Finance): these represents various partners/stakeholders and provide advice to – or in some cases may be part of – the governing structure
- Secretariat / Head Office: takes care of day-to-day business; sometimes also organise scientific conferences; under the leadership of a Director / Director General.

Many entities have however developed a specific governing organisation in response to their practical needs as well as to the legal requirements of their members. Five of the RIs analysed during our survey were for example governed through a system of directorship with a CEO who, depending on the RI's size, is assisted by directors of thematic or administrative (finance, etc.) units. For infrastructures that are part of a national research-performing organisation, the accountability on activities and strategy is to the governing authorities of these organisations. More detailed governance options for research infrastructures are described in earlier OECD GSF reports[12].

3.3. Financing and fundraising

Funding emerged as one of the most challenging issues during interviews. When multiple stakeholders are involved in a new project, which is increasingly the case for distributed RIs as well as for large single-site facilities, even support for the initial development phase may require complex funding arrangements.

Government funding, channelled through relevant ministries or national research funding agencies, remains the predominant source for the pre-operation phase. In the preparatory phase up to the design and decision to proceed, the funding is often provided by an existing RI which aims to implement major extensions or up-grades. More diverse is the initial funding for distributed-site RIs, depending on their subnational or international nature. Similarly, depending on the nature of the RI and the scientific discipline it covers, income from partner countries and private sources such as charities or foundations were mentioned as additional income streams. For RIs of pan-European relevance, design and preparatory phases can be funded through the EU Framework Programme (for the EU priority projects listed in the ESFRI roadmap), while construction remains a national prerogative although it can sometimes be supported by structural funds (which play a very important role in some European countries). In a small number of cases, private foundations may be involved in funding new facilities, and large RIs often rely on funding from multiple partners.

A decision to support the development of smaller-scale RIs is often the result of a bottom up process, either through internal negotiations on a case-by-case basis within host institutions or through open calls from funding bodies. Funding for single-site or distributed facilities is usually provided through the same mechanism. In the United States, research-funding and operating agencies often manage a facility's entire life cycle themselves. Funding schemes may vary with the required amount of investment, however. National nodes of distributed RIs are usually funded by individual host institutions with minimal central funding, while the central hub (if any) maybe funded by different sources (e.g. subscriptions). A facility's sustainability may be put in jeopardy when core funding from host institutions is constrained. Some countries also participate in smaller scale RIs through temporary funding schemes, e.g. the "Investing-in-the-future programme" ("programme d'investissements d'avenir") in France. However, without a robust business plan for continuing funding after the initial phase, the long-term sustainability of such RIs cannot be maintained.

The need for flexibility inside existing RI funding processes is required during the early/"design" phase, and is a pre-condition to ensure longer term sustainability.

During this study, several funders and decision makers emphasised the need for flexibility in funding instruments in order to be able to respond to various needs and events during the life-time of the facility and to support both implementation and operation without having to go through a whole negotiation and validation process each time. Currently, such flexibility is often lacking, either because of the legal structure of the RI, or due to the funding instrument itself. Some of the prioritisation exercises, connected to road-mapping in (some) countries are, for example, still disconnected from the definition of research budgets (which often are defined annually).

3.4. Challenges and risks

The number-one challenge mentioned by several RI managers concerns the need to stay up-to-date with technical developments so as to have state-of-the-art material and equipment when the RI starts operating. This does require an ability to detect sufficiently in advance major evolutions that can radically challenge the services or the business model of the infrastructure. One facility expressed that it would like to deal with this through contingency planning and a budget that allows rolling replacement of material and equipment, instead of having to buy required material at the same time on the basis of annual plans. Closely related to the technical challenge was the lack of experienced personnel (and sometimes of suitable companies) for designing, constructing and servicing infrastructures. Solutions mentioned are to have qualified science advisory boards accompany the process, to attract scientists and engineers that have emigrated or foreign experts (hence the importance for lowering barriers to human mobility), to hire and train young scientists, and to interest and retain qualified personnel in a long-term strategy. In that context, it has been noted that the recruitment of qualified staff is easier for projects that are challenging and innovative from the technical and scientific points of view.

The politico-economic context may be another impediment for the development of RIs, especially in emerging countries. This was highlighted as the key issue for one infrastructure due to the country's present difficult situation, requiring meetings with government officials on a regular basis. Political instability and related economic uncertainties are an additional burden when trying to secure and maintain national funding and they can negatively impact on a country's exchange rate and thereby heavily increase the price for imports. An additional complexity mentioned, particularly during the construction period, is the need to find a good ratio between investment from different partner countries and returns on this investment in the form of orders for the private sector in these countries. The host country of a RI can sometimes impose the obligation to build the facility with local companies despite their lack of experience in the domain involved. Geographic location of the infrastructure can also raise specific challenges. For instance, astronomy infrastructures may require large areas of land and sites without radiation interferences, both of which require skilful negotiations with relevant stakeholders, for example landowners.

In order to minimise serious subsequent problems, there is a strong interest in identifying suitable mechanisms to deal with contingencies as well as in establishing what constitutes appropriate contingency planning.

Risk assessment and management is critical to the planning for RIs. The equipment and techniques are frequently at the cutting edge of technology development, which introduces considerable technical challenges, including keeping pace with scientific requirements, that can impact on schedules and drive up the overall costs especially during the design, implementation and operations stages. Changes in national policies or in commitments from funders and stakeholder can also have serious consequences on research infrastructure development.

There are considerable differences in approaches to contingency planning. Only a few national funding systems (e.g. CFI in Canada or DoE and NSF in the United States) provide for contingency funds for the construction phase. In some cases, detailed instructions concerning contingency and related risk management in large projects are provided by the relevant agencies[13]. In the United States, the Department of Energy may designate a fraction of the budget for contingencies (based on an assessment of risks) in negotiation between funder and builder, and an agreement defines the use of contingency funds not needed during construction. In other instances, contingencies are being built into planning by funders; for example in France, where a small contingency fund is set aside for very large projects, or in the case of the European Spallation Source (ESS) where 10% of overall funding is allocated as contingency. Contingency may also be allocated to specific project cost items rather than top sliced from the total budget, as is the case for projects funded by the Canadian Foundation for Innovation. Contingency provisions are also currently under discussion in Korea. Where contingency is not allocated to projects or specific items, governments may act as the funder of the last resort.

While in kind contributions offered by funding partners is often a solution to increase the number of partners in RI projects, this may introduce risks associated with the additional process of managing and scheduling the in-kind contributions alongside design and procurement activities. Therefore, careful planning of handling such agreements is required to minimise delays and additional management costs.

Box 3.1. NSLS-II Risk and Contingency Management

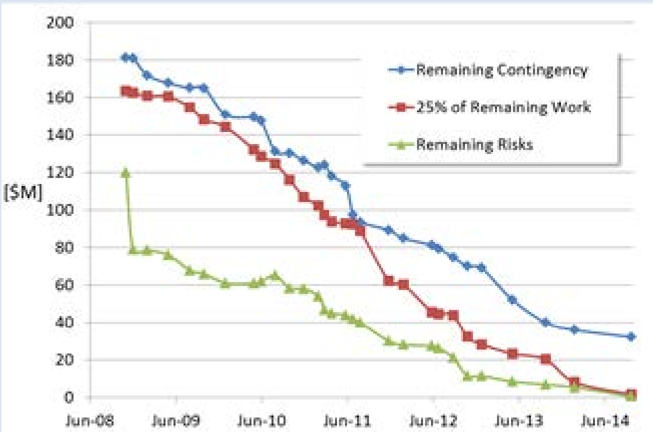
The purpose of the National Synchrotron Light Source II (NSLS-II) Project—supported by the U.S. Department of Energy and sited at DOE's Brookhaven National Laboratory—was to design, construct, install, and commission the world's newest, most advanced storage ring-based x-ray light source, an effort that required more than 4.25 million man-hours and USD 912 million. The specifications for NSLS-II were *at or beyond* the state-of-the-art when the project was initiated in 2005, so from the outset a rigorous approach for identifying and managing risks was developed.

During the estimating process potential cost, schedule, and technical risks were quantitatively evaluated from the perspective of their potential impact on project key performance parameters. These risks were weighted by their likelihood of materialising. The bottom-up process identified more than 400 risks. A subsequent integrated top-down assessment provided a manageable, actionable set of 28 key risks that consolidated estimate-based risks and included additional program risks not identified through the bottom-up cost estimation process. Mitigation strategies developed for these risks informed decisions regarding contingency allocation. As risks were reduced or retired, remaining contingency could then be utilised to optimise scientific capability within the overall design.

Altogether, robust integration planning, execution, and diligent management of project risk yielded tremendous benefits for the project and its stakeholders—enabling substantial enhancements for startup and operation of the facility while all the baseline key performance parameters were met or exceeded, and allowing the project to be completed ahead of schedule in 2015.

NSLS-II Project Risk and Contingency profile

Available contingency was managed to remain above 25% of the remaining project work at all times.



Synchronising different national ambitions to establish RIs in a given area and running previously different facilities under a joint organisation each were mentioned as additional challenges by RI managers.

According to the decision makers and funders interviewed, an increasing number of large or international RIs are undertaking extensive risk assessments, although these are not always robust. While risk assessment plans are trying to take account of various types of unexpected events, e.g. building cost escalation or delays, drop out of partners, changes in political orientation, there is no coherent procedure and case-by-case approaches prevail.

Very often, a problem is only analysed when it occurs and funding will be adapted by a mixture of cost-saving measures, including spreading costs over a longer time period, delaying recruitments and negotiating with builders, and negotiations with various funders for extra support. An exception to this scenario are domains where a large operation is more routine, e.g. in astronomy. Only a few countries, among them Australia, have more systematic risk assessments for various scenarios included in their business plans.

3.5. Implementation

The Design phase and its evolution into an Implementation phase is usually initiated when the project is sponsored by a sufficiently large (and politically strong and/or credible) research institution which has the capability to attract the involvement of at least one government and ensure enough continuity to allow the idea to "stick" (or gain enough critical mass to survive temporary setbacks) and enter into the prioritisation process. This primary supporter can be a national research (funding and/or performing) agency or an international organisation representing the scientific opinion in a credible way in one specific field (e.g. Astronet or Nucleonet in Europe).

The transition/relation between the "scientific consensus building" and "political lobbying" (or top-down planning) phase and the more specific "design" and "implementation" activities is not always sharp and may have several intermediate phases and re-iterations, connected to different maturities of the political support and/or amount of funding required/acquired. Sometimes there may be several "conceptual design ideas" in competition, and often also "dead ends" may be revived after years of apparent immobility, especially if there is a changeover between different animators or political frameworks. A mature or, where appropriate, a well-documented new technology must exist ahead of the implementation phase to allow for the construction of an RI within a reasonable time frame. This should not à priori rule out innovations from partners, suppliers or the RI itself during this period as long as they serve to establish a state of the art facility and do not substantially enhance costs and/or the time frame of the implementation.The technical maturity and needs for development are usually described in a conceptual design report. Both the earlier mentioned scientific case document and the conceptual report are necessary to justify the funding of a new or upgraded RI.

Major financial cuts during construction can undermine the viability of the project as they may lead to reduced performance during operation (and hence less attractiveness for users) and to larger maintenance and operation costs in the longer run, so the project should be regularly reassessed.

The design and the implementation (construction) phases are connected to longer-term sustainability through possible different technical choices of the type of facilities and of the organisation to operate them (e.g. the amount of staff and its balance between technical and administration). These choices impact on the cost of operation and may lead to unbalanced budgets when compared to the costs of other infrastructures. Very often, the consideration of the impact of technical choices on the longer-term operation costs is not clearly accounted for in the design studies (e.g. the cost of energy needed, or the maintenance costs, etc.).

In some cases, an RI concept may also be forced into a design phase too early by political intervention and/or because of an unexpected "early" availability of additional funding for design, allowing it to enter a prioritisation process and consequently move rapidly to the implementation phase. Insufficient maturity of the scientific case and subsequent design deficits as well as limited support from the scientific community can lead to failure. This may have been in part the case of the Superconducting Supercollider in the United States and of some of the early ESFRI projects which were launched after a "preparatory phase" funded by EU framework programmes.

Finally, the legal form and governance structure of any RI should be consolidated during the implementation phase. These may not necessarily be identical throughout the different phases (planning, design, construction and later, operation). During the preoperational phase and, at the latest upon entering the operational phase, both the organisation of the RI, its legal form and statutes can indeed be changed and adapted to practical needs during operation. However, the choice of a solid legal form and of corresponding statutes is critical for accessing diverse funding sources and fixing transparent responsibilities in the organisational set-up.

4. Operation period

The operation period of a RI corresponds to its active phase, when it provides the services for which it was designed and built. Enabling the RI **to remain operative, effective and competitive over its expected lifetime** is therefore the main objective for which sustainability policies during both the pre-operation and operation phases are developed and implemented.

4.1. Scientific excellence

Scientific excellence is the principal and most essential criteria required for assessing the effectiveness of any RI. Ensuring and measuring the scientific performance of RIs has been considered in a number of earlier studies and reports and was therefore not analysed in details within this study. Interviews conducted for this work confirmed its importance as the basis for the sustainable operation of RIs. Considerations of scientific effectiveness typically encompass:

- Provision of state of the art infrastructure and instrumentation and/or cutting-edge technology (particularly important when technologies are rapidly evolving, such as for data-storage and processing);
- Number and quality of services offered (including their actual availability) and take up of these services by users;
- Reliability of operation and access (both items are essential for attracting the best qualified users, including industry-based users who can provide additional resources for proprietary research);
- Quality of users' output (based on rigorous evaluations and taking into account users' successful access applications). This often also includes feedback from for-profit users whenever relevant.

Managers of contacted RIs emphasised the need for constantly monitoring the technological and scientific competitiveness of their facility with respect to the corresponding scientific environment. This includes internal monitoring and periodic review by external expert review panels but also serious consideration of comments and suggestions from the user community. The latter is particularly important when the RI may operate within some sort of monopoly status at national, regional or global level (i.e. CERN, ITER, etc.).

Innovations initiated by the management during operation can also lead to better technical solutions to maintain and enhance operative capabilities and therefore the competitiveness of the infrastructure (see Paul-Scherrer Institute case example). Innovative methods of operational maintenance can also be implemented in order to optimise the operation of the infrastructure (e.g. anticipative installation of spares, computer-assisted maintenance).

Internal innovation for state-of-the-art RI

The Paul-Scherrer Institute (PSI) is Switzerland's largest national multidisciplinary RI, serving different international science communities in physics, chemistry, biology, life sciences and engineering. It was founded in 1988, resulting of the merger of two existing RIs with different missions,. Since then it has, on the same site, established 3 new major RIs providing user services. These are the first continuous-beam neutron-spallation source (SINQ), the Swiss Light Source (SLS) based on a 3rd generation electron synchrotron facility and, most recently, the SwissFEL, a light source based on a free-electron laser installation.

In all cases, technological innovation was the enabler for the establishment of the respective installation with an internationally competitive level of performance. The SINQ is based on a proton accelerator which before 1988 was designed to deliver a beam of 100 μA but required an upgrading to a targeted 2 mA. Another major innovation was achieved by the development of high-quality neutron mirrors providing an effective transport of emitted neutrons to the various instruments. Apart from many key components, the main innovation for the SLS consisted in a novel design of the storage ring lay-out and, in the case of the SwissFEL, the design of a low-emittance electron gun which allowed to shorten the accelerator's length and therefore to lower the overall costs of the installation without making compromises with respect to the desired performance at the end stations.

In all these cases, the development of the key components was done in-house up to the prototype-level followed by industrial manufacturing under licencing agreements. This approach not only guarantees the control of the attempted performances but also is a most effective tool for technology transfer, usually achieved in the licencing procedure. In some cases, the in-house development led to launch of successful spin-off companies managed by former employees of PSI.

4.2. Governance

As described in section 3.2, the governance of RIs is usually defined during the pre-operation phase, although it can evolve during the life-cycles. The choice of the governance scheme depends on specificities of the RI (scientific discipline, size, single site, distributed) and the given legal responsibilities.

Evaluations by external panels of experts should be carried out periodically to check the status and management operation of the RI, recommending and/or refuting upgrade plans and providing advice for eventual termination procedures.

RI managements often benefit from regular visits of external advisory boards of experts relevant to the diversity of the RI tasks and periodic evaluations at intervals of 4 to 6 years by independent external experts is also considered as a must by both managers and funders regarding the optimal continuation of the RIs operation. For instance, in Japan, the targets and plans of all universities and RIs are periodically updated (every 6 years) and revised under the leadership of decision makers and funders. Regular opinion-monitoring of the user community and corresponding actions is one of the key components for securing the sustainability and effectiveness of RIs. External reviews can help RI governance and management by providing a broader contextual view and thus help in adjusting the overall RI strategy.

4.3. Financing and funding models

Financial support for the RI's operation phase had been identified during this study as one of the major issue for RI sustainability.

The aim of RIs to remain at the pinnacle of excellence has significant long-term financial implications. The increasing cost of RI operation, linked to the need to manage and provide access to increasingly large data-sets and to support broader scientific user communities often cannot be supported by RI's running budgets (or that of their host institutions if any). Furthermore, re-investment to maintain and upgrade instrumentation, particularly for large-scale physical infrastructures, is essential to maintaining scientific excellence throughout the lifetime of an RI.

Interviews conducted with decision makers, funders and RI managers, confirmed that it was usually much easier to obtain funding for the construction/establishment of a RI than to find stable long-term financial sources for its effective operation. This may be connected to construction/establishment often being supported by additional funding from outside the research budget (e.g. regional funding), while operation always falls on (more stable, but rigid) mainstream research budgets. However, there is a common view among decision makers and funders that such additional funding should not result in a RI deviating from its main purpose, as happened for a specific case in Canada where a change of ministerial responsibility led to a serious reorientation of a facility's objectives.

As is true for the pre-operation period, a wide range of funding models can ensure the financing of operations. Direct funding from national government is widespread for large and very large research facilities and for participation in large international consortia (usually through a membership-dues system). Funding may also be provided by member organisations from their own budget, usually for less expensive RIs. However, in countries with large and autonomous agencies, those will also often be responsible for the support of large RIs that they directly operate. In the United States, for example, there are numerous national departments and agencies which support research and corresponding infrastructures rather than a single centralised ministry or other decision-making body for all RIs. These departments and agencies make funding determinations based on their mission needs and plan accordingly, although their overall annual budgets are set by Congress and may deviate from the agencies' requests or expectations. User fees can also be an option, which is being implemented in a number of cases to cover a part or all of operating or other costs, particularly in domains of high Technology Readiness Level (TRL) where the RIs may have more applied research objectives such as in health/biomedicine or nanotechnology or deliver specific services or access to materials (data repositories, bio banks…). These different funding models may have pros and cons which were highlighted during our survey and are further detailed below.

Research facility managers consider government funding desirable as the primary funding source because of its often long-term nature, and because it often allows for providing facility services free of charge to the scientific community. In an attempt to nevertheless diversify the income and reduce dependency on sometimes volatile governmental funding, different RIs are tapping into alternative sources or planning to do so in the future. This could include funding from the private sector, from private foundations or from foreign partners for specific parts of the facility. Funders often perceive third-party income as adding complexity, particularly when partners have differing views on access policy. At the same time they themselves sometimes require such co-funding in-kind or for specific services (third party income often only covers the costs of the service to the third party, with no or very little net income to the RI).

The membership dues model finds application at RIs with multiple contributing partners. For distributed RIs, members will typically cater for the costs of their national node and infrastructure(s) and provide support for the co-ordination, governance and organisation of joint operations and the headquarters. Nevertheless, some of the interviewed managers of such RIs judged this system as not entirely satisfactory for their current needs due to the instability of members' engagement and the risk of them leaving at almost any time, the difficulty of moving money across national borders and the asynchrony between the duration for which members should commit themselves and national funding cycles. To stabilise the situation, Memoranda of Understanding (MoU) are sometimes considered during the early stages, or members are asked to sign up for providing specific in-kind services.

For other RIs, more ad hoc solutions are implemented which can be used complementary to one another: funding from research funding agency (either directly or via grant support for accessing the RI when there is a user fee), from private foundation, from the organisation that hosts the RI, or from public and/or private sector income attached to the provision of services or data deposit fees for example (for data RIs, see OECD report 2017). There are examples where multiple funding sources are established at the outset as part of the financial model of the RI. This is for example the case for RIs supported by the Canadian Foundation for Innovation. However, a solid core funding (60-70% of operational costs) is considered a healthy situation. Funding of upgrades often follows prescribed procedures leading to additional budgetary inputs but practices relying on a case to case judgement seem equally customary and successful.

Decision makers and research funders also increasingly encourage RIs to seek industrial partners. This is rarely linked to funding as fiscal regulation may complicate such partnerships, but rather intended to generate increasing economic impact. From the sample of people that were interviewed in the current study there was a strong feeling that the private sector is not generally interested in such partnerships, of which only a few were mentioned, including for example a public-private consortia in Korea.

Regarding the duration of funding commitments at the national level, interviews with decision makers and funders indicate a lack of long-term budget commitment even for large RIs (this is for example typically the case in Japan where provisions for almost all RIs, regardless of their size, are still made on an annual basis). Schemes are usually considered as unsatisfactory when facilities depend on fixed-term funds, often linked to the implementation phase, and/or when funding is renewed annually without any long-term guarantee. RIs set-up as intergovernmental entities often have a distinct advantage: in these cases budgets are deliberated by Parliaments, based on the international agreement, and therefore (in most countries) become a multiannual commitment. For facilities which are mostly supported by host-institution budgets, budget commitments can sometimes be medium-term, e.g. in the range of 3-4 years in Lithuania.

While research budgets are usually defined on a yearly basis, it turns out that a number of countries and/or funding institutions have been able to establish a legal basis that allows for stable funding commitments over longer periods of time, therefore allowing their RIs to operate with a better strategic vision. Indeed, countries with medium to long-term funding schemes usually consider these to satisfactorily cater for RIs' needs. The overall situation seems to be improving because funding processes are increasingly more organised and dedicated, with an increasing number of national funding processes pledging support beyond the traditional one-year system to take account of post-implementation needs. Interesting examples of medium- to long-term mechanisms can be found in several countries:

- South Africa: A 3-year budget cycle funding system from the country's Department of Science and Technology (DST) provides some stability for operation and planning. Adjustments are possible for unexpected events, but there is no budget insurance beyond the three years;
- Australia: As part of the National Collaborative Research Infrastructure Strategy (NCRIS) scheme (see box), operational funds are provided for research infrastructures that are in the national roadmap;
- United States: The Department of Energy (DoE) typically supports the research infrastructures in its realm during the entire life cycle, although funding is on an annual basis;
- Canada: The Major Science Initiatives (MSI) Fund created at the Canada Foundation for Innovation provides 5-year block funding, after which research infrastructures need to re-apply.

Such systems are in place in the minority of the surveyed countries, several being in transition with plans for longer funding schemes that are not yet in place however.

Additional but more restricted medium-term funding mechanisms were also identified in other countries. Funders such as the Netherlands Organisation for Scientific Research (NWO), Canada Foundation for Innovation (CFI) and United Kingdom Wellcome Trust often dedicate funds for the first 4-6 years, after which continued funding it is usually up to the host (the Wellcome Trust however have longer commitments for a small number of RIs). In the Netherlands, specific support can be provided to facilities with high running costs and there are funds earmarked for data access and curation. Norway has a similar policy: The Research council (RC) provides basic funding for some high cost RIs (covering the cost of unused capacity, four years minimum). In addition the RC provides funding for operational cost (user fees based on a full cost methodology) as part of the research grants. In Sweden the Swedish Research Council is now implementing a system where funding allocation for the investment into RIs is connected to a pledge from the host institution to fund operation costs.

Australian National Collaborative Research Infrastructure Strategy (NCRIS)

The Australian National Collaborative Research Infrastructure Strategy (NCRIS) provides funding to Research Infrastructures on a sustainable footing, by providing USD 1.5 billion over 10 years. Building on the Government's commitment of USD 50 million each year for 2015-16 and 2016-17, funding of USD 153.5 million will be provided in 2017-18 and on an ongoing basis, indexed for inflation. It provides a long-term, sustainable operational base for NCRIS to continue support world class science and research in Australia, and will enable Australian RIs to plan for investments into the future.

Funds are provided through biennium agreements, to ensure the facilities currently supported under the existing NCRIS network remain operational until the end of the biennium period as well as allow them to position themselves for the period beyond as a result of the long term arrangements for national research infrastructures.

Infrastructure funded through NCRIS should serve the research and innovation system broadly, not just the host/funded institutions. Funding and eligibility rules should encourage collaboration and co-investment. NCRIS does not to support institution or even small-scale collaborative infrastructures.

The NCRIS network currently supports national research capability through 27 active projects. NCRIS facilities are used by over 35 000 researchers, both domestically and internationally.

Along with the investment in NCRIS the National Innovation and Science Agenda also provides funding of USD 519.8 million over ten years for the Australian Synchrotron and USD 293.7 million over 10 years for Australia's commitment to the Square Kilometre Array.

Concerning cost arrangements for access to RIs, industry-sector users are consistently charged full cost for proprietary research (economic activity) at RIs, although this is being handled in a more flexible way if university-based partners are involved in research that is classified as a non-economic activity (in Europe, state aid laws regulates this area of collaboration with industry partners[14]). For public-sector scientists, three scenarios emerge from different comments around the globe:

- Cost-free access represents the majority of cases examined; access is provided free of charge by the research facility, often in combination with research grants, usually to cover travel expenses (this is often connected to an obligation to publish the results (non-proprietary research);
- The users' home institution covers all costs (experiments, local stay, travel);
- User charges are applied

The issue is often more challenging for international RIs, as members need to determine an agreed division of operation costs. This can be based on member countries Gross National Income-share, members' investments in the RI R&D or by actual usage. Although host countries often agree to support a large fraction of the construction costs as a site premium, this is less common for operation costs, and, to avoid delays, such cost-sharing between members needs to be agreed before operation starts.

A strong collaboration between funders and scientists in calculating the cost of operations and securing sufficient project funding to cover this cost (full cost or part of the cost) is considered as essential for the long-term sustainability of the RI operation.

This includes the possibility of users being asked to cover the full costs of their activity at the RI during operation[15]. When user fees are requested, they are typically calculated based on the full investment and operating costs, particularly for smaller RIs and RIs that are open for industry users. Access charge linked to added-value services can also be set up (e.g. for data RIs). For very large RIs, and for RIs where the host institutions cover investment costs and parts of the operating costs through basic funding, user fees may cover only variable costs to close a gap in funding. User fees based on full cost calculations typically include the following cost elements: buildings (space), common operating consumables, depreciation of equipment, and technical support. The capacity of the RI will determine the unit cost.

If this turns out to be the case, the full cost for use of an RI must be considered as eligible costs in research project funding, so that users are able to pay the requested user fee from the moment it is introduced, as access mechanism should not discriminate on the sole basis of the capacity of the user to pay the user fee. Treating “man hours” and “RI hours” in the same way by the funding agencies providing financial support for user projects can contribute to sufficient funding for RI operations. For RIs which have an international user-base, schemes to cover operation costs by full-cost user fees will require agreements across nations to be implemented and therefore will be applicable only in specific cases where user fees are an accepted approach by RI owners, scientists and funders such that they do not complicate and/or limit the accessibility of the RI[16]. To ensure that the best possible science is carried out at the RI, the owner(s) of the RI using user fee systems are suggested to provide some sort of “emergency funds” for qualified scientist in need of additional funding to cover their access, as a possible consequence of setting up a user fee can be a reduction in the scientific output quality in favour of the wish to optimise the workflow of the installation.

Full cost assessment: the French example

The French Ministry of Higher Education, Research and Innovation started in 2016 a study on RI's full cost calculation. The intent was to establish and share among all stakeholders the knowledge of the RIs' effective costs, including both direct and indirect or even hidden costs. As a result, this should provide better information for users, could be used to negotiate participations in partnerships projects or international consortia and, when applicable, for developing a price policy for the RI services.

A particular attention was paid to seek a consensus among all stakeholders on the calculation methods (allocation keys, depreciation, cost item definitions, etc.) and to identify more precisely all the personnel involved in running the facilities (valued in FTE and in euros).

The implementation phase started at the end of 2016, in a collaborative approach including pilot RIs and was followed by a monitoring committee. Thanks to the rapid dissemination of a practical manual, this new methodology was deployed among all the RIs of the French national roadmap within less than a year.

Content and outcomes

A first step of the study was to establish a precise cost perimeter for each RI, including a fine distinction of in-house research and users' operations. All costs were taken into account in the calculation, including amortisations, taxes, risks & contingencies, and decommissioning.

This study allowed to take into consideration many "invisible" costs (uncharged seconded staff, free access to equipment or services for internal users, costs covered by the host institution…) and to include in the calculation the impact of initial investments for construction. Nevertheless, despite all the care taken in identifying costs, some items proved to be difficult to integrate into the calculation methodology, such as the rental value of laboratories installed in exceptional sites such as high altitude observatories or within Paris Centre (e.g. a laboratory in the Louvre Museum).

Overall, the main long-term benefit from this exercise was found to be that identifying the effective full cost of the RI and that of each of its activities actually improves the personal accountability of the academic users.

4.4. Cost optimisation

Pressures on budgets are increasingly translated as requirements to save cost on RI operation by research funders. Asked about practices or solutions to reduce costs during the operation phase, the responses from RI managers can be summarised in four categories: curtail expenses, increase income, a combination of the former two or no measures envisaged.

Some 90% of facility managers indicate an awareness of the need for and the usefulness of cost reduction measures to help ensure the sustainability of a RI. Specific measures are given consideration by almost all of them as follows (in order of frequency of indication):

- Curtail operation costs: shut down parts of the operation (e.g. reduce data services), restrict the level of operations (e.g. run beamlines for fewer days), reduce energy consumption (e.g. place computer facilities in regions with lower average temperatures) or use already existing infrastructure and installations;

- Create synergy effects: Co-operate with other RIs and partner organisations by using common resources, cost sharing between facilities and economies of scale (common procurements). Funders cite data management as another area to save costs, for example by sharing soft- and hardware or setting up data networks;
- Reduce staff costs: Lay off people in the administrative support sector, redeploy staff from underutilised services to others on the basis of a monitoring system that identifies trends to help determine future staff allocation. RI funders report a strong pressure to control the salary mass by containing the number of staff at the operative or administrative level. Yet, such measures may endanger a facility's sustainability if lowering services make users turn to different facilities or if the administrative services fall below a reasonable minimum;
- Increase effectiveness and performance: Automated RI services to enable greater throughput of users (e.g. remote access), more sustainable energy provision etc.;
- Reduce import costs for replacements and upgrades; Negotiate with material suppliers abroad;
- Increase membership: Attract additional members if the host countries are not in a position to sustain operation costs and if funding through other funding mechanisms (e.g. European funds) is not available.

In many instances, cost optimisation will consist in a mix of the policies cited above, which can sometimes be organised into a more strategic policy (see Diamond Light Source case in box). Cost saving measures that lead to reducing the service operation and thus resulting in less users' access time are however considered, by both managers and users, as counterproductive. An idle RI with high-quality equipment or services is actually considered as a waste of money and likely to lead to a shift of users towards other similar facilities.

Diamond Light Source case

Research infrastructure efficiency is high on the United Kingdom government's agenda, with recent scrutiny focusing on the efficiencies of facilities and looking for ways in which they could either raise income or increase productivity for a given budget. For the Diamond Light Source, whose budget is provided by the Science and Technology Facilities Council (86%) and Wellcome Trust (14%), the current emphasis is on maintaining and improving the efficiency of the facility now that it has reached steady state in terms of recruitment and operations.

Diamond's objective is to continue to deliver strongly on its key performance indicators while minimising costs (within an operating budget that is no longer in excess now that the facility has reached full operational activity). The first element of this has been to set up an economic model to structure and understand where, in the event of a budget reduction, cuts in Diamond activities would have the least impact on outputs, starting with short-term, low-level impact (reducing frequency of some maintenance), through short-term medium-level impact (e.g. reducing the number of students), and longer-term, medium level impact (further reduction of some maintenance) and the way through to longer-term, serious impact (cuts to beamlines, front-line scientific staff – which will lead to reduction of scientific output in 12-25 months with lasting effect).). A similar analysis has also been conducted to identify how output might be most improved if the budget were to be increased and directed into particular areas of activity.

Diamond's approach creates a framework that provides a clear understanding of the relationship between budget lines and their profile and outputs. This ensures that all relevant members of Diamond staff are aware of what is essential – and also provides important information to the facility's advisory bodies (the Diamond Board, the Science Advisory Committee and the Diamond Industrial Science Committee). The 'Efficiency Framework' has been produced now and Diamond will be using this to implement cost-saving policies in the event of budget reductions. Diamond has also been optimising outputs for a given budget (increasing Output/Budget by increasing 'Outputs' rather than reducing 'Budget'). This is also of significant concern to United Kingdom government and feeds into measures of 'good value for money' within the science budget. For example, Diamond is working on increasing throughput (x3 on some beamlines) through increasing automation.

However, funders interviewed noted that there were still very few examples of RIs with cost-efficiency policies in spite of strong pressure to reduce costs, although they recognise that there are few strong incentives (e.g. matching contribution) for cost-saving from the RI's perspective. The only real incentive that appears to be a more common policy is to grant users the flexibility to use unspent funds for other purposes. Most, but not all, funds provided appear to be flexible enough, so that savings can be re-affected, i.e. no payback. In the cases where funds are not flexible, there is the risk of caps from the financial administration if not all funds were spent according to the initial budget.

The interviews also highlight the importance of trust between funders and facility managers to share and improve practices. In that context, there is an increasing trend, or even established policy (e.g. US Department of Energy), that RI managers share good practices and compare effectiveness of operation in order to establish economically sound procedures and achieve cost savings.

4.5. Risk and upgrade management

RIs are typically long-term enterprises, which can be affected by many unexpected events. At the strategic level, six of the twenty interviewed RIs (located in Europe, Japan and in the United States) admitted having no risk assessment policy or contingency plan. All others had some kind of risk management policy and some were regularly updating a risk register.

Although the variety of risks and their handling reflect the large spectrum of RIs surveyed, the following issues were specifically mentioned by the interviewees:

- Funding shortage. In two of the cases analysed, an annual assessment is being implemented to provide the necessary information required for the development of the RI's strategic planning. In a third case, the Chief Finance Officer is in charge of risk assessment and assistance in exceptional situations would be requested to the funding agency or the relevant government agency ;
- Lack of member support. The departure of several member countries was mentioned as undermining the ambition of a distributed RI in Europe to facilitate data exchange among member centres and thereby endangering its stability. Attracting additional members is one way to limit this risk.

In contrast to the construction phase, contingency funds for operation are usually dependent on host institutions. They are rarely determined in advance, but rather adapted as necessary and when possible to the needs of the specific facility. The need for provisioning resources for updates is also widely recognised among RI managers, only two of the interviewed managers declaring not to have long-term plans. In the majority of cases, this challenge is dealt with through pragmatic solutions when the necessity arises, usually by coming back to shareholders (member organisations, funding agency, national government, multinational organisation) for additional funding. At the other end of the spectrum, updates are part of long-term strategic planning with budgets foreseeing contingency funds in some (six) instances.

Decision makers and research funding organisations in several countries indicated that upgrade needs are identified during regularly conducted reviews. These usually include a critical assessment, often with international reviewers, following which facility management propose upgrades to be funded by ministries or funding agencies. Major upgrades may be included in national or regional roadmaps, which give them some sort of priority for funding, although with no guarantee. In many countries, upgrades require specific application for new funds on a case-by-case basis in a competitive process or through negotiation, and with no guarantee for success. Funding may come from funds dedicated to RIs or from more general-purpose funds. In Australia, a special fund provides assistance for urgent and unavoidable asset upgrades, but not for operation needs. Minor upgrades are usually itemised in the budget of the RI or the host institution, sometimes via reallocation of existing grant or budget lines (in Japan, the Grants-in-Aid for Scientific Research can sometimes be used for the upgrade of instruments when connected to new valuable science cases, but the size of the grant is modest).

4.6. Data management

Data management and long term stewardship to enable open access and reuse of data require substantial resources that can be difficult to secure if data preservation and curation are not explicitly within the remit of the RI.

RIs are the heart of the Big Data and Open Science movements that are rapidly transforming most areas of research. This is most evident when one considers dedicated cyber-infrastructure, such as High Performance Computing facilities, or a structure like the European Bioinformatics Institute whose main focus is data curation and provision of data services. However, many other major international RIs, such as CERN, are also contributing to generic cyber-infrastructure needs and other experimental facilities that generate and/or collect large amounts of data are under pressure to make these more widely available. Open access to data is expected to enable secondary analysis and new discoveries, as well as ensuring the reproducibility of reported findings. The linkage of data from different domains is seen as critical for addressing complex global challenges.

However, contributing to generic cyber-infrastructure services has costs and requires particular expertise. Likewise making increasing amounts of data openly available in a format that allows them to be understood and used by other scientists, some of whom may not be specialists requires significant investment. In depth data curation, including the generation and maintenance of complete metadata is essential if data is to be used beyond the limited community who were immediately involved in its primary production. *Real-time or quasi real-time data reduction/analysis is fundamental for many RIs as the volume of data increases, constituting a major challenge*. And intelligent triaging of data - deciding what data should be maintained and made openly available, what is of little use and should be discarded and what is potentially of some interest in the future but can be kept at lower cost in deep archives – is a conundrum for many RIs.

Many RIs rely, to a large extent, on tape-based data archiving to reduce storage costs, but in this situation, providing data access to the user can have significant costs, which are not always accounted for. Network bandwidth is still a bottleneck for many scientists, even if RIs may locally have very good internet connections. Distributed storage in data nodes or remote storage in the cloud are possible solutions, but as data volumes increase bandwidth is still a challenge for data sharing and access.

Policy makers are giving mandates for maximising data sharing and open data but the incentives, including funding, are often lagging behind. Both need to be taken together and are a critical factor in determining sustainable business models for the data related activities of RIs (OECD, 2017). Expectations of cost-recovery for data provision and or data associated services need to be considered in terms of their implications for optimising data access and use. And equally important as resources, are incentives to encourage scientists and institutions to share data. If time and resources are to be invested in good data stewardship so that data can be used by others, then the primary contributors should be rewarded and accredited accordingly. Having unique persistent object and user identities is key to digital tracing of data sources and users, over the entire time span of a data set. Such identifiers can allow data-sets to be linked to or cited in publications and other scientific outputs.

In addition to technical hardware, software and data standards, a variety of different data professionals are required for the effective operation of RIs. Some data management processes can be automated – provided that the technical tools and standards are in place – but in depth data curation and analysis requires skilled data technicians and data scientists. These people are in short supply and great demand, especially from industry, and it is a real challenge for RIs to attract, reward and maintain them. They often have a supporting role in research and do not necessarily fit into the traditional academic reward and career systems. They are unlikely to be first authors on papers in prestigious science publications but they make an increasingly critical contribution to RIs- their effectiveness and sustainability and need to be nurtured and looked after accordingly.

Implementing a data policy at the European Synchrotron Radiation Facility (ESRF)

After a long consultation period involving scientists and IT staff, the ESRF Council decided to adopt an open data policy at the end of 2015 (http://www.esrf.eu/datapolicy). The adopted policy is a slightly modified version of the data policy document produced within the PaNdata FP7 project and therefore is likely of being also adopted and implemented by other Photon and Neutron Research Infrastructures.

Although the adoption of the data policy was a major milestone, it was clear from the outset that implementing the policy would be an even bigger challenge requiring several years until all experimental data could be archived and made available for re-use. An implementation plan was therefore put in place to make sure that the different pieces of the puzzle were prepared and put together in a coherent fashion. Many of the issues which require big development and implementation efforts are linked to the fact that the ESRF is fully operational since many years with procedures and techniques in place, many of which require now to be re-designed to make them compatible with the data policy and professional management. This effort will not only be beneficial for "open data" but even more so for the scientists who come to the ESRF to carry out an experiment and who will be able to rely on well structured, protected, persistent, and citable data without individually having to address the complexity of large scale data management.

The main topics the ESRF actively pursues to implement the data policy are:

1. individual user accounts allowing to persistently identify each of the 7000 annual users of the ESRF in view of managing data access rights, embargo periods, and data ownership,
2. metadata definition for each of the 42 beamlines and associated instruments,
3. implement a modern file format with a single master file per experiment storing all the metadata, make sure the number of files per experiment is kept small and manageable (thousands of files instead of millions),
4. further develop an existing metadata catalogue,
5. convert data analysis programs to profit from the optimised file format,
6. implement electronic logbooks everywhere which are integral part of the metadata capture chain,
7. make data findable via search engines and tools, implement digital object identifiers allowing to link data to publications,
8. constantly upgrade the underlying IT infrastructure for long-term data archiving and retrieval
9. plan and start implementing extended data analysis and future re-analysis services,
10. work with other Research Infrastructures to harmonise tools and practices and to join forces on certain topics were developments can and should be done together,
11. a constant communication effort to make sure that all stakeholders understand why and how the above points are important for the future of the scientific life at the ESRF.

Each of the above points implies well-co-ordinated and competent IT staff being able to work in a team and very closely with and for scientists.

Where are we with implementing the ESRF data policy?

All the above points are being addressed in parallel but require different levels of effort and time-scales for implementation. Priority was given to the first four points because they are the basis for all the others. The first eleven ESRF beamlines are now connected to the central metadata catalogue. The raw data from those beamlines will soon be archived on tapes and linked to the data catalogue. It is planned that the data of all ESRF beamlines will be systematically recorded and archived when the new Extremely Brilliant Source becomes operational in 2020.

A clearly articulated and feasible policy on data access needs to be defined for all RIs and the necessary structures and resources need to be maintained to comply with this policy.

4.7. Human resources and staff policies

Qualified scientists and technicians are vital for the sustainability and effectiveness of RIs. Attracting, developing and maintaining such staffs require a strategic approach to human resource management. In addition to attractive employment conditions and career prospects, attention needs to be given to ensuring a balanced age distribution with due consideration to gender and minority representation. According to several decision makers and funding agencies, more detailed staff-management plans are required in a number of countries.

The profiles of staff employed vary a great deal, but they can be clustered in roughly three categories: scientists with academic background (including postdocs, PhD and MA students), technical support with or without scientific expertise and administration. Specific data provided by ten RIs around the globe suggests that the number of staff in the three categories varies according to the facility RI's disciplinary orientation and objective, with the ratio between scientists and technical support ranging from roughly 80:20% at a nanomaterial facility to 10:90% at a facility that involves a great deal of animal-care people. However, the bulk of cases lie in the spectrum from 50:40% to 40:50%. In all cases considered, administrative staff represents 3-10% of total staff.

A diversity of patterns also applies to the age distribution among staff. Six RI managers specifically addressed the need to increase the number of young scientists (age 25-35). Five facilities declared having a rather satisfactory age distribution with a balancing between the need to renew the staff population and the need for employees with longer experience.

About a third of the interviewed RI managers indicated that it was challenging to recruit as well as retain qualified scientists and technical staff, especially of a young age, for a number of reasons:

- Shortage of qualified people: Thematically different RIs in Australia, Europe and Japan highlighted a shortage of people with experience and the special skills required in reasonable proximity to the facility. Beyond this, decision makers and funding agencies raised the particular issue of skills at the management level, which often requires improvements, particularly for small and medium-size RIs. Other RIs experience a lack of trained people in the disciplines of interest;
- Salaries: Two managers mentioned the constraints in salaries that they could pay consummate with the skills of leading international scientists/experts;
- Low attractiveness: Two research facilities in Europe and Japan indicated the difficulty of attracting and keeping scientists, unrelated to expertise or pay;
- Shortage of technical support staff: a situation reported mostly by RI situated in remote or developing areas or with non-secure employment conditions.

RIs need to introduce the right incentives to attract qualified staff.

RIs located in scientifically emerging countries are in a particularly challenging situation, often confronted with a combination of the above-mentioned difficulties. Faced with a small scientific community related to the RI and a lack of experience in specific technical concepts, a Brazilian facility indicated needs for some 50 additional employees to complement the current staff; the recruitment of 180 of the present employees had already taken seven years since construction began in 2009.

The terms of employment are among the instruments that RIs may use to attract and retain qualified staff. Permanent positions are more interesting than fixed-term employment or contract labour, for example. Five RIs, located in Australia, Austria, Brazil, in the United States and in the United Kingdom indicated that 80-90% staff positions are on permanent contract, with fixed-term engagements being used for postdocs and PhD students. Similarly, the manager of a United Kingdom-based RI with 60% open-ended and 40% fixed-term engagements argued that, after a maximum of four years, fixed-term engagement should be converted into an open-ended engagement or the contract be discontinued. The remaining cases examined apply a mix of terms of engagement. This is exemplified by a European facility with sites located in three different countries, each with a different staffing policy. Feedback from two RIs in the United Kingdom and Brazil with public and private ownership status, respectively suggests a certain preference for the latter. While acknowledging the generosity of public-sector employment laws, the manager of the United Kingdom facility pointed out that these were not necessarily cost effective and that dealing with performance and redundancy issues were taking a lot longer than in the private sector. The manager of the facility in Brazil, run by a private organisation, was satisfied that he had more flexibility in dealing with human resources compared to government agencies.

Staffing policy and practice examples

In order to tackle the challenge of recruiting and retaining qualified staff, different avenues are being taken by research infrastructures:

- Extreme Light Infrastructure Delivery Consortium ELI-DC: this currently Brussels-based and distributed-site facility has launched initiatives to attract scientists with the necessary expertise from abroad and is developing dedicated training schemes (summer schools, Erasmus Plus, Master/doctoral programmes);
- National Centre for Atmospheric Science (NCAS): promotes staff development by facilitating their mobility among the different NCAS member institutions in the United Kingdom-based distributed facility;
- RIKEN Omics Science Centre runs a research database that gives the employees of this single-site RI in Japan access to a pool of research opportunities and positions outside the facility, thereby helping their promotion to academic university positions;
- The United Kingdom Science Council, a standards and registration body for practicing scientists, is currently introducing a professional registration scheme for technical staff to increase their recognition among facilities, hereby increasing their chance of mobility and career development;
- The Brazilian Synchrotron Light Laboratory (LNLS): has introduced three incentives – travels abroad, assignment of additional responsibilities, continuous education and training – to attract the more volatile young generation of scientists, because the intrinsically low salaries cannot be raised;
- The South African side of the SKA project managed to rally significant human resources with necessary expertise and engineering capacity for two reasons: people were highly motivated to work for a prestigious high-tech project, some even returning from abroad, and engineers had the prospect of subsequent engagement in a construction project elsewhere or to work for a SKA follow-up project in South Africa;
- The Atlas of Living Australia (ALA is now transforming the status of its essential staff from fixed-term employees to open-ended contract employees.

Good management of human capital is one of the key items for securing the sustainability of RIs, starting from the beginning of the construction phase and into the operational period.

As a rule, funders and other controlling authorities consider the staff policy, the management of the human capital and the securing of the necessary expertise to be the responsibility of the RI management (often under the host responsibility). However RI management is considered by funders and decision makers as not always as well qualified as is desirable in this regard. Human resource management needs to follow the regulations set by the relevant authorities. In some cases, these regulations are not considered to be favourable (in terms of salary scales, terms of employment etc.) for recruiting the best possible staff. As RIs mature, the balance of the staff’s age distribution needs special attention to ensure a regular renewal. Staff requirements also vary during the lifecycle of a RI. In this regard, an issue that requires special attention is the adaptation of the staff composition and expertise when moving from the period of implementation to the operational phase.

It is also necessary to facilitate the mobility of staff in order to give them the opportunity to develop their career. Indeed, whatever their choice of career path (management or expertise), they should have the opportunity to valorise and extend their know-how in moving from one facility to another, within the same distributed facility or between different single-sited large scale facilities. Due to their extreme specialisation and to the limited size of many research facilities, there is a clear risk of jeopardising their career in maintaining scientific as well as operational staff within the same facility for too long. Facility managers may also sometimes be reluctant to engage new professionals for replacing the mobile staff as long as they are not sure of the outcome. Pension funding and family issues remain the main barriers to this mobility and can often be tackled using administrative arrangements such as secondments and installation assistance for partners and families.

Efforts must be intelligently shared between the sending and the receiving facilities (or hosts) as well as with the concerned staff. To this end, the adoption of an "International Mobility Charter" to be shared by a large number of facilities could be an interesting step forward.

Special attention should also be paid to the existing educational tracks both in academia and professional training curricula.

Finally, the number of staff dedicated to administrative support is very often kept at a very low percentage of the total staff for budgetary reason. The danger of understaffing these sectors should be recognised and reasonable lower limits should not be undercut.

4.8. Users’ interests and access policies

Users are the drivers of scientific progress and should play a substantial role in the development of the RI both at the planning stage and during the operational phase.

Since the sustainability of a RI critically depends on its use by the scientific community, keeping a facility relevant and services up-to-date with user requirements is imperative. For that purpose, organisations representing users’ interests are sounding boards for a facility’s management. In a process of mutual benefit, user organisations serve as platforms to gather users’ views and needs on services and processes to feed into management decisions. The interviewed user group representatives described this system of interaction as effective and positive, with RI leadership being interested in and receptive to the views of the scientific community for integration in long-term planning at their facilities.

Overall, feedback from users in Europe and in the United States suggests that access procedures are usually satisfactory. Access is typically granted on the basis of proposals that can be submitted on a regular basis or based on specific calls addressed to the member institutions of a distributed-site facility. Analysing the latter case suggests that there is room for improvement concerning the number and frequency of calls. Following the evaluation by scientific expert panels, early notification is desirable, although it is common practice that the process can take several months. In addition to applications for regular access, some infrastructures offer fast access options, considered by the facility’s direction or by a selection of review panel experts. In that context, some user group representatives expressed a need to extend the range of options to fixed access periods for more routine experiments with no expected specific high-end output, but to benefit the scientific community in general, and to access for follow-up work after initial experimentation. The former option is rarely implemented because the loss in the competitive character at submission level is judged to undermine the scientific quality.

For a number of user facilities, research funding is obtained separately from proposal-based access to the facility. In one case, some concern was expressed by a RI manager about the double screening of access applications by both the RIs review panel allocating the necessary instrumentation and time for the experiment, and the scientific evaluation of the same project by the relevant Research Council. However, discussion between user representatives, the RIs review panel chairs and the management concluded in this case that the system was suitable to separately determine the projects prioritisation of access and its scientific merits. As a special service to users in this case, the RI administration offers advice for improving an access submission for which access has not been granted but the funding was approved.

The user access policy needs to be adapted to the requirements of each RI. It should be defined by the RI management in conjunction with the stakeholders (users and funding agencies) and needs to be periodically revisited after a certain number of years of operation. The Charter for Access[17] published by the European Commission can serve as a basis to draft a user policy according to the stakeholders' view, as it defines the elements that should be addressed by any access policy and provides a general guidance on a number of different issues, including the data management dimension. Other organisations (such as the US DOE Office of Science[18]) have also described expectations for user access models.

With the increase of importance in Open Access to scientific data, a careful data management and access policy should be drafted. This should optimise access and reuse of data, whilst ensuring recognition for primary data generators and providers including the RI itself.

For many experimental RIs, existing data policies and practices allow for an embargo period on data sharing beyond a defined community (of scientific investigators or members). This legitimately preserves the rights to the initial exploitation of the data to those who contributed to its generation. Practices in this regard differ from one field of science to another and across different RIs and there are opportunities for mutual learning. One of the challenges, discussed earlier under 4.6, is that the production and sharing of data in its own right is not valued within the current academic evaluation and reward system.

4.9. Innovation and technology transfer

Policy makers and funders increasingly expect to see economic benefits as well as scientific outputs resulting from R&D investments. RIs that demonstrate an actual or potential contribution to the wider innovation ecosystem are therefore more likely to be successful in arguing their cases for sustainable funding.

Innovation can occur at any stage of the life cycle of a RI and the types of innovation output can vary enormously depending on the specific context of the RI e.g. its type (single site, distributed), its geographical location, the local supply of skills/talent and its research discipline. However, for a majority of RIs, most of the innovation is taking place during their operation phase thanks to the outstanding knowledge transfer/acquisition they generate.

The main goal of many RIs is to develop fundamental science with potential benefits towards applications (note that they can also drive social innovation). However, they also develop and create state of the art technologies to meet their goals (e.g. in information acquisition and data management), although the developments made by RIs might only be exploitable decades after the operational phase; hence impact is difficult to measure on a short term basis. Nevertheless, these assessments are key to understanding the overall impact of the research supported by a RI. For example, wire-chamber and accelerator technology from high energy physics research conducted decades ago is now being used to address issues in healthcare. Similarly, the World Wide Web which arose as an indirect impact of CERN operational needs has dramatically modified our societies and economies[19]. More direct benefits to society, especially in the health-care sector are expected and intended from RIs active in bio- and life sciences.

The technological potential of RIs is increasingly recognised by industrial organisations. In the most direct approach, industries conduct their own proprietary research as users of specific RIs. Likewise, high-tech industry and services are being built around a number of RIs, creating innovation hubs. This trend of creating high-tech innovation parks and campuses close to RIs is being pursued in a number of countries, aiming at accelerating the transfer of technology and know-how.

In addition, during their operational phase, RIs train very qualified personnel, who are highly employable by industry and are an effective means for building relationships and transferring knowledge and ideas between industry and RIs that are an important part of the innovation process. A closer link between industry and RIs can help accelerate the transfer of know-how and promote innovation. This link between RIs and industry has been developed to varying degrees in different areas of the world.

Finally, it is common that an RI maintains the ownership of its ‘in house’ technological achievements to benefit from resulting commercial products, either by co-development or for a fair share of the returns. Efficient technology transfer can also be carried out through the foundation of spin-off companies initiated by RIs’ staff, which can be encouraged and supported by the RI management.

4.10. Public awareness and outreach

The operation phase of research infrastructures often involves activities to engage civil society, providing adapted information to enhance the understanding of the significance of the scientific results and of the related socioeconomic benefits. RIs can also improve the understanding of societal challenges and help strengthen the dialogue between research communities and society. This introduces a number of additional elements which may not have been fully considered during the design studies and in the implementation, but influence the evolution of the RI during its “useful lifetime”.

Specific attention should be given to the relations with the local authorities in order to prepare them for the unexpected events that can affect the facility (e.g. incidents etc.) as well as the unavoidable steps of their life-long operation (up-grades, transformation, termination…). One suggestion is to have regular meetings – through a Local Information Committee – where all the concerns in terms of social, economic and environmental impacts may be presented and discussed between the facility representatives and the local stakeholders. Such constant dialogue facilitates the acceptation of unexpected events by the local public and may help counter-balance arguments sometimes put forward by protesting organisations.

5. Termination and implications

Although RIs are usually expected to be active for many years, and sustainability policies are obviously focused on preserving such activity to the highest standards over their active life-time, the termination of RIs has to be included in the overall management of RI portfolios, and a balance between establishment and termination has to be found. This is increasingly important as the inflation of ongoing and planned RIs in recent years may lead to more terminations of older facilities in the coming years.

It is essential to find solutions such that society may continue to benefit from highly qualified and experienced people by transferring them to national industries or other RIs.

Many RIs (national or international) have evolved over the past 50 years, sometimes past the original mandate period by modifying their existing equipment, offering more possibilities to a user community through various upgrade phases supported by the scientific community or finding new roles by reaching out to a new scientific community. The case for maintaining a RI ceases when it can no longer provide state-of-the-art services for the scientific community and no further upgrade can be made to enable it to do so at a reasonable cost. When this happens there are two possibilities, closing and dismantling the RI or using it for other purposes such as education and development. A decision to close an RI is delicate and can be driven by political (e.g. in the nuclear sector) or funding considerations with or without consultation of the scientific community. Although the topic of closing an RI and its subsequent decommissioning is generally considered as being of very low priority by RI managements, the questions regarding the decommissioning and the management of very experienced staff (including their potential use during decommissioning and the maintenance of their pension rights after the dismantling of the RI organisation) are critical. In some cases, a RI could also be partially recycled to serve as a test bed for the development of new technologies to be used in building a new RI.

Termination plan should be co-developed by RI funders and managers well ahead of time.

This study indicated that the termination phase did not receive much attention, neither from RI managers nor from funders.

No specific consideration to the process and/or timing of termination was given by the management of nine RIs interviewed in different disciplines and in countries around the globe, although this was sometimes due to the facility being in its early days. Managers at three RIs were aware that a termination scenario could emerge, primarily for reasons of curtailed funding, but no contingency planning had been put in place in any of these cases: management of the first, a single-site facility, argued that the hoped-for discovery to occur only once every 50 years and operation therefore had to continue; the second, a distributed national facility was relying on the dependency that the scientific community had developed towards its services at national level to remain operative, while the third facility, with sites in four countries, was counting on national sovereignty considerations and prestige. In yet three further cases, managers indicated that operation would continue at a reduced level if funding were to reach a level that would no longer allow support for its full suite of activities. The interviewed decision makers and funders confirmed that very few RIs have a defined termination plan and budget for decommissioning if needed except those which must respect waste regulations related to particular technical risk management (asbestos, nuclear, toxic or genetically modified products) as well as professional operational regulations (marine or aeronautics). However, they point out the difference between countries that more recently started developing RIs, which do not usually consider termination, and more experienced ones (particularly in more structured research fields such as fundamental physics), which may do so. Seldom taken into account in ordinary budgets, funds usually have to be provided ad hoc, either from the host budget or through special money from funders.

Termination was found to have been considered to some extent in four of the RIs included in this study. For two distributed site facilities with a membership system, one in a national context and one at the global level, a sufficient number of member organisations to share their data was considered as a benchmark for continuation. In a further case, the facility’s principal funding agency specifically provides funding to ensure an orderly close out and the transfer of achievements of whatever kind to other institutions. The storage of data assets beyond operation was provided for in the fourth case, should the service no longer be sustainable.

Decision makers and funders note that termination is usually the result of an ad hoc process, although consideration may be addressed in the business plan during the establishment phase, during regular reviewing or for renewed funding. Furthermore, despite all these precautions and possible scenarios, the cessation of an infrastructure activity may result from an unforeseen event affecting the installation (meteorological disaster, fire, cancellation of a contract research, technical accidents etc.) which can trigger a decision already envisaged.

Termination itself is usually a complex decision because of the many interest groups involved, staff, users, local authorities, etc. Whether decision on closure should be made through a competitive process, i.e. to decide on terminating facilities versus launching new ones, is debatable. At the outset of a decision is usually advice from relevant bodies, often accompanied with recommendation for an action plan. This can be linked to the update of national roadmaps with recommendations on investment plans, decommissioning or on downgrading from national to local role. What usually follows is a review by the host institution and validation or decision by ministries, particularly for large facilities, in consultation with stakeholders or the host institution. Unless they are owners, funders usually have no formal decision power over termination, but they have important influence as they can stop funding and/or fund a reuse or transformation of the facility.

The costs for de-commissioning and end of mission are currently only rarely a component in the overall planning of an RI. It can be argued that appropriate accounting for this period is needed (and/or possible) only in some specific cases such as, e.g., in the construction of a nuclear-reactor based RI where the life-time is known to be limited by construction-materials fatigues. In most other cases and particularly for distributed infrastructures often created through the merging of several pre-existing, smaller facilities, termination is more likely to consist in re-organisation and at least partial re-use of existing infrastructures.

The US NIH bridge funding mechanism

The US National Institutes of Health (NIH) does not operate research infrastructures directly but provides funding to various host institutions to set up and operate various resource facilities (e.g. animal or tissue sample facilities). It has a general policy to safeguard the investments already made in case of difficulties and therefore to avoid closing down resource facilities without providing support for a good transfer solution.

In case of specific difficulties, such as unsuccessful grant application by the host, the wish of the host to disinvest from the facility or a decision to close down, a mechanism to provide bridge funding is available. Such funding is available for up to one year, and may be used to maintain staff and operation at reduced level until a new successful grant is obtained, facilitate the transfer of the resources to a different host institution, or help managing an orderly close down.

Bridge funding is usually provided following an extensive discussion with the facility host, which has to submit a request for the funding and undergo the normal grant application process. Funds are calculated based on actual cost of the facility and typically adjusted based on previous grant received (a close look at the financial statements will usually be done to evaluate the real needs).

More serious is the problem of a controlled de-commissioning of RIs with radioactive or toxic components and waste. A major challenge here is to motivate experienced staff to be available for professional assistance in the practical process of the decommissioning and to avoid early retirements and hence loss of essential know-how by offering incentives to continue their employment.

An issue that is however common to all RIs toward their end of life is that of the preservation of data (and of other physical resources and specimen in some cases). The NIH bridge funding system described above remain rather unique among funding bodies and most data and specimen transfer to other hosts appears to be carried out through very ad hoc procedures which can lead to important losses for the scientific community and the general public.

The question of the longer-term development or decommissioning of an RI has often been posed in the last decade, mainly in response to the requirements introduced in some countries for designing the “full life” and introducing it in the budget expenditures. The understanding of the concept has not yet found its way into the common approach and the development of appropriate methodologies for this accounting is lacking.

The known and analysed cases of de-commissioning and of re-orientation of RIs are so far limited to a few areas of research. The best documented are related to laboratories dedicated to nuclear research and reactor technology which were built in the 50’s-60s of last century and the “small astronomical observatories” which had a specific history in Europe and the United States. A broader study of these cases does not exist as yet, but might provide a stronger basis for policy development. The study of different cases in other scientific areas such as libraries, archaeological excavations, medical research laboratories, etc. might help to establish a broader basis of experiences with respect to RI’s limited life-times and the handling of closures.

6. Conclusions and recommendations

Analysis of the main observations and findings reported in sections 2-6 of this report suggests a small number of key areas that need to be addressed in order to improve the sustainability and efficiency of RIs. The recommendations that follow are aimed at addressing these needs. Taken together and with reference to the 'good practices' identified in this report these recommendations can provide a framework for RI sustainability

6.1. Recommendation 1

For any new RI, a **comprehensive Business Plan** should be created early in the development stage of the RI. This should be based on a clear business model that identifies income streams in relation to the services that will be provided by the RI, and describes how science, technical, financial and data-management issues will be addressed during the lifetime of the RI. And because many RIs also have an important role in promoting innovation, the plan should also highlight the processes through which innovation and technology transfer will be promoted throughout the RI lifetime.

The business plan needs to be produced and approved before the launching of the implementation phase. The contents of the Business Plan, complemented by a Science-Case document, will need to reflect the rationale and the specific needs of the RI as well as its context. These should be evaluated through independent international peer review which should include experts in RI management.

The business plan should describe the decision-making process for progressing from one stage of RI development to the next. In particular, the transition from the Design phase to the Implementation phase should only proceed once a clear agreement is in place, setting out the financial responsibilities of the funders and hosts in the operational phase.

6.2. Recommendation 2

Risk assessment processes and contingency arrangements should be put in place during the early stages of the development of an RI.

The risk assessment process should outline the steps to be taken to identify, mitigate and manage the risks associated with changing resources, costs, memberships, scientific, technological or political context and describe the arrangements for accessing contingency funding.

An initial risk assessment should be conducted early in the development process and considered alongside the Business Plan and science case and a risk registry should be reviewed and revised periodically, on a timescale appropriate to the fiscal and financial planning cycle for the context of the particular RI.

Funders should develop, in co-ordination with RI management, appropriate **contingency funding mechanisms,** with defined eligibility criteria to respond to important unforeseen needs associated with unexpected events.

6.3. Recommendation 3

Data Management is an increasingly important activity of RIs that needs to be recognised by both RI management and funders. It should include the following practical actions:

- a data access policy which should in particular describe how the RI conforms with any open-data mandates and describe any privileged access or embargo arrangements.
- the implementation of a coherent and user-friendly data access system (this is particularly important for RIs offering access to a large number of different and independent pieces of equipment);
- a scheme describing how data will be processed stored and made accessible for external users, and staff and budget for offering this service. This should include consideration of any embargo periods and or restricted access arrangements that might be appropriate for certain types of data;
- Synergies and links with cyber-research infrastructures whenever applicable, to optimise resources and cost and increase data availability;
- plans for data preservation and corresponding access procedures after termination;

Funders also need to find solutions to ensure that the framework of Open-Access (Open Data) is financially viable and thus sustainable.

6.4. Recommendation 4

For any RI, a robust **staffing policy** should be developed by the governing body and management, the host institution and the RI staff employer (which may be the same as the host institution). Such a policy will necessarily evolve over the lifetime of the RI and should be therefore regularly updated and renewed from conception of the RI to the end of its life-cycle period. It should in particular include measures for:

- attracting young scientists (e.g. opportunities to travel, providing additional responsibilities…)
- attracting and retaining scientists and engineers for the technical support of the RI (e.g. increased recognition, career track…)
- the selection, training and development of RI staff at all levels(including to the upper management level);
- the career development and succession planning of RI staff;
- the mobility of staff among internationally-leading RIs and between RIs and universities as well as the private sector. To this end, the adoption by the RI employers of an “International Mobility Charter” could facilitate the development of adapted employment conditions for RI staff and hence their mobility between institutions.

6.5. Recommendation 5

Where they already exist, **medium to long-term funding mechanisms,** to provide support to RIs during their operational phase, have been shown to facilitate RI sustainability. Funders (governments, funding agencies…) should consider setting up such schemes, where appropriate, and are encouraged to share experience and good practices as various options have already been tested that may be adapted to specific contexts.

Allocation of such funds should be done on the basis of appropriate scientific, technical and management criteria being met, should depend on periodic external review, and should ideally be provided without being administratively burdensome or complex.

If the partial coverage of operational costs requires user fees, the full cost for use of an RI should be considered as eligible costs in research project funding. For RIs serving an international user-community, schemes to recover operational costs via user fees require agreements across nations. Cost recovery from users should be considered only when the access mechanism is such that it does not discriminate on the sole basis of the capacity of the user to pay the user fee.

RIs governing structures should be encouraged to investigate various funding streams (including from the private sector) with the aim to reduce the dependence on a single source.

6.6. Recommendation 6

Funders (governments, funding agencies…) and RI management should co-develop appropriate **cost optimisation** procedures to ensure they are using resources most effectively and efficiently. In particular, RI management should have a clear understanding of their income streams, cost lines and related outputs, to identify where costs might be reduced without significantly affecting the RI performance.

Funds allocated to RIs should ideally be flexible enough to allow for some re-allocation to priorities or later time periods as determined by the RI governance structure.

Incentives should be provided for RIs to implement cost saving measures that do not affect their effectiveness. Co-operation in investment and use of resources between RIs and with relevant partner organisations should be promoted. Potential areas for co-operation include common procurement procedures, the sharing of software and hardware or federation of data networks and services.

6.7. Recommendation 7

In order **to remain at the cutting edge**, RIs should develop appropriate innovation policies and procedures, and set up internal innovation development capacities and the capacity for knowledge exchange with external partnerships (public or private organisations) whenever appropriate.

RI managers should develop a real “innovation culture” and implement innovative solutions as much as possible in all areas of activities of their facility such as:

- maintain a “total quality service” to all types of users
- foster technology-oriented ecosystems close to the facility (“Innovation Hubs”)

- train RI staff to a serendipity culture and reward as appropriate
- let young talents going for new resources off the beaten tracks
- exchange experience and human resources with all potential partners
- dedicate professional staff to industrial relations
- encourage a diversity of staff background and gender equality

Funders and RI management should provide incentives to promote such continuous innovation effort and support the sharing/transfer of technologies and know-how developed through RI development and their commercialisation.

6.8. Recommendation 8

Many RIs are expected to have a positive socio-economic role. For some this is part of their core mission and may be manifested in a variety of ways. Hence, RIs may contribute to understanding and addressing grand challenges, to providing knowledge for regulatory purposes or policy decisions or to enhancing public engagement in science. They may also have an active economic role by transferring the technologies developed in-house to society through licensing, spin-off, staff mobility to industry etc. These activities constitute part of the overall value proposition for RIs and impact on their sustainability. Although the socio-economic added value will be specific to each RI, maximising this value requires:

- a clear vision of the socio-economic missions and their regular monitoring and assessment through a set of adequate performance indicators (OECD GSF framework on socio-economic impact of RIs). Including external users from the socio-economic sector in the governance of RIs may help reaching such a goal;
- a public outreach and communication strategy (i.e. dedicated visitors programmes and promotional events, educational activities for schools, curricula for relevant non-academic professional education, user-friendly informative and updated website);
- a knowledge and technology-transfer policy enabling the RI staff to optimise the potential use of innovations developed in-house and facilitating their dissemination.

6.9. Recommendation 9

Very few RIs have made any preparations for the end of their life and this is increasingly an issue in a context of rapid expansion in the number of RIs that governments and funding institution have to manage and support. Where necessary, funders and RI governing structures should co-develop appropriate **plans for an RI's terminal phase**. These should be developed earlier rather than later and whenever reviewing mechanisms indicate that a particular RI is unlikely to be able to provide a valuable user service in the foreseeable future.

Termination plans should provide specific information on the process and possible timing and close down scenario (termination/decommissioning, reuse, transformation…). Critical elements to address are the preservation of data (and/or specimens in some cases) and expertise, which should be the object of appropriate data archiving and transmission policies and staffing transition plans. The foundational basis for considering some of these issues should ideally be embedded in the formal agreements associated with the establishment of an RI.

Termination should be implemented following an adequate external evaluation and options analysis process. This should typically include consideration of the potential for upgrades, reuse or reorientation of the mission of the RI, or the closing down of the RI. Discussions around RI termination are often avoided but the RI community as a whole could benefit from a more systematic case study analysis to identify useful practices and options.

Endnotes

1. Group of Senior Officials on Global Research Infrastructures Progress Report 2015.
2. Long-term sustainability of RIs was, for instance, one of the foci of the July 2014 EU Informal Competitiveness Council.
3. http://www.oecd.org/sti/sci-tech/47027330.pdf.
4. http://www.oecd.org/sti/sci-tech/international-distributed-research-infrastructures.pdf.
5. http://www.oecd.org/sti/sci-tech/CERN-case-studies.pdf.
6. http://www.eiroforum.org/downloads/20150325_discussion-paper-research-infrastructures-sustainability.pdf.
7. Cost control and management issues of global research infrastructures: report of the European expert group.
8. The cost of large RIs: comments.
9. A framework for biobank sustainability.
10. Sustainability of e-infrastructures (for the Social Sciences).
11. The upcoming OECD report on Business models for sustainable data repositories will provide useful options for data RIs.
12. See http://www.oecd.org/sti/sci-tech/47027330.pdf and http://www.oecd.org/sti/sci-tech/international-distributed-research-infrastructures.pdf.
13. See, e.g., the NSF Large Facilities Manual (https://www.nsf.gov/pubs/2015/nsf15089/nsf15089.pdf) and DOE Order 413.3B on Program and Project Management for the Acquisition of Capital Assets (https://www.directives.doe.gov/directives-documents/400-series/0413.3-BOrder-B-chg3-pgchg).
14. http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52014XC0627(01).
15. Note that there can be different access modes, as for instance described in the European Charter for Access to RIs.
16. The recent change in Europe to include the cost of use of RI as eligible cost in Horizon 2020 is an important step in this direction.
17. European Charter for Access to Research Infrastructures.
18. See https://science.energy.gov/user-facilities/user-resources/access-models/ and related pages.
19. http://www.oecd.org/sti/sci-tech/CERN-case-studies.pdf.

Appendix 1. Members of the international expert group

Country / Institution	Name	Organisation
Australia	Ditta Zizi	Research and Higher Education Infrastructure Department of Education and Training
Belgium	Laurence Lenoir	Belgian Science Policy Office (BELSPO)
China (People's Republic of)	KANG Qi	Chinese Academy of Science and Technology for Development (CASTED)
	LI Zhe	Director, Institute of Science and Technology System and Management, CASTED
Czech Republic	Jan Hrušák	J. Heyrovský Institute of Physical Chemistry, Academy of Sciences
France	Jean-Pierre Caminade	Ministry for Research and Higher Education
	Christian Chardonnet	Ministry for Research and Higher Education
Germany	Matthias Barth	DLR Project Management Agency
	Verena Müller	DLR Project Management Agency
Italy	Carlo Rizzuto	CERIC-ERIC (Central European Consortium of Research Infrastructures-ERIC)
Japan (co-lead)	Satoru Iguchi (co-chair)	National Astronomical Observatory of Japan
Korea	Man Hyung Cho	Hannam University
	Sun Kun Oh	Konkuk University
Netherlands	Hans Chang	Royal Netherlands Academy of Arts and Sciences KNAW
Norway	Lise T. Sagdahl	Norwegian University of Science and Technology
South Africa	Daniel Adams	Basic Sciences and Infrastructure, Department of Science and Technology
Spain	Juan Antonio Fuster Verdú	Institute of Corpuscular Physics (IFIC) National Research Council (CSIC)
Sweden	Mats Johnsson	Ministry of Education and Research
Switzerland (co-lead)	Hans Rudolf Ott (co-(Co-chair)	ETH Zurich / Swiss Academies of Arts and Sciences
	Roger Pfister	Swiss Academies of Arts and Sciences
United Kingdom	Catherine Ewart	Science and Technology Facilities Council
United States	Altaf Carim	Office of Science and Technology Policy
EU + GSO	Andrea De Candido	DG Research & Innovation Secretary of the G8 Group of Senior Officials (GSO) on RIs
EIROforum	Massimo Altarelli and then Tim de Zeeuw	XFEL and then ESO
	Duarte Borba	EUROFusion
	Frédéric Le Pimpec	XFEL
ESFRI	Philippe Lavocat and then Jan Hrušák	
Science Europe	Maud Evrard	Science Europe secretariat
	Christian Renner	Deutsche Forschungsgemeinschaft (DFG)
OECD	Frédéric Sgard	GSF Secretariat
	Dai Qian	GSF Secretariat
	Taro Mastsubara	GSF Secretariat
	Carthage Smith	GSF Secretariat

Appendix 2. Survey framework

The objective of the survey was to gather information in order to identify major obstacles and existing successful practices related to the sustainability and effectiveness of Research Infrastructures (of national, regional and international dimension).

Interviews were flexible to appreciate the variations between different countries and organisations. Three sets of questions were designed for the three categories of stakeholders: RI administrators/managers, RI funders/decision makers, and RI users.

Interviews were confidential (no statement were attributed to any interviewee) to foster trust and openness.

Questions for RI administrators/managers

1. Brief presentation of the RI:

- Creation date, duration of establishment phase, current position in its life cycle
- Members, legal status
- Funding/financing organisation
- Governance organisation

2. What are, for you, the key elements of sustainability for your RI (i.e. the capacity for your infrastructure to remain operative and effective over its planned lifetime), and what are the most challenging ones?
3. What are, for you, the key element of effectiveness for your RI (i.e. the capacity for your infrastructure to deliver the expected scientific services and output over its planned lifetime), and what are the most challenging ones?
4. More specifically,
    a. Is your funding/financing/operating model adapted to your needs? Was it developed according to your anticipated needs?
    b. Did you face specific challenges during the construction/establishment phase? How were they addressed?
    c. Was a risk assessment strategy set up to deal with unexpected costs/events? How do you deal with unexpected needs (e.g. linked to cost overrun, new technological developments, new scientific needs, gain or loss of funding members, political instability and delays in funding ...)
    d. Is your funding/financing/operating model appropriate for your operation phase? For medium to long term planning? Do you have flexible mechanisms set up? (if not, how do you deal with current needs ? what model would be more appropriate ?)
    e. Have you identified practices/solutions to reduce costs during the establishment, construction and operation phases?
    f. Have you identified new/innovative external sources of funding for operation? What are they? What budget percentage do they cover? What are the drawbacks (do you realise a neat gain?)?

g. Have you identified practices/solutions to increase the operative efficiency of your RI (cost-control, training, network/mutualisation with other structures, reduced access cost/improved efficiency of access…)?

h. How are the costs for upgrades met? Was that planned initially?

i. How do you evaluate the various contributions from members (in kind, tangible vs intangible…)? Do you take amortisation/depreciation of assets into account in your financial plans and funding requirements?

j. What is your current human resource policy and strategy? Are you facing specific challenges in recruitment? Training? Retaining staff? What is the statute of your staff? Is it appropriate for your needs?

k. Have you agreed a financial and operational strategy for potential termination?

Questions for RI funders/decision makers

1. Brief presentation of the funding/decision-making institution:
   - Role in funding or strategic decision-making for RIs
   - Funding and decision-making process
2. How is RI sustainability (i.e. the capacity for your infrastructure to remain operative and effective over its planned lifetime) taken into account in your funding/decision making process? What are the main criteria analysed? What main challenges have you identified that threaten sustainability from your viewpoint?
3. How is RI effectiveness (i.e. the capacity for an infrastructure to deliver the expected scientific services and output over its planned lifetime) taken into account in your funding/decision making process? What main challenges have you identified that threaten effectiveness from your viewpoint?
4. More specifically:

a. Is your funding/financing/decision-making process adapted to RI needs? (for national and international RIs). Was it adapted specifically according to anticipated needs (or is it just a subpart of the normal research funding/decision-making process)

b. Is your funding/financing/decision-making process adapted to RIs' life cycle phases? (establishment, construction, implementation, operation, upgrades, transformation or termination). If so, how?

c. Are you using or inviting risk assessment strategy set up to deal with unexpected costs/events? How do you deal with unexpected needs (e.g. linked to cost overrun, new technological developments, new scientific needs, gain or loss of funding members, political instability and delays in funding ...)

d. How do you fund/support RI operation phase? For medium to long term planning? Do you have flexible mechanisms set up? Do you have long-term funding schemes available? (is it allowed within your current country budget system ?) If not, how do you deal with current needs/requests? What model would be more appropriate?

e. Do you require/invite/reward cost saving actions? How so?

f. Do you allow/invite/reward RIs to seek external sources of funding? How so? what feedback do you get?

g. How do you fund/decide on upgrades?

h. How do you take into account the various contributions from various members, if any (in kind, tangible vs intangible…)? Do you take amortisation/depreciation of assets into account in your financial plans and funding process?

i. Do you support a specific human resource policy and strategy for RIs? What are they (statute of the staff? training policy? policy for non-nationals…?)

j. How do you plan and support potential termination or re-use of RIs?

Questions for RI users

1. Brief presentation of the user/user institution:
   - RIs used
   - Objectives in using RIs, importance in research projects (How important to your research is the use of a specific RI?)
   - Funding and decision-making process for users
2. What does RI sustainability means to you (i.e. the capacity for your infrastructure to remain operative and effective over its planned lifetime); how important is it to you as a user? What are the main challenges you may have encountered related to RI sustainability that may affect you as a user?
3. What does RI effectiveness means to you (i.e. the capacity for an infrastructure to deliver the expected scientific services and output over its planned lifetime); What are the main challenges you may have encountered related to RI effectiveness that may affect you as a user?
4. More specifically:

   a. How do you fund your access/use of RI; Is it adapted to your need?

   b. What are your needs regarding long-term/regular access to RIs; do you encounter difficulties in fulfilling such needs?

   c. How efficient is your use of RIs in terms of access (processing proposals, seeking funding support…) and use (training, support, data gathering and processing…) ; do you have suggestion to improve such processes ?

   d. How costly is the use of RIs? Is it correctly evaluated? Do you have to pay for access? Are you prepared to pay for access (and if so, under which condition?)

   e. Do you have specific exchange with RI administrators regarding your special needs? Future needs? Needs for upgrades? Use of competing RIs ?

Appendix 3. List of expert interviews

Decision makers

- Christian Chardonnet: Head of the Large Scale Facility Department, Ministry of Higher Education and Research, France
- Daan du Toit: Deputy-Director General for International Co-operation and Resources, Department of Science and Technology DST, South Africa
- Kyung Hoon Kwong: Director General, National Research Facilities and Equipment Center NFEC, South Korea
- Salvatore La Rosa: Ministry of Education, University and Research, Italy
- Beatrix Vierkorn-Rudolph: Deputy-Director General for Large Research Infrastructures, Energy and Basic Research, Federal Ministry of Education and Research BMBF, Germany
- Ditta Zizi: Manager of the Research and Higher Education Infrastructure, Research and Economic Group, Department of Education and Training, Australia

Funders

- Benjamin Brown: Senior Science and Technology Advisor in the Office of Science, Department of Energy, United States
- Tom Collins: Senior Portfolio Developer, Wellcome Trust, United Kingdom
- Maria Faury: Deputy Director for Research Infrastructures at the Directorate for Fundamental Research, French Alternative Energies and Atomic Energy Commission CEA, France
- Algis Krupavičius: Lithuanian Research Council, Lithuania
- Kas Maessen: Secretary of the National Committee for Large Scale Research Infrastructures, Netherlands Organisation for Scientific Research NWO, Netherlands
- David Moorman: Senior Advisor for Policy and Planning, Canada Foundation for Innovation CFI, Canada

Research Infrastructure Managers

Single sites

- Prof. Andrew Harrison: Chief Executive Officer, Diamond Light Source, United Kingdom
- Dr Yoshihide Hayashizaki: Director, RIKEN Omics Science Center, Yokohama, Japan
- Prof. Stephen Mobbs: Director, National Centre for Atmospheric Science NCAS, University of Leeds, United Kingdom
- Prof. Antonio José Roque da Silva: Director, Brazilian Synchrotron Light Laboratory LNLS, Campinas, Brazil

- Prof. Suprakas Sinha Ray: Chief-Researcher and Director, National Centre for Nano-Structured Materials, Pretoria, South Africa
- Prof. Jan Steyaert: Head of the Steyaert Lab on nanobody-enabled structural biology, Vlaams Institute for Biotechnology, Free University Brussels, Belgium
- Dr Yoichiro Suzuki: Director, Kamioka Observatory, University of Tokyo, Japan
- Dr Sara Wells: Director, MRC Mary Lyon Centre, Oxfordshire, United Kingdom

Distributed sites

- Dr Robert Martin ‘Rob’ Adam, Director, Square Kilometre Array SKA South Africa Project, Cape Town, South Africa
- Prof Tim Clancy: Director, Terrestrial Ecosystem Research Network TERN, Canberra, Australia
- Dr Franziska B. Grieder: Director, Office of Research Infrastructure Programs ORIP, National Institutes of Health NIH, Bethesda, MD, US
- Prof. Yashwant Gupta: Board Member, Square Kilometre Array SKA & Dean of the Giant Metrewave Radio Telescope GMRT Observatory, India
- Dr Alison Kennedy: Director, Partnership for Advanced Computing in Europe PRACE, Brussels, Belgium
- Jana Kolar: Director, Central European Research Infrastructure Consortium CERIC, Trieste, Italy
- Dr Steven Krauwer: Executive Director (2012-15) & Senior Advisor (2015-), Common Language Resources and Technology Infrastructure CLARIN, University of Utrecht, Netherlands
- Dr John La Salle: Director, Atlas of Living Australia ALA, Canberra, Australia
- Prof. Jan-Eric Litton: Director-General, Biobanking and BioMolecular Resources Research Infrastructure BBMRI, Graz, Austria
- Dr Catalin Miron: Deputy Director, Extreme Light Infrastructure Delivery Consortium ELI-DC, Belgium, Brussels
- Dr Mark Moore: Executive Director, International Mouse Phenotyping Consortium IMPC, California, US
- Prof. Beth Plale: Co-Director and Chair, HathiTrust Research Center, Bloomington, IN, US

User Group Representatives

Single sites

- Prof. Jon Goff: Chairman, ISIS User Committee, Royal Holloway, United Kingdom
- Antonio Tejeda: President, ORGanisation des UtilisatEurs de Soleil ORGUES, Orsay, France

- Prof. Claire White: Vice-Chair and Chair (2013-16), User Group of the High Flux Isotope Reactor HFIR and the Spallation Neutron Source SNS, Oak Ridge, TN, US

Distributed sites

- Prof. Andrea Mele: Polytechnic University of Milan, Materials and Chemical Engineering "G. Natta", Milan, Italy, user of the Central European Research Infrastructure Consortium CERIC, Trieste, Italy
- Prof. Ullrich Pietsch: Chair, European Synchrotron User Organisation ESUO, Siegen, Germany

Appendix 4. Participants at the OECD GSF workshop in Geneva, May 2016

Name	Country	Institution
Hans Rudolf Ott*	Switzerland	Swiss Academies of Arts and Sciences;ETH Zurich/ co-chair, GSF Expert Group
Satoru Iguchi*	Japan	Head of Radio Astronomy Division, National Astronomical Observatory of Japan/ co-chair, GSF expert group
Roger Pfister*	Switzerland	Swiss Academies of Arts and Sciences
Catherine Ewart*	United Kingdom	Head of Stakeholder and International Relations, STFC
Massimo Altarelli*	EIROforum	Chair, EIROforum/ Managing Director XFEL
Frédéric le Pimpec	EIROforum	EIROforum/XFEL
Maud Evrard*	Science Europe	Senior Policy Officer , Science Europe
Lise Trondsen Sagdahl*	Norway	Senior Adviser, Norwegian University of Science and Technology
Jan Hrusak*	Czech Republic	Academy of Sciences
Matthias Barth*	Germany	DLR Project Management Agency
Man Hyung Cho*	Korea	Hannam University
Andra de Candido*	EU	Policy Officer, DG Research
Hans Chang*	Netherlands	Former Director, Royal Academy of Sciences
Laurence Lenoir*	Belgium	Senior advisor, BELSPO
Daniel Adams*	South Africa	Chief Director: Basic Sciences and Infrastructure, Department of Science and Technology
Ditta Zizi*/**	Australia	Branch Manager, Research and Higher Education Infrastructure, Department of Education and Training/Chair, G7+5 GSO on RIs
Mats Johnson*/**	Sweden	Senior advisor, Ministry of Education and Research
Christian Chardonnet*	France	Department Head, Research Infrastructures, Ministry for Research and Higher Education
Duarte Borba*	EIROforum	Senior Advisor, EIROforum/EUROfusion
Altaf Carim*	US	Assistant Director for Research Infrastructure, Office of Science and Technology Policy (OSTP)
Carlo Rizzuto*	Italy	Central European Consortium of Research Infrastructures-ERIC
Frédéric Sgard*	OECD-GSF	OECD GSF
Hiroshi Nagano**	Japan	GRIPS/Chairman, OECD GSF
Asbjørn Mo**	Norway	Director, Research Infrastructures, The Research Council of Norway
Jeanette Ridder**	Netherlands	Senior policy advisor, Ministry of Education, Culture and Science
Jana Bystřická**	Czech Republic	Head of Unit of Strategic Programmes´ Management, Ministry of Education, Youth and Sport
Jarmila Horská**	Czech Republic	Ministry of Education, Youth and Sport
Sun Kun Oh**	Korea	Konkuk University
Sky Gross**	Israel	Director, Division of Social Sciences and Humanities, Ministry of Science, Technology and Space
Thierry Courvoisier**	Switzerland	Swiss Academies of Arts and Sciences
Adrian Rohner**	Switzerland	Scientific Advisor , State Secretariat for Education, Research and Innovation
Robert Grabel**	Poland	Chief Expert, Ministry of Science and Higher Education
Arja Kallio**	Finland	Director, Academy of Finland
Michal Rybinski**	Poland	Ministry of Science and Higher Education
Omer Furkan Sirkeci**	Turkey	Policy Expert, TUBITAK
Erik Van de Linde**	Netherlands	Head of science policy and advice, Royal Academy of Arts and Sciences
Umberto Dosselli**	Italy	Italian Permanent Mission in Geneva
Fabiola Gianotti***		Director General, CERN
Ulrich Pietsch***	Germany	Chair, European Synchrotron Users Organisation (ESUO)

Francesco Sette***	ESRF	Director General, European Synchrotron Research Facility (ESRF)
John Womersley***	United Kingdom	Chair, ESFRI/CEO, STFC
Stevan Krauwer***	Netherlands	Senior advisor, CLARIN
Catalin Miron***	Roumania	Deputy-Director General, Extreme light Infrastructure ELI
Beatrix Vierkorn-Rudolph***	Germany	Deputy-Director General for Large Research Infrastructures, Federal Ministry for Education and Research (BMBF)
Antonio José Roque da Silva***	Brazil	Director, Brazilian Synchrotron Light Laboratory
Carthage Smith	OECD-GSF	Head, OECD-GSF
Taro Matsubara	OECD-GSF	OECD-GSF
Dai Qian	OECD-GSF	OECD-GSF
Jean Moulin	Belgium	BELSPO/OECD-GSF
Myung S. Lee	Korea	Senior researcher, Korea Institute of S&T Information (KISTI)
Inmaculada Figueroa	Spain	Deputy-Director General for International relations, Ministry of Economy and Competitiveness
Jana Kolar	Slovenia	Executive Director, Central European Research Infrastructure Consortium (CERIC-ERIC)
Christian Renner	Germany	Progamme Director, Deutsche Forschungsgemeinschaft (DFG)
Denis Perret-Galix	France	Research Director, CNRS-IN2P3/CERN
Ondrej Hradil	Czech Republic	Senior Analyst, Central European Institute of Technology
Merja Särkioja	Finland	Senior Science Adviser, Academy of Finland
Sinha Ray Suprakas	South Africa	Director, DST/CSIR national centre for Nano-Structured Materials
Maurizio Bona	CERN	Advisor to the Director-General, in charge of relations with International Organisations, CERN
LIN Xin	China (People's Republic of)	Deputy Director-General, Chinese Academy of Science and Technology for Development (CASTED), Ministry of Science and Technology (MOST)
KANG Qi	China (People's Republic of)	Associate Researcher, Institute of S&T System and Regulation ,CASTED/MOST
LIN Xianlan	China (People's Republic of)	CASTED/MOST
YANG Juan	China (People's Republic of)	CASTED/MOST
GAO Yi	China (People's Republic of)	CASTED/MOST
Christiane Alba-Simionesco	France	CEA/ Chairman, European Neutron Scattering Association (ENSA)
Maria Faury	France	Associate-Director for Material sciences and Research Infrastructures, CEA
David Moorman	Canada	Senior Advisor, Policy and Planning, Canadian Foundation for Innovation (CFI)
Gabriel Chardin	France	Chair of the CNRS Research Infrastructures Committee, CNRS/IN2P3
Allen Weeks		Head of Communications, External Relations and In-kind Management, European Spallation Source (ESS)
Ute Gunsenheimer		Head of External Relations & EU Projects, European Spallation Source (ESS)
Sofie Björling	Sweden	Head of Division, Research infrastructures, Swedish Research Council
Helmut Schober		Director of Science, Institut Laue Langevin (ILL)
Martin Walter		Senior Advisor Directorate, Institut Laue Langevin (ILL)

* Member of the GSF Expert group on RI sustainability
** Delegates to the GSF
*** Invited speaker.