**OECD Global Science Forum (GSF) Activity**

**“Strengthening the sustainability and effectiveness  
of international research infrastructures”**

**Literature review (state: 7 December 2015)**

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1. **Introductory notes**

This literature review relies on texts provided mainly by the Secretariat at the OECD Global Science Forum (GSF), complemented with information from staff at the Swiss State Secretariat for Education, Research and Innovation (SERI) and work by the author of this documents, i.e. the assistant to the co-chair of this GSF Activity. All available texts were scanned alongside the terms of reference proposed for this GSF Activity and relevant passages were organised in corresponding chapters below. All referenced literature is compiled in a bibliography, followed by a list of additional questions that emerged as a result of the literature review.

With the exception of two texts (Péro 2011 and 2007), all other references have an online link to documents that are available open access (NB. If clicking on the link produces an error message, copy the link and insert it in the address line of your Internet browser). In addition, the material is also available on the web platform <https://www.innovationpolicyplatform.org/strengthening-sustainability-and-effectiveness-international-research-infrastructures-0/ri-1-0>.

1. **Literature review**
2. **Essential general reading**

European Commission. 2010. [*Cost control and management issues of global research infrastructures: report of the European expert group*](https://ec.europa.eu/research/infrastructures/pdf/cost_control.pdf). Brussels.

Chapters “Political issues” (p. 9-10), “Governance” (p. 11-12), “Project approval” (p. 13-16), “Management” (p. 16-17), “Project controlling and culture” (p. 18-19) and “Costs” (p. 22-23).

[Ramiri handbook](http://www.ramiri-blog.eu). 2013. (online tool, funded under a grant agreement of FP7, the 7th Framework Programme for Research and Technological Development of the European Union).

Chapters 4 “[Finance](http://www.ramiri-blog.eu/index.php?n=Main.Fina)” and 5 “[Human resources](http://www.ramiri-blog.eu/index.php?n=Main.Hure)”

1. **Financial issues**

Chapter 3 “Cost-sharing” (p. 8-15) on the models for operation and construction of the vessel and on regarding contributions foreseen for the consortium members as well as Chapter 5 “Investment vs access” (p. 19-23) on the trade off between member contributions and their access rights to the vessel. (ERICON, 2011)

1. **Best practices and/or novel solutions to help reduce costs for construction and implementation**

“Research funding agencies, institutions, and private and philanthropic organizations have often assumed the initial start up and infrastructure costs and some initial operational costs of individual biobanks. But there has been an underlying belief that biobanks at some point should be capable of becoming ‘‘self-sustaining.’’ This may be achievable in the context of planning a large national infrastructure with a 15- to 20-year life cycle period. But for most existing types of biobanks this has not proved possible (...).” (Watson, 2014, 60-1)

“Stakeholder Engagement and Financial Commitments. Identification and the sub- sequent engagement of stakeholders should be done early in the conceptualisation. The commitments of the institutions behind the scientists who initiate the project are crucial because ultimately research infrastructures should be embedded in institutions. From the start they should be involved in the project development. Stakeholders from the funding side (governments, research councils, EC, private sector) are obviously important for funding the construction and operations. lt is important to engage them early in the project development. Especially the engagement of governments is both essential and often complex. Essential because including the project on national and ESFRI Roadmaps often is a condition for receiving funding. Complex because in different countries the processes for accessing the various government levels are different. This should be made a specific work-package in the project development, requiring high-level leadership with the right competences.” (European Commission, 2013, 20)

1. **Operating models most appropriate for different types of RIs (single sites, distributed, e-RIs, etc.)**

“While “one-off” project funding can be used to address a specific research question, or to emphasize priority areas for investment in research, it is not an adequate mechanism to support the operation of a large-scale RI and, through this, to build and maintain basic research capability in the long term.” (EIRO, 2015, 4)

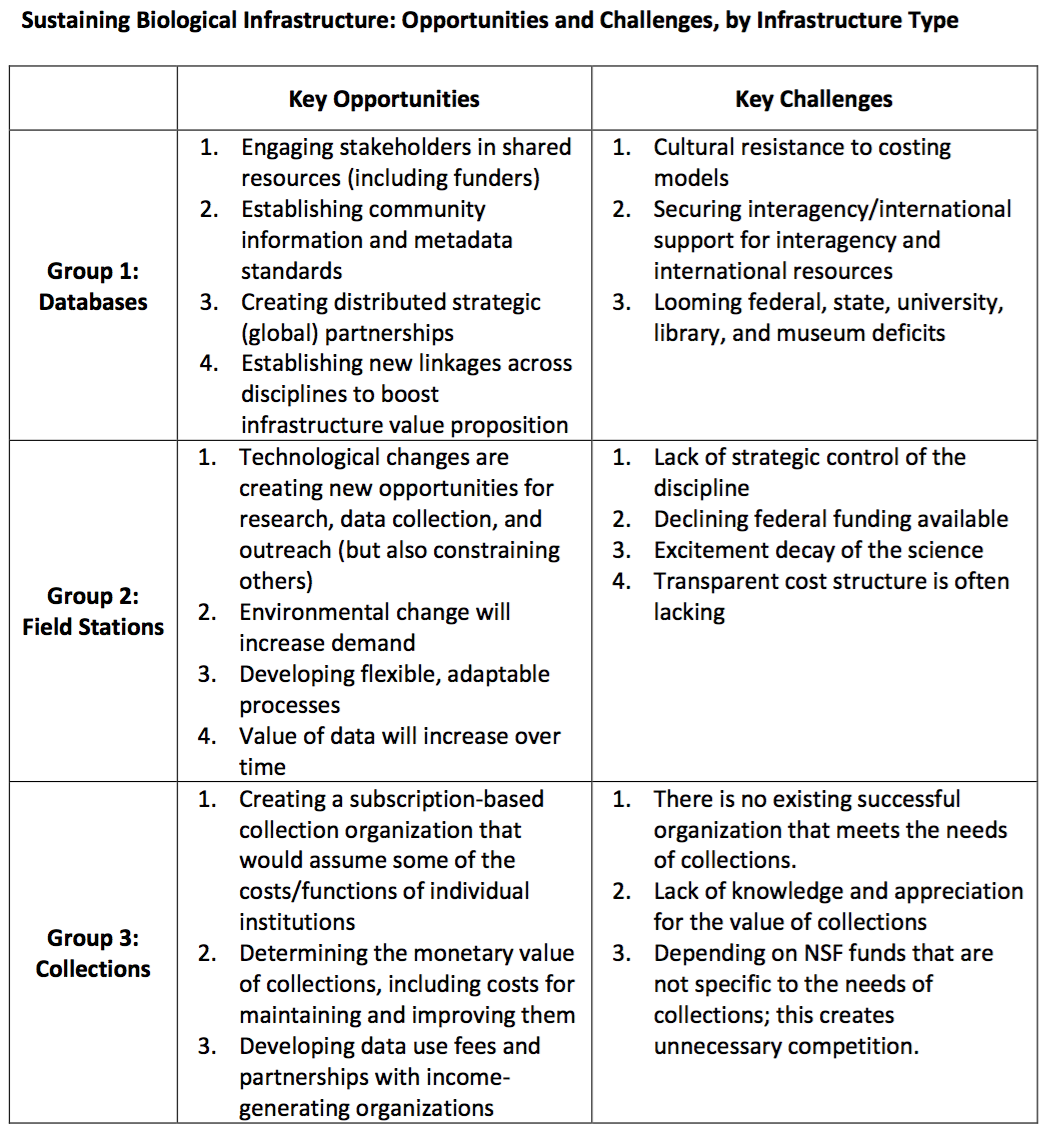
“Considering therefore that all RIs need adequate resources to stay at the front-line – both human and capital resources – these facilities can only be successful if they operate with a favorable long-term perspective, i.e. one that enables long-term financial planning with appropriate guarantees by the funding countries or other shareholders. This implies the existence of regulations ensuring a long-term commitment from the funders. Crucially, the long-term financial planning must cover operations cost, including the necessary maintenance and instrumentation upgrade costs. The long-term nature of basic research calls for long-term security for the supporting RIs. A common characteristic of the EIROs is that they are able to link long-term funding with clearly defined scientific objectives/programmes. In addition to the strong scientific case, transparent evaluation and reporting arrangements facilitate funding decisions.” (EIROforum, 2015, 5)

“In the ensuing discussions, one of the most common challenges that participants identified was the user community’s aversion to fee structures. When exploring funding models that do not rely entirely on   grant funding, many organizations have at least investigated some type of user fee. Depending on the resource and the user community, these discussions can result in serious backlash. In communities where free access to infrastructure is typical, significant cultural change may be necessary for a user- pays model to be successful. Participants identified several broad factors that would be important to this cultural change:

1. Each project needs to analyze its own user community to determine how to implement user fees effectively. Important questions to answer include:
   * 1. What do the users value the most?
     2. What are they willing to pay for, and how much? For example, most users are currently  more receptive to charges for software and services than they are to data access fees.
     3. What level of cost would be prohibitive?
     4. How can we make services personally useful, important, and enjoyable, so that users  are willing to donate to keep the system going?
2. There is a need to involve agencies and the international community. If there are other related  projects out there providing free access, competition will render any user fee model ineffective.
3. It is important to get advice from independent, external experts who are not wrapped up in the  day-to-day use of the resource.

One participant described how they successfully implemented a user fee for their project:

*Because our Governing Board was initially comprised entirely of scientists, they had the same strong resistance to implementing user fees to build a sustainable funding model. There was a conflict of interest, so we brought in members from the non-profit world to help rethink our funding model; some distance between the users and decisions about usage fees was needed. Our rate structure started out very low – the only way we were able to figure out what people were willing to pay was to charge a fee and monitor its impact on use. As it turned out, our rate structure was low. We have been able to increase our fees without seeing a drop in use, while simultaneously increasing the value and demand of our services.*” (ESA, 2010, 3-4)



(ESA 2010, p.5)

“At the top-most level, the concept of sustainability is relatively easy to define: eventually, e-Infrastructure provision and usage will need to become independent of *specific* funding streams such as the UK e-Science Programme. If e-Science produces enough additional value for a large enough number of people then it should be possible to establish business models that guarantee the provision of the necessary funding to sustain an e-Infrastructure.” (Voss, et al. 2007, 1)

“Different biobanking network models have evolved and can be viewed as fostering sustainability primarily in one or more of the three dimensions. For example, in the operational dimension by focusing on components such as consent, biospecimen accrual, and/or shared storage; in the financial dimension by focusing on components such as performance metrics, user access, and customers’ needs; in the social dimension by focusing on components that promote common standards. A well established and successful example of a network in the United States that addresses the operational dimension is the Cooperative Human Tissue Network (CHTN). Adaptations of this model have involved creating a common efficient accrual system for biobanks. An example of fostering sustainability in the social dimension is the Canadian Tumour Repository Net- work (CTRNet) whose funding from the Institute of Cancer Research Canadian Institutes of Health Research (ICR-CIHR) is restricted to network activities (as opposed to biobanking) such as creating certification programs, standard operating procedures and policies. The Public Population Project in Genomics and Society (P3G) and the Biobank Resource Centre (BRC) are examples of re- sources that have harnessed collective knowledge across different networks to further develop and disseminate tools to implement sustainability strategies. The P3G is a not-for-profit consortium that works to encourage collaboration between researchers and biobankers, promotes harmonization of data, optimizes the design, setup and research activities of studies, biobanks, research databases and other similar health and social research infrastructure and facilitates the transfer of knowledge and provides training. The BRC was developed in partnership by the University Of British Columbia Office of Biobank Education and Research (OBER) and CTRNet to provide services and tools that support researchers in establishing and operating biobanks, to educate and promote certification of biobanks in order to enhance quality through adoption of best practice standards, and to publish biobank market research data. This kind of data is essential to successfully execute a biobanking business plan to facilitate shifting to customer focused biobanking. The BRC is an example of a resource that offers strategies and solutions in all sustainability dimensions.” (Watson, 2014, 63-4)

“Many BRCs currently charge fees to those who want to obtain biological materials and gain access to associated databases. Varying fee structures can be applied for access depending on the nature of the biological material, the status and constraints of the institution holding the resources and its relationship with the public and private sectors, national policies and relevant international frameworks.

There are two major models that have been examined and are currently in use by different BRCs:

*Cost recovery*

Cost-recovery is defined as recovering the full or partial cost of a project or service, including both its fixed and marginal costs. Typically, it is discussed in the context of cost recovery from users of the services provided, although direct grant funding can be considered as a particular form of cost recovery and is discussed below. (...)

*Institutional funding*

A common model for the financial sustainability of a resource is through allocated funds obtained from a single public institution towards the respective BRC. This approach is most commonly applied to data resources. An example of this model are the databases operated by the National Center for Biotechnology Information (NCBI; http://www.ncbi.nlm.nih.gov/) which receives funds from both the National Library of Medicine (NLM; http://www.nlm.nih.gov/) and the NIH (http://www.nih.gov/).” (Chandras, 2009, 4-5)

“With regard to the business models examined in this manuscript as potential patterns to be adopted by BRCs for their financial sustainability, the ‘full cost recovery’ model which has already been tested by some resources has proved to not be viable for data resources. The ‘fee- for-service’ or ‘partial cost-recovery’ model is already practiced, at least in part, by some BRCs. For data provided this is contrary to the UPSIDE recommendations, according to which data should be shared, but in practice most BRCs employing this approach are providing material resources, which have substantially higher costs and it is open to debate if these can reasonably be provided completely free of charge. The most promising model examined in this manuscript is ‘Institutional Funding’ which seems to provide a secure environment for the BRCs to develop and implement a secure data management plan and potentially ensure the long-term accessibility of the related project data. Indeed agencies around the world such as the NIH and the EU through ELIXIR (http:// www.elixir-europe.org), are now turning their attention to working out how best to assist the growth of validated and accessible databases.” (Chandras, 2009, 8)

“Several research infrastructures planning the development of a large physical infrastructure depend on large in-kind contributions from the participating institutions. This exposes the project to the risk that crucial components might be late, therefore delaying the development of other crucial elements and negatively affecting the project schedule and cost. The hiring, procuring and spending related to the in-kind contributions from the different participating institutions should be assessed and monitored by an in-kind committee or project office with real powers, and interface documents should be developed to make sure that the contributions are properly valued and delivered on time and within budget.

For all distributed research infrastructures, care should be taken to minimise the project cost increase that may derive from splitting the planned major procurement into individual contracts of national nodes with suppliers. This is sometimes compounded by the stringent time constraints for the use of structural funds or other types of financial instruments and the incomplete definition of the 'fast-track' procurement procedures that projects hope that ERICs would be allowed to use. A reasonable procurement plan, describing specific initiatives to bring the project to the Implementation Stage on schedule, should be developed and independently assessed. The support of an international procurement task-force might be warranted for multi-site research infrastructures.” (European Commission, 2013, 135)

1. **Effective models for securing operational costs**

* “Spreading costs across institutions or a member network. This can reduce overall expenses, particularly if all members are invested and truly value the common infrastructure.
* Positioning data as something new and/or creating software or services. Users are more receptive to fees that are built into a product or service. This increases value as well, so users are willing to pay more.
* Including infrastructure costs explicitly in all grants and contracts to the program. (…)
* Building relationships with partner institutions and state governments to ensure the  infrastructure is relevant. Partners can help take up slack if needed, particularly if the project is important to their own work, and reaching out to state institutions can help justify the project’s importance and need for state funding.
* Beginning initial efforts at creating endowments. This can be challenging in the current economic climate and is a long-term effort, but one with significant potential for long-term, stable funding.
* Charging more for commercial clients, so academic users can pay less.
* Creating economies of scale. Sometimes increasing products and lowering prices can be  financially advantageous. Associating infrastructure with an existing institution or university can  help reduce some overhead costs.
* Charging membership fees.” (ESA, 2010, 2-3)

“**Uncertainty about funding**: uncertainty about funding caused by short-term funding models and lack of diversity of funding sources, leading to an exposure of multiple efforts to the same risks. **Response**: negotiations with funding organisations to provide longer-term funding opportunities, subject to regular review. Transition of software/services to a commercial environment, which develops, maintains, and sells the services/software.” (Voss, et al. 2007, 4)

“ESDS [Economic and Social Data Service] is the UK’s national data service, funded jointly by ESRC [Economic and Social Research Council] and JISC[[1]](#footnote-1), which provides access and support for an extensive range of key economic and social data, both quantitative and qualitative, spanning many disciplines and themes, and available to researchers free at the point of use. It must be questioned whether the e-Infrastructure project would be sustainable under this model. First, as noted above, there are unmistakable signs that, in the future, UK funding bodies will expect institutions hosting research projects to absorb some of the costs of maintaining the research resources these projects create. This may, in turn, encourage host institutions to introduce charges for services provided, such as the micro-payments model adopted by many journal publishers.” (Voss, et al. 2007, 6-7)

“The preservation of high-quality biospecimens and associated data for research purposes is being performed in variety of academic, government, and industrial settings. Often these are multimillion dollar operations, yet despite these sizable investments, the economics of biobanking initiatives is not well understood. Fundamental business principles must be applied to the development and operation of such resources to ensure their long-term sustainability and maximize their impact. The true costs of developing and maintaining operations, which may have a variety of funding sources, must be better understood. Among the issues that must be considered when building a biobank economic model are: understanding the market need for the particular type of biobank under consideration and understanding and efficiently managing the biobank’s “value chain,” which includes costs for case collection, tissue processing, storage management, sample distribution, and infrastructure and administration. By using these value chain factors, a Total Life Cycle Cost of Ownership (TLCO) model may be developed to estimate all costs arising from owning, operating, and maintaining a large centralized biobank. The TLCO approach allows for a better delineation of a biobank’s variable and fixed costs, data that will be needed to implement any cost recovery program. This article represents an overview of the efforts made recently by the National Cancer Institute’s Office of Biorepositories and Biospecimen Research as part of its effort to develop an appropriate cost model and cost recovery program for the cancer HUman Biobank (caHUB) initiative. All of these economic factors are discussed in terms of maximizing caHUB’s potential for long-term sustainability but have broad applicability to the wide range of biobanking initiatives that currently exist.” (Vaught, et al., 2011, 24)

“The current access policies and funding schemes of computing e-infrastructures represent a huge challenge for the sustainable growth of computing e-infrastructures and a serious jeopardy for investments made into these e-infrastructures. In order to be able to address these issues, the economics of computing e-infrastructures has to be understood thoroughly. As a first step in this direction, this paper conducts a set of computing e-infrastructure case studies and discusses the economic issues of different global computing e-infrastructure efforts. The analyses results show that the major shortcomings that need to be resolved are the insufficient involvement of the private sector in the development of computing e- infrastructures, the restricted user access to e-infrastructure resources, and the lack of sustainable funding. As a solution to these shortcomings, we propose a new funding and governing model for computing e-infrastructures. It follows a token-based market mechanism that allows a business-oriented operation of the computing e-infrastructure. We argue that this new model fosters the transition towards a sustainable computing e- infrastructure, being another requirement for successfully implementing the cloud computing vision. Our arguments are supported by an analytical analysis.” (Bany Mohammed & Altmann, 2010, 739)

“Funded by the European Commission under FP7 the OSIRIS project started on January 2010. The OSIRIS consortium is composed of participants involving several institutes, Public Authorities and National Champions across 13 EU Members States and Associated Countries and regions with direct links to existing and future ICT European research infrastructures (RIs), i.e., High Performance Computing, Grids, Networks, Micro/Nanoelectronics and Future Internet. The main aim of the OSIRIS project is to build the platform, mechanism and models required to secure the efficient involvement of Member States, Associated Countries and regions in developing cross border public-public partnerships and to establish a coordinated approach to future large scale investments in international European ICT RIs. For this reason, a thorough analysis of the business models of current international ICT RIs is required. This analysis will be presented in this report. (…) The aim of this report is to provide a source of information on the possible business models of how ICT RIs can be managed and supported once a need for them has been identified and the RI has been founded.

Once the RI has been founded, there are four important aspects that describe the RI business model:

* + Governance;
  + Sustainability;
  + Access Policies;
  + Operational principles.

These aspects are described in detail in this document. Governance describes the control of the RI, in other words who determines the direction the RI will take in the future. Sustainability describes the future of the RI and how it will continue to operate. Whereas the arguments prior to the founding define whether an RI will be created, sustainability defines whether the RI will continue to exist. Access policies describe the interactions of the international ICT with one of its most important stakeholders: namely its users. Operational principles describe how the sustainability, the governance, and the access policies are implemented at an operational level.” (OSIRIS, 2012, 3)

“Some key insights and general recommendations for financing a biobank RI include;

1) The population of biobanks in the UK is extremely diverse, reflecting differences in purpose, location and ownership; size, scale and scope; as well as financing and access arrangements. The cases presented in this report illustrate that it is not possible (or desirable) to apply a standard cost model across such a diverse population.

2) Coordination across this diverse population requires dedicated resources. This could take a variety of forms. A coordination centre may be required and this should be financed centrally by public funds, possibly supplemented by industrial funding. Such a scheme requires careful consideration to allow fair access by all users. Central funding is necessary to support the development and maintenance of a national searchable portal for HBS [human biological samples] and drive quality standards across the biobank population.

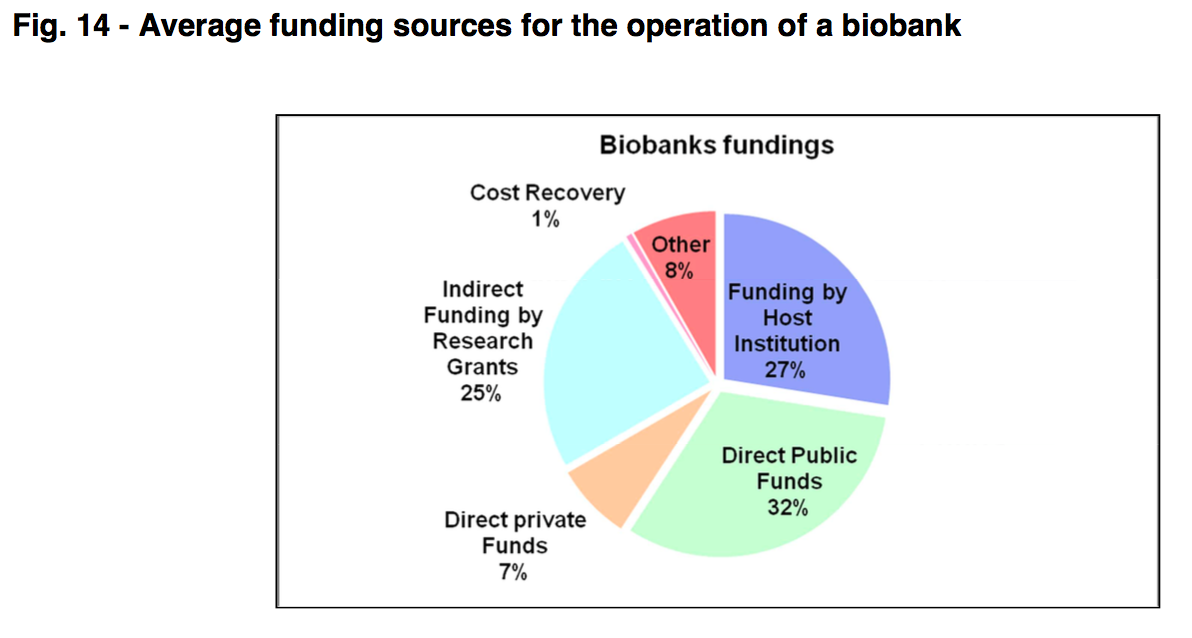
3) The majority of the existing financial arrangements do not support the long-term maintenance and provision of high quality HBS. This report recommends that; a) HBS acquisition should continue to be costed into projects and project proposals to ensure biobanking is driven by research needs; b) core biobanking activities and facilities should be supported by central public funds to overcome discontinuity of funding problems and enable investment in best practice. These core costs could be distributed directly to the host public institutions; and c) the marginal costs associated with accessing samples could be paid for by the user.

These financial arrangements, incorporating the adoption of standards and the enrichment of the annotated data associated with HBS by users, will support the creation of a sustainable distributed biobanking RI necessary for the delivery of stratified medicines, and the realisation of the associated societal and economic benefits. The opportunity costs to the UK of not investing in a comprehensive biobanking RI could be significant.” (Lee, 2013, 6)

“The Research Infrastructure Resource Model (RIR model) presented in this document, provides a method to declare costs for use of research infrastructure based on the full costs generated by the activity. The model has been developed to ensure that state of the art laboratories and scientific equipment can be made available for research and education, and so that the price for use of a RIR can be calculated using a transparent and relatively simple method. Furthermore; the model should contribute to maximisation of the primary operation of the laboratories while keeping the transaction costs as low as possible. The motivation for introducing RIRs is found in changes in the funding schemes and the focus on direct costs. The RIR model presented here has been developed in accordance with the guidelines from The Research Council of Norway. (...) The costs related to a Research Infrastructure Resource consist of four elements:

1. Space – rental and building related costs for research space such as laboratories and workshops
2. Scientific equipment – depreciation costs
3. Common operating consumables and service-/maintenance contracts, i.e. shared costs for all  users
4. Technical support – personnel costs for the technical support staff needed to sustain the operational infrastructure.” (Norwegian Association of Higher Education Institutions, 2014, 2014, 1)

“The soundest and most precise way of considering these costs would in our view be to allow full cost accounting as an option for research organisations operating RI. This would ensure that, where high indirect cost are generated by large RI and are precisely recorded in a sound accounting system, this precision does not get lost in approximations just for EU projects. Should this not be possible, a use of lump sums per unit of access (hours of beam time or days of ship use) might be the best solution, since this would at least assure that the sum would be fixed before the project starts and no ex-post audits would be necessary. This would be in line with the simplification purposes of H2020. In order for such a system to be in line with the usual accounting principles, it would however have to respect the underlying cost calculation of the participants for setting the lump sum, which would certainly challenge the concept of lump sums. In any case, a very precise and participant-specific mechanism for setting the amount of the lump sum would be needed, possibly based on the mechanisms used in FP7 for calculation unit cost for Transnational access. This again would certainly challenge the current concept of lump sums, but it might still be the best of the available options.” (Helmholtz Association of German Research Centres, 2013, 2)



BBMRI, 2012, 48

“The total costs of BBMRI-ERIC will be financed by cash and in kind contributions of Members and other income. Contributions of Members will be calculated according to the following model:

1) The membership contribution of each Member shall be composed of a base contribution and a variable share. Concerning the base contribution Members are stratified in two groups according to their number of inhabitants:

1) 20.000 € base contribution for Members whose number of inhabitants is below 3 Million

2) 25.000 € base contribution for Members whose number of inhabitants equals or exceeds 3 Million The overall amount of the variable share proportion is determined by subtracting the overall amount of base contributions from the overall amount of contributions by Members. The overall amount of the variable share is split among Members based on their percentage of total GDP of all Members.

International organizations shall pay 0.1 per mill of their annual regular budget as variable share proportion if they are Members. The fixed contribution for Observers shall be 30% of the respective category. None of the Members shall pay more than 25% of the overall amount of contributions by Members/Observers. (…) The Members of BBMRI-ERIC will set up their National Nodes under BBMRI-ERIC early in the first quarter of 2013 so that efficient interfaces between national biobanks and the Central Executive Management Office and the BBMRI Common Services can be implemented. The National Nodes are funded directly by each Member Country and are not part of the common BBMRI-ERIC budget. The size of the National Nodes and their budgets will depend on the complexity of the biobanking structures in the individual countries. There are minimal requirements defined for the set-up of a National Node to participate in BBMRI-ERIC. At least one person (National Node Director) reporting to the Director General has to be designated for each National Node. For financial planning National Nodes of an average size are assumed.” (BBMRI, 2012, 52-3)

“Financial and Stakeholder Support

An aspect of maturity of capital importance that many projects failed to meet at this stage is financial maturity. Few research infrastructures can show firm financial commitments for the relevant investments and operations from prospective partners, stakeholders and funding agencies. This is in stark contrast with the fact that many projects indicated that a major motivation for the establishment of a research infrastructure is to achieve visibility at the international level that would yield some type of priority at the national level and secure long-term financial commitments from the national governments and/or funding agencies. Several other findings and recommendations about financial and stakeholders support put forward in Chapter 3 are also of more general significance.

Often, during the interview process it emerged that there was no clear 'action plan' at European level, nor at national level, on how the research community should engage with the stakeholder community to have a project approved and funded. Seeking real engagement and commitment from stakeholders and funding agencies often occurs too late in the project, leading to delays, misunderstandings and potential disappointment. This often reflects weak links between the project leadership and national governments and a lack of knowledge of how the political process works. This in turn leads to unrealistic assumptions regarding the number of Member States ready to participate in the new research infrastructure. On the contrary, the AEG believes that a convincing Investment Strategy and an Engagement Policy with stakeholders should be developed early to pursue commitments at government level.

There are many different approval systems at national levels for funding research infrastructure projects. Sometimes commitments have been made at the level of the re- search institutes involved, sometimes, the commitments have been part of a national roadmap, and in some cases, the funding has been secured at the level of the Ministry of Research or other Ministries. Well-defined rules on 'who-does-authorise-what-by-when' are essential to avoid loops, where everybody waits for decisions to be taken by others. Even if some countries have well-defined rules and a model for approving funding, it is sufficient that one member of the Consortium not complying with the mechanism of transparency in the approval process of engagement with the stakeholder community can create problems for the research infrastructure as a whole. Credible parameters to monitor performance and target values for such parameters as KPis (Key Performance Indicators) for the project as a whole and for the user base expansion should be developed, also as an important tool to document the value added. This should be treated as a work-package in itself, requiring leadership with appropriate skills.

In several research infrastructures with a mainly academic user base, but proposing activities of obvious potential interest to industry and to the private sector, there appears to be a variable degree of uneasiness about the role of possible industrial sponsors. In modern times and in view of the emphasis that the European Union and governments worldwide are putting on societal impact and economic development, the diffidence towards the private sector seems outdated and difficult to justify. In some cases, the direct involvement of the private sector could be a useful avenue for expanding the activities, funding and societal impact of the planned research infrastructure.

In view of the difficulties encountered in achieving financial maturity, many research infrastructures propose to use a whole range of financial instruments, including grants from national funding agencies, structural funds and - far too often and optimistically - contributions from the European Commission under Horizon 2020. Some research infrastructures propose to use EIB financing as a mitigation strategy, without a clear prospective of who will be the borrower and where the money to pay back the loan will come from. The resulting potentially poor synchronisation of funding decisions from different sources is a major reason for potential or actual inefficiencies. A fundraising strategy to mitigate the consequences of this should be a project work-package, and in all cases, mitigation strategies should be put in place in case fundraising is only partially successful. This is sorely lacking in most of the research infrastructures examined.” (European Commission, 2013, 132-3)

“Ensure long-term sustainable funding and adoption of best user/stakeholder engagement and management practices Foster a long-term view of RI lifecycle and carefully crafted organizational concepts for pursuing sustainable high-end knowledge and technology evolution and innovation. Long-term sustainable funding of research and e-Infrastructures (networks, data and computation) is essential for trust and acceptance between users and infrastructure providers. Long-term funding needs to be based on the involvement of all stakeholders, including the European Commission, as in GÉANT; self-sustainability of RI depends on their nature and some may require partial continued support. Investment and operational costs should be made explicit as well as the associated sources of funds. Flexible business models, taking into account all investment and operational cost items and the various sources of cost coverage, are essential (i) to keep RI sustainable in the long run, (ii) to cope with societal, political and dynamic technological changes, and (iii) to initiate Public Private Partnerships (PPP).

EU project support tools and funding schemes should be used with full flexibility to allow support (Integrating Activities should be open to application by infrastructures with pertinent partners). Funding should be sustainable also after the establishment of the RI. Also, RI should be supported to bridge the funding gaps between planning, construction and operational phases (avoiding “near death experiences” when the funding of one phase ends without new funding for the next phase, risking to lose the people involved). This demands careful planning of the RI from the very beginning (including construction and operation).” (H2020 Advisory Group, 2014, 3)

“Financial aspects and business models with respect to sustainability of RI (RI) are briefly investigated below. This important aspect of sustainability is emphasised here because of the overall not-for- profit character of RI activities. In most cases, there is no need for a fast return on investments, and there is no need for an effective profit-making model. In the case of scientific advancement however, it is not straightforward to calculate any form of explicit return-on-investment. However, in a wider indirect sense, via economic exploitation of the research results achieved from utilising the available RI, the RI investments can in fact produce a return in a short period of time. On the other hand, there is a need for careful handling of the financial aspects (costs and cost coverage) and also a need for sophisticated business models towards arriving at an assessment of the financial stability of RI development and operation. The achieved financial stability is a basic pre-condition of sustainability. (...) Obviously the traditional funding practice has to be revisited and new business models are to be developed, tested, and, in cases where appropriate, duly applied.” (H2020 Advisory Group, 2014, 10-1)

“Five important comments should be made here.

1. First, there is of course no common, uniform business model for all infrastructures. A set of such models can perhaps be developed and introduced so that in the simplest case the traditional financing is maintained while in more complex cases some of the models can well be fitted to the specific features and characteristics of the infrastructure and its operation.
2. Second, it is of great importance to better learn to split operational costs from innovation costs, since their underlying funding scheme is completely different.
3. Third, paying for access to research infrastructure has never been taken into consideration in the past when calculating aggregate project costs, whether estimated or predicted. Therefore the need for assessing such costs when preparing project proposals and later, during the execution of the projects, is something new, which of necessity will have to be understood, accepted, and also learned, experienced, and finally, mastered by the researchers, research teams, or research organisations and also research funding bodies.” (H2020 Advisory Group, 2014, 12)
4. **Costs for agreed upon upgrades**
5. **Funding policies of contributing partners for good medium to long-term planning**

“**Continuity of Funding**

* Research infrastructure funding programs should be ongoing and predictable, to achieve optimal use of funds.
* Infrastructure that continues to be a priority should be able to access funding for ongoing operations.

*Guiding considerations*

* *Ongoing and predictable funding programs support a more strategic, collaborative and planned approach to research infrastructure investment.*
* *Ongoing operational funding for priority national and landmark research infrastructure assists in maximising the benefit from the original investment.*

**Holistic Funding**

* Funding required to support research infrastructure will vary between elements, including capital costs, governance, skilled technical support staff and operations and maintenance. Support should be available to cover these key elements.
* Funding programs should allow some funding for project development costs, either for a facilitation‐based process or for project development and scoping activities.
* In the context where not all national and landmark infrastructure would necessarily be replaced, depreciation for these facilities should not be funded by Australian Government funding programs. (…)

**Co‐investment**

* Co‐investment in research infrastructure is desirable as it demonstrates a commitment by the investing party/ies to the project. Any program requirements for co‐investment should be flexible to leverage maximum support.” (NRIC, 2013, 2-3)

1. **Contributions and tangible/intangible assets, taking amortisation/depreciation into account**

* “Organizations employ diverse methods for cost management and revenue generation, depending on their size and type. Almost all projects rely primarily on grants and contracts for  funding, but almost all are also trying to diversify their revenue streams.
* One core challenge for everyone was that many funders don’t see infrastructure sustainability as a priority; they tend to prefer funding new initiatives, rather than maintaining something that  already exists.
* Everyone agreed that simple maintenance versus being able to adapt, add value, and grow are  two very different trajectories with significant implications for managing costs and developing budgets.” (ESA, 2010, 3)

“Using this definition of sustainability, the following models are commonly used for the assembly and application of resources to *create* and then *sustain* an infrastructure element:

* + Open source: a leader (or a set of leaders) promotes a goal of creating an infrastructure element in a public manner and a community voluntarily forms to work together on this goal.
  + Closed partnership: a set of partners works together to create an infrastructure element, but the partner- ship is not open to external contributions.
  + For profit: a group creates an infrastructure element using its own resources with the goal of later selling, leasing, or licensing the element or its design to recover the expended resource and make a profit.
  + Dual licensing: a group creates an infrastructure element using its own resources with the goal of allowing academic free use (and depending on the license, perhaps gaining further free contributions from that academic community), while also selling, leasing, or licensing the element or its design to industry in order to recover the expended resource and perhaps make a profit, or at least, break even. This model also often has an implicit goal of not allowing other companies to financially profit directly from the element.
  + Open source and paid support: a group supports an open source element in exchange for resources from the users of that support. The support can include helping the users with the existing element, and adding features to the element for the supported users, though these added features become available to all users, not just those who have paid for support.
  + Foundation or government: one or more groups convince an organization that promotes public advancement that creating an infrastructure element will be a public good that should be supported.  (Katz and Proctor, 2014, 3”

“Large sensor-based infrastructures for radio astronomy will be among the most intensive data-driven projects in the world, facing very high power demands. The geographically wide distribution of these infrastructures and their associated processing High Performance Computing (HPC) facilities require Green Information and Communications Technologies (ICT): a combination is needed of low power computing, power and byte efficient data storage, local data services, Smart Grid power management, and inclusion of Renewable Energies. Here we outline the major characteristics and innovation approaches to address power efficiency and long-term power sustainability for radio astronomy projects, focusing on Green ICT for science.” (Barbosa, 2014, 1)

1. **Risk management strategies that can help mitigate unforeseen cost escalation**

“We believe elements of e-Research infrastructure can be placed in a three-dimensional space, as shown in Figure 1, and that doing this will lead to increased understanding of issues related to creating and sustaining these elements. The first axis is the temporal duration of the element. This ranges from 5 years for computer systems, to about 10 years for networks and instruments, 20 years for production software, 40 years for people, and infinity for data, including publications, which can be viewed as a subset of data. Note that these values are approximate and can be debated; they do not completely define the duration of the elements. They are points of reference, and any given infrastructure element might have a shorter or longer duration than the point of reference given above. (In particular, the idea of a temporal duration for an instrument is unclear, but one can certainly consider an instrument as having a lifetime during which it is useful to a research community as shared infrastructure.) However, the key point is that decisions that are made about creating and sustaining infrastructure elements need to include awareness of the expected lifetime of the element. The second axis is the spatial extent of the element. In an academic setting, this might range from a particular laboratory to a department, college or school, university, university system or regional alliance, nation, and beyond. This could also be thought of for general research institutions, which might have alternative administrative units in place of departments, colleges or schools, such as divisions or directorates. The third axis is the purpose of the infrastructure element. This ranges from the element being used for one particular problem—though in this case it’s unlikely to be infrastructure—to it being used for a variety of problems in one discipline (e.g., climate data from Arctic ice cores), to it being used for a variety of problems across a set of disciplines (e.g., molecular dynamics software), to it being used generally across all disciplines (e.g., a network, an HPC system). There are linkages between the temporal duration of an element and its purpose, e.g., although the lifetime of a given software element may be 20 years when just considering its technical context, if the element ceases to be useful to its user community then the life- time will be shortened.” (Katz D and Proctor, 2014, 2)

“In the financial dimension of sustainability we have de- fined three key areas: market strategy, customer focus and brand recognition. While there are many important activities within each of these three areas, the fundamental element should be the development and maintenance of a strategic plan.” (Watson, 2014, 64)

“One of the conditions for the real word’s sustainable development is the occurrence of a social change (also referred to as social development). By the same analogy stated above, this means that an e-Infrastructure can be sustainable only if a change occurs in the way we consider and support Virtual Organisations of users. Any model of long-term sustainable e- Infrastructures should then put the user at the centre and be scalable and dependable.” (Barbera, 2009, 4)

“Economic risk assessment:Owing to the complexity and long-term nature of such projects, a cost-based risk analysis is essential for obtaining the most realistic estimate possible of the development costs for a research infrastructure. Therefore, in the text, please specify and explain all foreseeable and significant risks and uncertainties that could result in changes in the individual and overall costs, and quantify the monetary consequences in table form in annex 4 “Economic risk assessment”.

Implementation phase risk analysis: In the implementation and realisation concepts, the potential risks and uncertainties should be described that are associated with the individual implementation steps. Please provide an extensive description of the type of risks that might occur in annex 8 “Implementation phase risk analysis” and briefly describe the economic impacts in the text (cf. 4.3.1). These risks include, for example, possible delays in work schedules, missing milestones, partners dropping out, or also technical and scientific risks that could arise particularly if preparatory R&D work is needed. Please also describe the impacts of the risks and uncertainties in respect of time schedules and the impacts on the scientific benefit of the research infrastructure, and specify the planned counter-measures.” (BMBF, 2015, 14-15)

“Risk strategy. To avoid costly miscalculations, mitigation strategies in the form of different scenarios, including multiple financial and technical options, should be elaborated. Who is in charge should something go wrong should also be listed. The research infrastructure should be able to rely on a well-defined track to reduce and manage all the risks linked to this inherent uncertainty. Risk considerations and evaluation are an essential part of each one of the five ‘modules’ explained above. Risks should be managed carefully at each project stage, to avoid surprises and unexpected cost escalations. Professional cost engineering procedures should be used and contingencies appropriate to the carefully evaluated risk should be planned to ensure effective and timely management of potential emergencies or cost overruns. Technical risks should be identified and mitigated as carefully as possible. A risk register appropriate to the project should be developed as soon as possible and updated regularly. Currently the exercise of developing such a register is extremely useful und helps the scientists to better understand the paths and procedures to be followed.” (European Commission, 2013, 21)

“The achievement of scientific goals in both basic and applied research can never be guaranteed so that the impact of scientific research infrastructures is inherently somewhat risky. Here, only the experience and the intuition of top scientists can give confidence to those having to support the project that important novel results will be obtained. Only the scientific proponents can do a substantial risk assessment of achieving the scientific goals and only a scientific peer-review of specialists in that research field could give substantial advice. In the more conventional fields needed to design and operate a research infrastructure, risk assessment can give a good picture of the likelihood of problems and of their sources. When dealing with management, organisation and procedures, engineering, ICT, cost engineering, quality control and reliability, market opportunities of services, administration (financial business, HR, procurement), safety and security etc. experience in those fields provides specific know-how and well-proven procedures to assess the probability of an infrastructure working smoothly, identify critical issues and select mitigating strategies to be put in place. Several other findings and recommendations reported in Chapter 3 are also of more general significance.

Risk considerations require a very in-depth knowledge of the organisation of the planned infrastructure and/or the technologies and the design of the technical facilities. At the time of applying for approval/financial support of an infrastructure, only the proponents can present a fairly reliable first risk list or report and should be expected to do so.

Some 50% of the projects examined had performed no risk analysis at all, and therefore had no credible mitigation strategies in place while a further 30% had performed only a partial risk analysis in some selected areas. Many of the risks- not only in technical infrastructures - can be identified only at a later stage of construction or even only during operation. A Risk Report therefore always requires a staged approach. With the organisation further maturing, new risks come up in more 'conventional' fields, where a lot of knowledge in fields far from the main discipline of the planned infrastructure is required. The management in many cases are not strong in such fields because of lack of experience and expertise. Here it is essential that help is sought from experts. Many of the possible risks at this stage are standard in industrial environments and assistance could be found from companies available on the market.” (European Commission, 2013, 137)

1. **Plan and management costs for termination phase**

“Costs of the utilisation and closure phases: For the presentation of costs for the utilisation and closure phases (operating costs, costs for closure and dismantling if applicable), the overall level of detail can be lower than in the presentation of costs for the development phase. The costs for the utilisation and closure phases are not estimated by the external experts. It is mainly a question of the plausibility and consistency of the concept as a whole; moreover these costs are even more difficult to predict owing to the longer time-span. In the cost estimation meeting, the experts check and assess the plausibility of the operating costs. In the text, please briefly explain and give reasons for the anticipated costs of the utilisation and closure phases, and include an annex 3 “Costs of the utilisation and closure phases”. Please also include binding statements in respect of taking on or covering the facility‘s operating costs in the utilisation phase and the costs for the closure phase.” (BMBF, 2015, 14)

“**Termination Stage:** Entrance into this stage occurs when the first financial investment is made to divest or decommission the RI. The decision to terminate happens at the end of the Operations Stage. The decision to terminate is generally made when the government or governments involved determine that the RI is no longer considered an operational priority with regard to advancing science. This final decision is often the most politically challenging due to the human element and political landscape. Management of expectations is critical, especially if the decision is made to terminate an RI earlier than expected. Termination could include divestment to another entity’s operational and financial control or decommissioning, including complete de-construction and removal of the infrastructure. Cost of decommissioning can be substantial. Re-deployment of skills and fostering a position of resilience within the RI and the science community is highly valuable.

The diagrams below illustrate the five life-cycle stages in terms of flow, relative cost, and relative time scales. The boundaries between the stages may not always be distinct (e.g. some facilities may be capable of science operations before construction/implementation is complete).” (GSO, 2015, 19)

1. **Human resources**
2. **Policies/practices to attract and retain scientific, technical and administrative staff**

“Critical mass of scientific talent is based on outstanding scientific opportunity but can be built up through mechanisms such as attractive employment conditions, transparent recruitment practices, openness to diversity, and adaptable PhD and post-doctoral curricula. Additionally, RIs can finance or co- finance studentships and doctoral and postdoctoral fellows. In order to preserve links to national educational systems, doctoral and post-doctoral programmes can be designed together with universities, thus enabling young researchers to acquire hands-on experience at the RI while maintaining links to their home universities. Developing and managing new instrumentation also generates the need to train technologically skilled personnel and ensure their mobility. It should be noted that at the moment RIs in Europe are very successful in attracting the best scientific talents but face difficulties in attracting experts in instrumentation and engineers. RIs can build up their pool of scientific talent by enabling inter-institutional and trans-national mobility at all career levels but with particular focus on young researchers. This can be achieved through short- term visiting exchanges (from lab to lab), organization of scientific events or dedicated workshops, as well as targeted training opportunities. RIs can consider innovative mechanisms, such as engaging in partnerships with industry, in order to facilitate participation of talented researchers and engineers from less developed regions in their training events. For all EIROforum organizations, training the next generation of researchers and engineers is part of their core mission. EIROs have in place training programmes for doctoral and postdoctoral fellows as well as other young researchers and scientific and technical staff, which encourage mobility and exchange of knowledge.” (EIROforum, 2015, 5)

“**Lack of professional support**: there is a lack of professional support offered for many technologies involved and support available is often ill-matched to users’ needs, e.g., in terms of the level of skills assumed. **Response**: provision of support through national centres of excellence for particular research areas and in combination with local provision at research institutions.

**Lack of availability of technical skills**: relevant skills required to develop and operate e-Infrastructures and research applications are not widely available. **Response**: development of specific training programmes such as the Master in e-Science offered by the University of Edinburgh.” (Voss, et al. 2007, 4)

“Furthermore, there is a need to provide a sustained supply of IT professionals with the required technical skills to operate, maintain and further develop advanced e-Infrastructures. Programmes like the MSc course at the University of Edinburgh are an important step in this direction. While it is true that technologies are changing rapidly and that, therefore, ongoing training is required, it is crucial for IT professionals to have a solid understanding of the core principles of distributed computing and those are difficult to learn in relatively short training courses.” (Voss, et al. 2007, 8)

“The workshop discussions highlighted cross-cutting challenges of i) new and changed skills needs which combine technical and scientific skills and require interdisciplinary thinking and communication; ii) recognizing new job profiles and tasks rising from the emergence of computing intensive and data-driven science with integral role of e-infrastructures; iii) need for effective European level collaboration and coordination to avoid duplication of efforts and join the forces for developing high quality human capital for e-infrastructures. Furthermore, there are specific challenges relating to the skills and human resources for i) e-infrastructures development, ii) digital research service provision, iii) scientific usage of e-infrastructures, and iv) the institutional strategies for effectively tackling the human resources challenges. During the consultation, several suggestions for promoting skills and human resources for e-infrastructures were raised. It is necessary to better map the current situation and future needs, and support recognizing and establishing new job profiles and career paths. Specific investment should be addressed to innovating new education and training approaches: creating new specific curricula for e-infrastructures personnel; integrating technical and scientific aspects into cross-disciplinary curricula; encouraging collaborative mindset and computational thinking into education already from early age; on-the-job learning through knowledge transfer from and between experts in terms of short-term courses and staff exchanges. These should be supplemented by encouraging ‘communities of practice’ between e-infrastructures actors, including developers, operators and scientific users.” (European Commission, 2012, 4)

“The purpose of this document is to make concrete suggestions and identify a **pragmatic solution** that would increase employability and facilitate staff mobility within European RIs. Such a solution could be the introduction of **an attractive scheme for the temporary secondment of expert staff** from a **sending RI** to a **receiving RI**.”

“**It is proposed to establish a Europe-wide secondment-based scheme for staff mobility within an integrated structure of European RIs covering one, or several, research communities.** This would provide a solid framework within which staff mobility could occur, individual experts could follow a career path across a wide range of RIs and career development within a group of RIs, rather than within a single RI, could be envisaged.”

“**A financial scheme should be established to support this secondment-based mobility.** It is proposed to include a specific set of accompanying measures:

* A set of **financial measures** that include a living allowance and the reimbursement of removal expenses; exceptional solutions may be considered to cover education expenses or the loss of a partner’s job; existing European-level financial rules should be examined for applicability;
* An additional funding mechanism should be established to provide the **budget needed to cover the supplementary costs associated with these measures.**”

(EIROforum/ERF, 2011, 2, 4, 5)

“Personnel requirements:

* What scientific, scientific-technical, technical and management competencies are required in the responsible organisation(s) for the development, implementation and operation of the research infrastructure? Please describe these from a scientific perspective. Please provide additional information such as existing concepts in annex 6 “Management concepts” (cf. 5.2.2).
* To what extent does/do the responsible organisation(s) have personnel available, and can these personnel be used for the development and operation of the research infrastructure? If not, how can these personnel be recruited?
* What personnel development concepts exist for the various personnel groups and for young academics?” (BMBF, 2015, 10)

“HR policy and Project Management. (…) Unless the research infrastructure has a clear staffing plan and an effective recruitment strategy, it is unlikely to attract the necessary human resources required to achieve its goals. The project requires an organisational chart and a process flow, with clear roles and reporting lines, on how the different lines of management interact at national and international levels. Again, the requirements differ at each project phase.” (European Commission, 2013, 20)

“Lack of Human Resources Constructing and operating RI can only be done if a critical mass of researchers in different countries and key scientists are explicitly committed to the RI, if they are strongly engaged in building the case for the need of the RI and in its design, and if highly qualified experts are available. For researchers, infrastructure building is often not attractive as a career option and further infrastructure experts (such as, special equipment operators, experts in modern analytical techniques, data scientists, information specialists, technologists, communicators) are scarce. These bottlenecks need to be overcome.” (H2020 Advisory Group, 2014, 8)

“(Recommendation): Training: support training for RI staff and users by:

* Developing training programmes for RI staff, including legal training for RI managers, data management training for engineers and data scientists, ethics training and gender awareness, and support mobility for exchange of skills;
* Developing training and user support for researchers to use international RI;
* Recognising and fostering the new profession of 'data scientist', including education programmes in schools, undergraduate and postgraduate programmes.” (H2020 Advisory Group, 2014, 13)

“Training, education and human capital development are key to exploiting RI to their full potential.

Users benefit from training and user guidelines pertinent to RI to inform their data preparation, their use plans, and their findings; trained users will be more effective and consume fewer resources.

Higher Education courses targeting data science, data management, data analytics, digital archiving, and information science should be prioritised with suitable accreditation, in order to train the cadre of data scientists required for both RI and also the data industry. As well as dedicated courses, hands-on skills workshops and online educational resources for researchers who find themselves using significant quantities of data can enable improved data management and use. Use and re-use of RI should be incentivised via metrics that feed into career progression. Similar to the ‘h-index’ there need to be standardised, commonly used metrics to capture the use and citation of RI.

Data metrics are currently under development, and a standard approach to data publication, citation and attribution would speed up this process, with the adoption of standard metrics into funding assessment processes incentivising their use. Data scientists need to be rewarded and incentivised with a recognised career progression path, so as to build a sustained skills base to ensure that RI can be sustained.

The relationship between RI and Research Organisations (Universities, Colleges, and Research Institutes) should be reviewed to maximise human synergies, through exchange of personnel and shared training and skills exchange. Research Infrastructure staff should receive the same supports and benefits as RPO staff.

Gender balance should be addressed for Research Infrastructure human capital. Research Infrastructure staff should work towards gender balance, and promote gender role models where appropriate. In implementing a transparent access charter for RI, care must be given to ensure gender balance appropriate to the range of access requests received.” (H2020 Advisory Group, 2014, 17-8)

1. **Other**
2. **Unforeseen challenges during the construction phase (e.g. developments in science and technology)**

“**Uncertainty about Development**: there is significant uncertainty regarding the direction of technological development and standardisation in e-Infrastructure technologies (e.g., the recent shift from OGSI [Open Grid Services Infrastructure] to WSRF [Web Services Resource Framework], cf. Czajkowski *et al*. 2004). **Response**: provision of forecasting reports and roadmaps for technical development by experts in the field and increased outreach activities by institutions such as the Open Grid Forum.” (Voss, et al. 2007, 4)

1. **Legal framework**

“The continuity and steady progress of intergovernmental RIs is guaranteed through their founding treaties, which offer a regulatory framework that is both flexible and reliable. All EIROforum organizations [CERN, EMBL, ESA, ESO, ESRF, EUROfusion, European XFEL, ILL] are based on arrangements amongst member states, such as intergovernmental conventions or treaties, although they have opted for different legal models as regards their implementation. These vary from an international organization, a non-profit company model established under national law or a joint undertaking and a multi-party agreement. These legal models ensure that the administrative workload within a particular RI is minimized.” (EIROforum, 2015, 3)

“For pan-European RIs, the host country - or in distributed RIs the host countries - play a vital role in ensuring the smooth establishment and functioning of the RI. The relationship between the RI and the host country(ies) is often regulated in a separate legal document.” (EIROforum, 2015, 4)

“The European Research Infrastructure Consortium (ERIC) legal entity has been identified as the most appropriate legal entity to support the distributed operation of the BBMRI. BBMRI-ERIC is established for an unlimited period under the Council Regulation (EC) No 723/2009 of 25 June 2009 on the Community legal framework for an ERIC. The ERIC is set up to sustainably establish and operate, on a non-economic basis, the distributed pan-European Research infrastructure “Biobanking and Biomolecular Research Infrastructure, European Research Infrastructure Consortium” (BBMRI-ERIC).” (BBMRI, 2012, 37)

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1. **Questions emerging from the literature review**

* What is understood by infrastructures (physical equipment, provision/availability of data, etc.)?
* Definition of sustainability (physical plant, data curation)?
* What makes an infrastructure “international”?
* Are biobanks a special case of RIs?
* Distinction between “large” and “small” RIs?

1. Formerly the Joint Information Systems Committee, JISC is a UK non-departmental public body whose role is to support post-16 and higher education, and research, by providing relevant and useful advice, digital resources and network and technology services. It is funded by all the UK post-16 and higher education funding councils. [↑](#footnote-ref-1)