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International Comparative Study: Appraisal and Evaluation Practices of Science Capital Spending on Research Infrastructures

Final report

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Executive Summary

This report presents the findings and conclusions of a **comparative study on international practices** in the governance, appraisal, monitoring and evaluation of science capital funding for research infrastructures (RI). The study was undertaken by Technopolis between February and July 2017, on behalf of the UK Department for Business Energy and Industrial Strategy (BEIS).

The international comparative study

BEIS is currently developing a **framework for appraisal and evaluation** that is specific to science and research capital spending. To inform this process, it wants to better understand the arrangements and approaches taken in other countries. It therefore commissioned Technopolis to:

- Synthesise existing documentation and evidence on international best practice in governance, appraisal, monitoring and evaluation of science capital funding of research infrastructure
- Review and compare the strengths and weaknesses, similarities and differences, of the different international frameworks or models for governance, appraisal, monitoring and evaluation

The focus was medium- and large-scale research infrastructures (projects / facilities with capital costs over €1 million). Investments in research centres and smaller research equipment were out of scope.

During the study, a series of eleven **case studies** were developed, explaining the approaches taken in selected comparator countries. Information was gathered through publically available secondary sources (websites, programme documentation), as well as interviews with key experts in each of the national systems. This was complemented by a review of academic and grey literature on the topic.

The case studies themselves (appended) serve as a knowledge base, containing detailed information on the practices within each country. The main report looks across these cases to provide an overview of international approaches, illustrated with examples of observed practices in individual countries, and combined with reflections on the current state of the art, future challenges, and relevance of findings to the UK context. A summary of the findings and conclusions is presented below.

Governance processes of allocating science capital funding

There is growing interest across countries in the governance of research infrastructure, driven in part by general improvements in public management, but also by recognition of the critical importance of this class of infrastructure to a country's research performance, and countries are becoming more strategic in their management of RI as an asset. Related to this is a general view that the cost of infrastructure is tending to increase more quickly than prices more generally, leading to: (i) greater selectivity as to what infrastructure is commissioned/funded, (ii) more stringent demands on facility performance, to ensure fuller utilisation and earlier return on investment, and (iii) increasing deployment of collaboration and co-financing, both with other countries and the private sector.

All countries considered in this study maintain a **dedicated science capital budget**, recognising the need to manage these large and irregular investments in a rather different manner to either institutional block grants or research grants. Most countries have also established national or federal **RI strategies**, setting out objectives for the successful operation of key facilities, as well as their maintenance, expansion and renewal going forward. Typically, these include a mix of general principles, as well as commitments to major new initiatives, and are refreshed every four or five years.

Most countries have also developed associated **RI roadmaps**, which include inventories of proposed (and prioritised) facilities. In most cases, these RI-related strategies and roadmaps are developed by expert committees, including high-level panels of researchers, and are refined through consultation with a broader set of stakeholders (ranging from small topic-specific groups to large-scale 'public' consultations with several hundred contributions). The work can be quite involved, and is often distributed across multiple thematic groups. There is also some level of filtering on importance, affordability and strategic relevance, for example through discussion of draft roadmaps with ministers.

Several countries are doing more to feed the results of past **monitoring and evaluation** into the management of research facilities, and it seems likely that this will become more important over time to help guide policy teams in making tough decisions about future investments in the estate overall.

The UK's governance arrangements for research infrastructure are broadly in line with the more developed arrangements we have identified and explored through this international research, and there are no obvious policies or practices that would immediately recommend themselves as improvements. For instance, the UK has possibly gone further than most in monitoring and evaluation, and the inclusion of such evidence within the government and STFC's strategic oversight of the science capital budget. Nevertheless, there are some specific aspects identified in individual approaches that may be worth further consideration. For example, the greater transparency to priority setting processes in Denmark, or the greater weight given to strategic criteria (i.e. societal needs and potential economic benefits) within the priorities and rules for future RI funding in Australia.

Ex-ante appraisal approach to science capital investments

There has been an associated growing interest in methodologies, tools and indicators for the appraisal of potential science capital investments, in order to better inform ex-ante prioritisation and decision making on new/upgraded infrastructure. Across many of the countries considered there have been recent changes and developments in both the overall approach and in the specific details of the appraisal process, reflecting ongoing learning and a greater recognition of the role of RIs.

Most comparator countries now operate a **tiered appraisal process** for RI proposals, with two or sometimes three layers of assessment. There is usually an initial assessment of individual proposals by panels of independent experts, always including eminent (and usually 'foreign') scientists, as well as (sometimes) industry experts and other specialists. This is then generally followed by a review of individual assessments at the portfolio level, identifying the best proposals based on the panel advice and consideration of strategic issues and financial guidelines. Finally, there is a review of the recommendations from the 'technical' appraisal process, which is carried out by research councils or internal policy teams within a science ministry. In all cases the final decision is then taken by a ministry (the minister) or the board of an executive agency with the mandate of the minister.

The statements of **criteria** used in the appraisal process are often not very detailed – just a few words, or sentences in each case. This may be a pragmatic response to the need to apply these criteria across a wide range of project types and sizes, or shifting emphasis across calls. However, it also provides the current study with limited insight into the exact basis upon which assessments are being undertaken.

We found that countries are using broadly similar criteria to assess RI proposals, although with different levels of specificity and with differences in the degree of focus across different dimensions. Our analysis suggests that there are three main **categories of criteria** being used:

- Scientific criteria - covering the extent to which a proposed investment will support research of the highest quality, of an innovative character, and at the frontier of knowledge
- Financial and technical criteria – covering whether the proposed investment is affordable and technically feasible (in the short term) and financially sustainable (in the longer term)
- Criteria relating to access and utilisation – covering plans to support access by a large number and broad range of users (beyond the host institution) and therefore maximise utilisation

There are then other aspects considered within specific countries that are really extensions to the classic scientific and technical criteria. These can be categorised into two broad dimensions:

- Criteria relating to wider strategic relevance and benefits – including alignment with national or institutional research needs, strategies and priorities, coherence with other infrastructures and the potential to contribute to enhanced visibility and reputation of domestic science internationally
- Criteria relating to potential socio-economic impacts – covering the economic benefits foreseen from RI design, construction and use, the benefits for innovation and industrial competitiveness, and the potential contribution of the research enabled to tackling wider societal challenges

It is evident reading across the country examples that the socio-economic impact criteria are still the least common and often the least well developed in terms of the specificity of their wording. However, it is also clear that the appraisal criteria and process are developing in all countries, with societal benefits and strategic interests beginning to weigh more heavily in the process overall.

The appraisal panels are usually required to **score individual proposals** on each of the specified dimensions or criteria, typically employing a Likert scale of e.g. 1-7. Scores are given by individual peers *independently* in the first instance and then as a panel, to arrive at a common final set of scores for each proposal, along with a qualitative explanation of each score.

In our case study work we have not identified any use of explicit **weighting** in the scoring and ranking systems (e.g. for attaching more weight to scientific criteria). However, there is often some implicit weighting within the choice of criteria used as the basis for assessment (e.g. a greater number of criteria relating to scientific merit), or in the approach to appraisal (e.g. where certain aspects are only to be 'considered' as part of the assessments, or where certain evaluation dimensions are assessed separately, resulting in findings and recommendations that are advisory only).

The appraisal arrangements for research infrastructure **in the UK** are broadly in line with the approaches we have identified and explored through this international research, although comparator countries tend to make greater use of international experts. However, the robustness of appraisal procedures for science capital investments both in the UK and elsewhere has often been found not to be aligned with the size and complexity of those investments, and there is a widely-recognised need for a more structured, consistent and systematic approach to ex-ante evaluation and selection. This is an area that is a focus of some considerable developmental activity in many of the countries we have looked at, but is also an ongoing process, with apparent weaknesses still evident in current approaches.

For example, it is often unclear how one scores some of the criteria specified for appraisal (especially potential future socio-economic impacts), or appropriately adds up the scoring of very different dimensions. There also appears to be a lack of transparency or clarity to the final decision process, e.g. the extent to which the panel reviews and scores may eventually have been 'over-ridden' by other political or strategic concerns. There is also little evidence that past evaluations are being fed into ex-ante appraisals, allowing peer reviewers to learn from past experience and score with more confidence.

Monitoring and evaluation of science capital investments

Formal **monitoring** of research infrastructures is usually done internally by a ministry, funding organisation, or government agency responsible for the funding. However, there are some exceptions, such as the monitoring of the construction phase by external parties. Efforts focus particularly on monitoring progress during construction, and primarily on financial and administrative aspects. There is also ongoing monitoring (e.g. through annual reporting requirements on RI projects), which also addresses scientific or innovation-related outcomes – though often only simplistically, based on pre-determined and easily obtainable indicators and associated reporting requirements. The templates for reporting often require a mix of qualitative descriptions of the current status quo and outlook of the RI, as well as a set of basic quantitative indicators for activities and outputs.

A more detailed analysis of scientific, innovation-related and societal outcomes or impacts is usually only undertaken as part of one-off **ex-post evaluations**. These are usually carried out by independent external parties – either international scientific experts or evaluation professionals.

In general, we find that these evaluations of RIs are **dominated by qualitative approaches** such as case studies (e.g. describing effects of industry collaboration with the RI) and qualitative assessments by international scientists (based on site visits or interviews with RI stakeholders). The focus on qualitative approaches for evaluation is not a bad thing *per se*. Qualitative instruments have the advantage that they can be applied to a wide range of different projects. The "openness" of these approaches also avoids some of the methodological challenges which exist for the quantitative measurement of impacts of research infrastructures (i.e. how to quantify the socio-economic impact of a RI). It is therefore a reasonable strategy, especially if there are several RI to be evaluated, to rely on the expert views and qualitative assessments, potentially enriched with basic standard indicators for publication efforts or with a larger number of case studies illustrating the different effects of the RI.

Our country case studies did not identify a wide-spread use of **quantitative approaches** like cost-benefit analyses, the calculation of net present values or other possible quantifications of RI impacts. These are chosen only in a minority of cases and on an ad-hoc basis. However, quantitative approaches like detailed impact studies do have the advantage of producing results which are easy to communicate. For example, allowing messages such as "the RI delivers at least X in net economic impact over the years Y to Z" or "The RI has delivered a Return on Investment (RoI) of at least X%".

Panel-based peer reviews still dominate evaluation activity in numerical terms, however, there is a growing concern with the question of impact, which has led to various **developmental work** around assessment methods. The state of the art remains a work-in-progress, however, with very much less sophisticated techniques being deployed than in other areas of economic impact assessment, in recognition of the highly particular nature of most RI investments and the long-run and diffuse impacts they tend to produce. So, far it seems no one has managed to find an intermediate solution between macro-economic models and deeply qualitative and backward looking case study approaches.

Our case studies suggest that in all countries some kind of evaluation approach for RI is in place. However, **the UK** appears to be doing more evaluation than the other countries we researched, especially with regard to ex post evaluations and the quantification of wider social benefits. We were unable to find any examples of countries with an overarching evaluation strategy for research infrastructure, which describes the principles used to determine what is evaluated, when and on what terms. There is an arbitrary quality to the mixture of published studies we identified, at least when looked at from the outside, which suggests studies are triggered by other factors or events.

The European Commission has funded several methodological studies regarding the evaluation of RI and its wider societal benefits, and this work has produced several evaluation design guides (e.g. the FP7 project, Foresight-enriched Research infrastructure Impact Assessment Methodology [FenRIAM]). The outcomes, though, look very similar to the development work already underway in the UK: they are essentially micro-economic studies working within a CBA framework, with qualitative research (case studies) being used to capture and value some fraction of the knowledge spillovers.

1 Introduction

This report presents the findings of a study on international practice in the governance, appraisal, monitoring and evaluation of science capital funding. It summarises the information collected in 13 countries on their approaches to assessing and evaluating investments in Research Infrastructure (RI). The study was commissioned by the UK Department for Business Energy and Industrial Strategy (BEIS), and undertaken by Technopolis between February and July 2017.

The study is intended to contribute to BEIS' work to develop a new framework and guidelines for the appraisal and evaluation of research infrastructure. With this in mind, the study has two **aims**:

- To synthesise existing documentation and evidence on international best practice in governance, appraisal, monitoring and evaluation of science capital funding of research infrastructure
- To review, and compare the strengths and weaknesses, and similarities and differences, of different international frameworks or models for governance, appraisal, monitoring and evaluation of science capital funding of research infrastructure

The focus was medium- and large-scale research infrastructures (projects / facilities with capital costs over €1 million). Investments in research centres and smaller research equipment were out of scope.

The **study approach** drew on both primary and secondary evidence. This included a review of the literature, as well as in-depth exploration of current practices internationally, whereby desk-based research and 35 expert interviews were used to develop 14 brief country overviews, and then 11 detailed country case studies. These cases explored practices in Australia, Belgium (Flanders)[1], Canada, Denmark, Germany, Finland, Ireland, the Netherlands, Norway, Sweden and the United States of America[2]. Initial reviews of Austria, France and New Zealand were also undertaken, but these countries were excluded from the more in-depth case study review.

[1] Since the early 1990's, Belgian research policies have been fully decentralised to the regions (Flanders, Wallonia and Brussels Capital region), with complete autonomy for decision making. The governance arrangements for science capital appraisal and evaluation have diverged as a result, and it did not make sense to consider Belgium (as a whole) as a comparator country in the current study. From Technopolis' previous experience it was clear that Flanders would offer the most interesting lessons, and it was therefore agreed with BEIS that Flanders would be the specific focus of the Belgian case study.

[2] Country abbreviations (AU, BE, CA, etc.) are used in the report. Please refer to Appendix B for a reference list.

The collated material was analysed to prepare a more synthetic overview of international approaches, illustrated with examples of observed practices in individual countries, and combined with reflections on the current state of the art and future challenges, as well as on the relevance of findings to the UK context. Key findings were initially presented at an interim meeting in June 2017, before being elaborated and developed further for the final report. BEIS was involved throughout the process, through weekly calls and a series of meetings, providing feedback on specific fieldwork tools and interim outputs, as well as input to the initial and final choice of countries to be covered.

Following this introduction, the next three **sections of this report** present findings in relation to each of the three broad areas of interest for the study:

- Section 2 - the governance process of allocating science capital
- Section 3 - the (ex-ante) appraisal approach to science capital investments
- Section 4 - the monitoring and evaluation approach to research infrastructure investment

Each section follows a consistent structure, with a brief introduction, followed by a presentation of the main findings from across countries (with selected illustrations) and a summary of the current state of the art and likely future areas of development. Each section ends by reflecting briefly on the relevance of these findings and conclusions for the UK. Section 5 presents some concluding remarks.

A series of supporting appendices provide details and results of the literature review, as well as the individual country case studies and overviews for reference.

2 The governance process of allocating science capital funding

2.1 Introduction

Governance of science capital funding is one of the key elements in the process that determines and later informs the appraisal, monitoring and evaluation of science capital funding.

When it comes to the topic of research infrastructure, governance is usually linked with the process of decision-making on overall science capital funding in a given science system and the allocation of those funds across different scientific (or other) priority areas and projects. The key decision-maker, or governing body, may be a government department or an executive agency, or even a specific agency dedicated to the management and operation of research infrastructure nationally. In most countries, decisions on overall spending levels remain with central government, while specific decisions on individual allocations are usually reached by actors very much closer to the science system. These top-level decisions are informed by ex-ante evaluations (i.e. forward-looking national roadmaps for research infrastructure), which in many cases are calibrated through community-wide consultations. Ex-post evaluations (e.g. reviews of a facility's scientific performance and wider socio-economic contributions) are less widely used at this highest level of decision-making, reflecting the challenge of measurement, as well as the highly particular and unique nature of much large research infrastructure.

Governance may also include consideration of the division of responsibilities for decision-making (between policy makers, research funders and research performing organisations), as well as aspects such as principles for prioritisation (i.e. criteria for inclusion of research infrastructures in national roadmaps or priority programmes), principal funding mechanisms (their rationale, objectives, size and focus) and budgeting arrangements (annual, multi-annual, etc.).

Kohler et al (2012) recognise the importance of good governance to decision-making around large-scale research infrastructure,[3] where the funds involved can cast a long shadow and create substantial opportunity costs for many other constituencies whose proposed research facilities cannot be supported because of the choices made. In most countries, there are more good, even urgent, proposals for science capital investment than might be afforded, and a robust governance structure and decision-making process is important for both a healthy research base and contented taxpayers.

Good governance is not only a question of leadership and a willingness to take and defend tough decisions on the selective allocation of scarce funds. The top-down approach really needs to be complemented by a bottom-up approach to ensure ownership of overarching strategies and individual decisions. Horlings (2009)[4] notes that the governance system also determines how planning, monitoring, evaluation and support is approached. While in most cases the top-down approach is taken and a "one-size-fits-all" system is implemented, a bottom-up approach may prove even more useful in considering the different actors, interests, resources and ideas of the participants.

Our case studies found that national ministries play the leading decision-making role in a majority of countries, albeit research councils often play a prominent role in convening forward looks, consulting research communities and providing advice to science ministers. A quick review of the organisational affiliations of members of the European Strategy Forum on Research Infrastructures (ESFRI) provides a good window onto the diversity of players. Three common models can be identified:

- In more than half of the cases, government departments own the strategic decision-making process. In a few instances, research infrastructure is one of the topics in a portfolio of responsibilities within a unit of the ministry. In other cases

[3] Kohler et al., 2012, Governance of Large Scale Research Infrastructures: Tailoring Infrastructures to Fit the Research Needs

[4] Horlings, E., 2009, Investeren in onderzoeksfaciliteiten. Prioritering, financiering, consequenties, Rathenau Instituut, https://www.rathenau.nl/en/file/362/download?token=rJUhHEQs

specialist units within the ministry coordinate the processes of roadmapping and prioritisation – often involving independent expert committees – and the synthesis of advice for ministers. In smaller countries, these expert committees may also serve as peer review panels appraising individual research infrastructure proposals, while elsewhere there is a separation between the domain specialists that advise on priorities and the experts appraising applications submitted to those priority calls for proposals.

- Elsewhere, it is the research funding agencies that provide oversight and manage the process of roadmapping and prioritisation, albeit with final approval coming from ministries. In most cases, these funders are supporting researcher training, research grants and research infrastructure.
- In a few cases, we found dedicated facilities funders – like the UK's Science and Technology Facilities Council (STFC) – that take a lead in strategy development and operational oversight.

2.2 Overview on the findings for the case study countries: similarities and differences

In this section, we present current practices of the governance processes in eleven countries chosen as cases for this study, providing an overview of commonalities and differences in their approaches. These findings are presented according to key aspects of the governance process: the strategic context influencing the decisions around RIs; the processes around priority setting; and the approach to funding (principles, changes over time, frequency, etc.).

2.2.1 National context

Discussing a process of capital funding allocation (of any other funding allocation) inevitably has to start with a discussion of the governance structure of a country. It influences how the decision power and processes are distributed between different levels of political hierarchy.

Federalism (such as is found in Australia, Canada, Germany, and the United States) is a hierarchical system of government under which the power is divided between a central national government and smaller regional or local governments connected to one another by the national government. Some topics are under the control of the national government; whereas some others are under control of the local governments. Such a system is different from a unitary system of governance (like those in Finland or the Netherlands), under which the national government maintains exclusive power over all geographic areas as well as topics. However, even in the case of unitary systems, some level of devolution of powers from national to subnational levels has taken place, with countries (e.g. Belgium) delegating the authority on certain topics to a subnational level.

Examples from case studies of these centralised and de-centralised approaches in relation to research infrastructure are given in figure 1.

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Figure 1: Examples of general approaches towards governance processes of research infrastructure funding

Examples of a de-centralised approach

- DE: In Germany, the general research infrastructure programme and the “Large research infrastructure” programme are co-funded by the German Federal Ministry of Education and Research (BMBF) and the states’ ministries.
- USA: The decisions are decentralised to different Federal departments and agencies. The National Science Foundation is the only federal agency with a mandate to support fundamental research and education across all fields of science and engineering.
- CA: Funding for RIs on the federal level goes through the Canada Foundation for Innovation (CFI). In addition, individual funds for supporting RIs on the provincial level exist.

Examples for a centralised approach

- FI: The Academy of Finland (a funding agency for basic research) has been in charge of funding RIs since 2011.

NL: A Permanent Committee for Large-Scale Scientific Infrastructure was appointed in 2015 with a task to formulate national strategy for investment in large-scale RIs.

The above are Technopolis case studies for this project.

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Different national structures determine how the process of decision-making and funding takes place. On the one hand, decision-making may be easier in a unitary (and hence more centralised) system, with a single governing body informed by a series of (advisory) committees working to a common template. In such cases, a central government ministry or agency will not have to arbitrate between equally powerful regional governments as to the best investment for the country overall. This system may therefore be particularly good for making decisions related to the funding of large-scale research infrastructures. On the other hand, the federal approach may be more effective when it comes to deciding priorities for mid-scale RI. The states can presumably afford to buy most of their particular priority RI projects, no matter the fit with the priority lists of other parts of the country.

2.2.2 Priority setting

Without going into a detailed analysis of dedicated strategic documents, it is noticeable that countries have either **‘strategies’** with a focus on research infrastructures or with the research infrastructure topic having an important place in that strategy **or ‘research infrastructure roadmaps’**.

The choice may indicate a focus on a strategic versus a more operational or visionary approach. Or, the difference may simply be semantic. Some strategies will include or cross-reference roadmaps, while some roadmaps open with a set of strategic commitments. In most cases, the strategies and/or roadmaps also fit with the national Science, Technology and Innovation Policy (or similar). Some countries have both a roadmap and a strategy: Australia has been drawing up national roadmaps for investing in large-scale research facilities since 2006, and one of the outcomes of the initial roadmapping process was the establishment of the National Collaborative Research Infrastructure Strategy (NCRIS), through which the Government funds research facilities around the country.

Examples from case studies of the use of different strategic documents for research infrastructure planning are given in figure 2.

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Figure 2: Examples of strategic documents describing the approach towards planning of RIs

Specialised strategies:

- AU: A National Collaborative Research Infrastructure Strategy (or NCRIS) has existed in Australia since 2006.
- DK: The Danish National Fund for Research Infrastructure has a specially designed programme for funding large-scale RI.
- IE: Since 2004, Ireland had a national Research Infrastructure Programme, but the budget is not ring-fenced.
- NO: Norway funds its RI through the National Financing Initiative for Research Infrastructure (INFRASTRUKTUR) (no other funding streams exist).

National roadmaps:

- National roadmaps exist in many countries. Australia has had one since 2006; the Netherlands since 2008; Finland since 2009; and Germany and Norway since 2010.
- No roadmaps are present in Flanders (where the process was initiated but is currently on hold) and Ireland (where although there is no national RI roadmap, a basic roadmap for further development of Ireland’s RI does exist).

Other approaches:

USA: The United States is different when it comes to RI dedicated programmes/strategies. Specialised ‘mission agencies’ (e.g. Department of Energy or NASA) have their own long-term RI roadmaps specifically supporting these agencies.

The National Science Foundation has long-term commitments to existing research infrastructure, but it is also more reactive to research community initiatives.

The above are Technopolis case studies for this project

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There are different approaches towards roadmapping present in the case study countries. Three clearly different examples are:

- Australia - The National Research Infrastructure Council of Australia supported the early roadmapping exercises, but the latest (2016) Roadmapping process was led by the Chief Scientist for Australia. The process was additionally supported by an Expert Working Group (EWG).
- Belgium - The Flemish government involves the (former) Hercules Foundation (which since 2007 has been funding medium- and large-scale research infrastructure for fundamental and strategic research) and the department for Economy, Science and Innovation (EWI).
- Denmark - The Danish Ministry for Higher Education and Science is the responsible authority for research infrastructures. It allocates money to the Danish Globalisation Fund which since 2006 has run the Danish National Fund for Research Infrastructure as a specially designed programme for funding large-scale research infrastructure. (There are several other examples of countries where ministries of education and science are involved in preparing RI roadmaps).

In preparing the case studies we analysed how the decisions on which RIs to fund and when to fund them come together, as well the role of various national stakeholders in this process. A mix of approaches is evident, echoing the findings from the literature. These can be broadly classified into two groups (though some countries use a mixture of the two):

- A bottom-up approach – involving the engagement of stakeholders, ranging from small topic-specific groups to large consultations (involving hundreds of people).
- A top-down (prioritisation) approach – in some cases involving academic panels specifically set up for these exercises and focusing on their research areas; in other cases involving panels of wider stakeholders, from the research community, businesses, research users and wider society.

Examples of the two approaches in different countries are presented in Figure 1.

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Figure 1: Examples of strategic approaches

Bottom-up:

- AU: In preparing their national Research Infrastructure Roadmap, the appointed Expert Working Group consulted with 580 stakeholders (public and private research community).

Top-down:

- DK: Six expert panels supported scientific prioritisation within six research areas.
- IE: Prioritisation is done without an RI roadmap. A Research Prioritisation steering group decides on the RI alignment with one of 14 national research priority areas.

Mixed approach:

CA: CFI follows a top-down prioritisation process but does gather regular feedback and input from the provincial partners in order to better understand their development needs. This allows building a high level of synergy in the activities of CFI and the provincial governments.

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Once priorities are in place, the RI for funding are usually selected through calls. The type and frequency of calls vary between countries. For example, in Finland the calls are partly open (i.e. proposals are aligned with the national roadmap and proposals for new non-roadmap initiatives) and partly targeted (i.e. proposals invited only from organisations responsible for Finnish coordination of international research infrastructures where Finland is a member). In the Netherlands, the calls are bi-annual (€80m per round), with only the RIs included in the National Roadmap eligible to apply. Calls in Denmark, on the other hand, are organised as an open competition. In Sweden, calls for applications are now released every other year and the applicants must be listed in the 'inventory of needs' priority list, whereas previously annual open-competitive calls took place.

2.2.3 Funding principles

Larger facilities tend to be seen as important public goods, where there is going to be limited interest for investment from the market and a strong case for government support.

Medium-scale facilities will still tend to exhibit similar market failures, however, there is a trend towards picking new facilities that will be operated in support of academic science *and* commercial technology development. There is an expectation that private money can be leveraged, in order to cope with the rising cost of individual facilities, and also to intensify the social and economic impacts of science capital funding. This kind of co-financing comes with an expectation of more open or equitable access for the private sector. This increased focus on technology development, economic impact and attempting to leverage more private sector funding is probably also true for larger infrastructure – but it does not seem to be driving investment decisions to the same extent.

Most countries have a main science capital fund and multiple smaller national and local funds. The budget for membership of international scientific organisations, like CERN or ESA, is typically a separate line in the national or federal science capital budget, albeit responsibility for that funding and the benefits of membership will typically fall to a national body with the equivalent competence or mandate nationally.

Most countries now look to leverage their main science capital budgets through co-funding, whether through international projects, national public-to-public investment or public-private. A collaborative approach towards funding research infrastructures is evident in most of the analysed countries.

This means that in addition to the 'main' pot of money, contributions come from other sources. The money can come from regional/provincial governments in federal decision-making systems, or from the research institutions themselves. The split of the contributions level varies (see Figure 2).

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Figure 2: Examples of funding approaches:

- CA: National funds cover 40% of the costs and the additional 60% is to be covered by the funding mechanisms of the provincial governments.
- AU: Institutions involved in the NCRIS network must participate financially as well and make co-investments.
- Flanders: The original Hercules programme subsidised infrastructures for fundamental and strategic basic research (Flemish government covered 70-90% of the investment costs).
- SE: The Swedish Research Council plus other research funding agencies fund RIs.
- DK: Co-funding of 50% is required, usually from the main target groups of universities and/or research institutes.

The above are Technopolis case studies for this project.

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In general (from the limited trend data available) the budgets for research infrastructure appear to have been increasing over recent years. For example, by +86% over three years in Australia, by +9% over three years in Finland and by +355% over 5 years in Norway (see Table 1). However, we have insufficient information to know whether this apparent trend is reflected elsewhere.

Table 1 Trends in budgets for research infrastructure, selected countries

	2010	2011	2012	2013	2014	2015	2016
Australia (€m) - Funding provided through the National Collaborative Research Infrastructure Strategy (NCRIS)				57	71	106	
Finland (€m) - State budget allocated for research infrastructures					17	17.8	18.5
Norway (€m) - RCN funding for research infrastructure.	11				40	50	

Technopolis case studies for this project

2.3 Current state of the art

Looking across the countries analysed for this study, we would highlight a number of common features that we see as constituting current good practice:

- Countries maintain a dedicated science capital budget, reflecting a common recognition of the need to manage these large and irregular investments in a rather different manner to either institutional block grants or research grants.
- There are *explicit* national or federal RI strategies setting out objectives for the successful operation of key facilities and their maintenance, expansion and renewal going forward. This is typically a mix of general principles and selected current commitments to major new initiatives. The strategies are typically refreshed every five years.
- The strategies are associated with national RI roadmaps, with an inventory of proposed facilities. This mirrors the type of presentation in the ESFRI roadmaps, with major proposals showcased as mini business cases.
- Usually, the teams overseeing the preparation of a strategy and underpinning roadmaps sit within units of science ministries or research councils. In some cases, these are dedicated research infrastructure teams. There can also be dedicated RI agencies that own the national strategy and take the lead in overseeing the implementation of that strategy and the operation of facilities.
- In the majority of cases, the strategies and roadmaps are developed by expert committees, including high-level panels of researchers, and are refined in consultation with the wider informed public. The work can be quite involved and is often distributed across multiple thematic groups, which consider the scientific, social and economic case for each proposal. There is also some level of filtering on importance and affordability. Typically, the published roadmap is finalised in discussion with ministers, and will go through a further filtering process emphasising more strategic criteria, and working across fields.
- Considering the widely acknowledged high importance of close collaboration between academia and industry for innovation outcomes, governance processes

bringing together multiple stakeholders for research infrastructure planning can be regarded as "good practice".

2.4 Outlook on future developments

There has been a growing interest in the governance of research infrastructure, driven in part by general improvements in public management, but also by a recognition of the critical importance of this class of infrastructure to a country's research performance.

There is also a general view that each generation of infrastructure is much more powerful, sophisticated and extensive than its predecessor, causing costs to rise more quickly than prices in general[5]. Increased demand for access to RI (including from 'new' scientific communities) is also likely to be putting upward pressure on RI costs. At the same time, obsolescence rates are accelerating – in areas like supercomputing, new facilities can move from the global top 10 to top 100 within two or three years. Working at the cutting edge of science demands moving to the next generation way before machines are approaching their technical end of life; equipment can be re-purposed or re-used in other settings, which can help reduce capital costs overall, but there is substantial redundancy.

Where the private sector may increase sales and profitability through earlier rounds of capital expenditure and rebalance workforces to reflect changing levels of automation, the public sector has no such feedback loops. Government's principal control on price inflation is twofold: i) greater selectivity as to what infrastructure is commissioned and ii) more stringent demands on facility performance, to ensure fuller utilisation and an earlier return on investment. Another tactic that is increasingly deployed is collaboration and co-financing, with other countries and the private sector.

Selectivity and cooperation have dominated policy agendas in the recent past, and have reinforced the movement towards the more strategic oversight of science capital. Strategic oversight is also being extended further along the financial scale, with medium-scale infrastructure increasingly subject to top-down direction and scrutiny. Monitoring and evaluation is rising up the political agenda too. However,

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[5] For example, the Danish Roadmap for RI (2015) highlights a "prevailing characteristic… that today's research infrastructures call for far larger investment than formerly", citing that "new research tools often need to be custom-designed for a given research specification or environment" and that "research infrastructures are often so complex and advanced that.. it is often necessary to develop brand new technological solutions in order for the facilities to function as intended". It also points to "new and costly supercomputers and advanced computer networks, as well as the digitisation and collection of vast data volumes". Similarly, the ERA-Instruments report 'Mid-size instrumentation in the Life Sciences: Development of Research Infrastructures in Europe' notes the fact that "cutting edge instrumentation becomes increasingly expensive and, yet, indispensable for world-class research".

the measurement challenges are non-trivial and the evaluation of research infrastructure is still given too little attention in many countries.

Several countries are doing more in this space and feeding those results forward into the management of the country's research facilities more generally. It seems highly likely that this will become more important over time, to help guide policy teams in making tough decisions about future investments in the estate overall. We would also expect to see more work on monitoring too, maintaining more complete and visible asset registers along with statistics about users and usage and even impact, again, as a means by which to provide decision-makers with a more robust evidence base in their deliberations about future priorities and investments.

2.5 Some reflections on implications for the UK

The UK's governance arrangements for research infrastructure are broadly in line with the more developed arrangements we have identified and explored through this international research. There are no obvious policies or practices that we have seen being used in other countries that would immediately recommend themselves as improvements.

There is perhaps greater transparency in the priority setting processes in Denmark, while the latest Australian strategy for research infrastructure is interesting inasmuch as it gives very much greater weight to strategic criteria (e.g. areas where Australia can lead the world) in its explanation of priorities and the rules that will be applied to its RI calls for proposal. Scientific excellence is a pre-requisite for proposals to be considered, but final decisions reflect societal needs and potential economic benefits to a very much greater extent than is the case in most countries, including the UK.

3 The (ex-ante) appraisal approach to science capital investments

3.1 Introduction

To inform the development of its own framework, BEIS are seeking to understand the approaches taken by other countries to the appraisal of science capital investments for research infrastructure.

The literature reveals that policy makers' expectations towards RIs have been changing. While previously understood as facilities aimed (primarily) at contributing to scientific research, research infrastructures are also increasingly expected to tackle socio-economic challenges. This is highlighted in a report by ESFRI which recognises the potential of scientific outputs by ESFRI RI facilities to have a "global impact" and "to tackle global societal challenges such as health, climate change and energy"[6]. Pancotti et al (2014)[7] also note, that in addition to "'grand challenges" such as climate change, health, energy and ageing populations, other objectives, such as economic growth and job creation, or innovation and knowledge transfer, are also increasingly explicitly assigned to RI. The pooling of financial and human resources, open access, synergies, national relevance and maximised utilisation have also become more important in the face of budgetary constraints and drives for greater efficiency.

The ex-ante appraisal of potential RI is therefore a complex topic due to these various and evolving expectations for RIs. Appraisal processes require methodologies that adequately respond to all of these challenges in a structured, consistent and systematic way, and there is "a demand for credible principles, methodologies, metrics, procedures, and good practices" (OECD, 2008)[8] stemming both from policy makers and funding agencies, as well as infrastructure managers and users.

In this section, we synthesise evidence drawn from the literature and current practices in eleven countries, providing an overview of common features as well as differences in approach to the ex-ante appraisal of science capital investment in research infrastructures. These findings are presented according to key aspects of the appraisal process:

- The **criteria** used for the appraisal of research infrastructure investment options and proposals

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[6] ESFRI, 2011, *European Research Infrastructures with global impact; https://ec.europa.eu/research/infrastructures/pdf/esfri_brochure_0113.pdf*

[7] Pancotti et al., 2014, Appraisal of Research Infrastructures: Approaches, Methods and Practical Implications, http://wp.demm.unimi.it/files/wp/2014/DEMM-2014_13wp.pdf

[8] OECD (2008), *Report on Roadmapping of Large Research Infrastructures*, Paris: OECD. https://www.oecd.org/sti/sci-tech/47057832.pdf

- The approach to the **scoring**, weighting, comparison and selection of potential investments
- The structure and **approach** to the appraisal process, including key responsibilities

The section concludes with a summary of recent developments and the current state of the art, as well as a brief discussion of areas of outstanding weakness and likely future developments.

While research infrastructure roadmaps were discussed in the previous section, in many countries these also now serve as the starting point of the ex-ante appraisal procedure; at least in determining broad priority areas and overall intentions, if not also identifying particular funding opportunities and projects of relevance / importance. In several countries, this process comes closer to a commitment to fund specific infrastructure, increasing the role and importance of the ex-ante appraisal of investments *during* the roadmapping process itself. Elsewhere, the focus of appraisal activities sits within dedicated funding programmes, with periodic calls for proposals, followed by the assessment and selection of specific infrastructure investment opportunities. We draw on lessons from across this variety of approaches, as appropriate, within this section.

3.2 Overview on the findings for the case study countries: similarities and differences

3.2.1 Assessment Criteria

The countries we have looked at as part of this study are all found to be using broadly similar criteria to assess RI proposals (applicable to medium and large-scale RI), although with different levels of specificity and with some differences in the degree of focus they place on different dimensions.

Three broad elements (**scientific** criteria, **financial & technical** criteria, and criteria relating to **access and utilisation**) feature in all cases, while there are several other dimensions that are evident in some cases (specifically, around **wider strategic relevance/benefits** and potential **socio-economic impact**), and which are really extensions to the classic scientific and technical criteria.

Below, we examine each of these broad elements in more detail, setting out specific examples of the relevant criteria used in the countries examined. As will be seen, the statements of criteria used by different countries (at least in publicly available information) are often not very detailed –just a few words, or one or two sentences in each case. This lack of detail provides limited insight into the exact basis of the assessment being undertaken in different countries. However, the succinctness with which criteria are described may also be a pragmatic response to the need to be able to apply these across a wide range of project types and sizes, or shifting emphasis within individual calls.

Further, in many of the examples we identified, the wording used against single criteria often contains several distinct elements (for example, in Denmark, there is a criterion that requires investments “be of national interest, support institutional strategy, be of great scientific value”). Such distinct elements have been separated in our presentation of examples below, where appropriate, so as to more clearly show the extent of coverage of certain types of criteria across the countries examined.

Scientific Criteria

The scientific criteria used for appraisal across the different countries generally cover the extent to which a proposed investment will support research of the highest quality, of innovative character, and at the frontier of knowledge. This includes consideration of the purposes for which the infrastructure will be used, and the quality, potential and / or track record of likely core user groups. Examples from different countries are shown in …

Figure 3.

…

Figure 3: Examples of scientific appraisal criteria used by different countries

<u>Support high quality, innovative research</u>

- In areas where Australia is or has the potential to be world-class in research and provide international leadership (AU)
- The scientific quality, relevance and innovative character of the research programme to be executed by means of the research infrastructure (BE)
- The research or technology development activities are in novative, feasible, and have the potential to lead to breakthroughs (CA)
- To be of great scientific value (DK)
- Enabling scientific excellence and the potential for world-class research and scientific breakthroughs. National and international scientific significance and added value of the research infrastructure. (FI)
- The importance of the project to access existing or develop new research areas. (DE)
- The proposed use of infrastructure by the named investigators (IE)
- Potential long term benefits and impact of the infrastructural investment to enhance current research activities of researchers and the wider research community (IE)
- The importance for science (NL)
- Scientific importance of the infrastructure (NO)

- The scientific impact of the infrastructure, including consideration of: how the infrastructure meets the needs of the research; how it promotes world-leading research; long term synergy effects; scientific, organisational, technical and operational comparison to similar European and international infrastructures; dissemination of research results and competence. (SE)
- Intellectual merit – the potential to advance knowledge. A compelling science case, with well-articulated project goals. (USA)

Support high quality, innovative research groups

- The quality and competences of the involved research group or groups, and their scientific position in the international context (BE)
- The team is composed of established or emerging leaders and has the expertise and breadth, including relevant collaborations, to conduct the research or technology development activities (CA)
- Quality of the potential user community (FI)
- The scientific impact of the infrastructure, including consideration of the merits of the Swedish scientists connected to the infrastructure, as well as the merits of the Swedish scientists who participates through in-kind contributions. (SE)

…

Financial and Technical Criteria

The financial and technical criteria used across different countries generally cover a consideration of whether the proposed investment is affordable and technically feasible (in the short term) and financially sustainable (in the longer term). This includes financial aspects relating to efficiency, cost sharing and leverage, as well consideration of the quality, expertise and experience of those proposing the investment, the host institutions and the broader governance structure involved in managing and operating the infrastructure (operational sustainability). Examples of each are shown in Figure 4.

The role of access charges in supporting long term financial sustainability is also relevant here, but such criteria are included within the next broad area, which focuses on the assessment of user access proposals and the potential for infrastructure utilisation.

…

Figure 4: Examples of financial and technical appraisal criteria used by different countries

Affordability (short term)

- **Strength of case made for leveraging non-exchequer funding if infrastructure investment is made. Favourable negotiation with suppliers for**

discounts, maintenance and technical support. There will be an expectation of industry cost-share in this regard. (IE)

- **Financial aspects. (NL**)

Technical feasibility (short term)

- The technical feasibility of the research infrastructure to be constructed (BE)
- Whether proposals are feasible from a technical perspective (focused on potential factors that could increase overall costs in the lifetime of the RI). (DE)
- Technical feasibility. (NL)
- ICT infrastructure. (NL)
- Feasibility. (NO)
- Realistic time plan considering construction, development and operation of the different modules of the infrastructure. (SE)

Financial sustainability (longer term)

- Gives due regard to the whole life costs. (AU)
- The research infrastructure is sustainable through tangible and appropriate commitments over its useful life. (CA)
- Whether proposals are financially sustainable, based on a quantitative review of costs. (DE)
- To be long term and scientifically, financially and technologically mature enough within five years. (DK)
- Economic capacity and stability of the infrastructure during its lifespan, with a long-term plan for maintenance and financing. (FI)

Operational sustainability (longer term)

- The proposal builds on existing institutional capacity and track record of key investments in people and infrastructure in the same area. (CA)
- The feasibility of the project is assessed on the basis of the technical, institutional (e.g. form of ownership, terms of use) and personnel requirements during the whole life cycle of the RI. (FI)
- Realisation – including governance, personnel and institutional factors. (DE)
- Organisation and governance. (NL)
- Administrative management of the infrastructure. (NO)
- Plan for establishment and operation. (NO)

- Competence of the leadership and the partners (both scientific/strategic and leadership). (SE)

…

It is worth noting the case of Flanders, which has gone further than most other countries examined in introducing an enhanced focus on technical and financial feasibility alongside the core assessment of scientific merit. A separate 'strategic investment committee' has been established, which considers further the technical and financial elements of applications that have been assessed as 'excellent' by the main scientific committee. This relatively new committee undertakes a second review of these proposals and provides written comments and recommendations on their findings, which are then taken into account as part of the final decision-making process and in subsequent contract negotiations. There are no set criteria used (or scores given) by this committee. Instead, it provides an overall assessment based on consideration of the proposed investment, how the infrastructure will be obtained, the user plan, the quality of the wider facility, the estimated financial, personal and material costs, and the budget. The committee also conducts a risk analysis, which considers risks regarding the necessary building and environmental permits, the financial position of the organisations involved, and whether funding is sufficient (co-funding, potential revenues from use and reserves, as well as likely upgrade needs). These are also fed into the final decision process. Similarly, in Canada and the USA, the assessment of the planning process and exploitation is also a part of the review process.

Access and utilisation

Most countries include within their assessment criteria some form of explicit consideration of plans with regards to access to the infrastructure and the resultant scale and scope of utilisation, which should be optimised/maximised. Infrastructure is expected to allow open (or at least broad) access to users, both within and beyond the host institution (based on some form of merit based access), so as to maximise utilisation and ensure best use of the infrastructure. Finland and Ireland specifically point to industry as a desirable user in the wording of criteria, while most other countries are more vague, talking more generally of users or researchers. A small number of countries also mention the extent / quality of support to users as one of the areas to be considered as part of assessment.

Examples of relevant criteria used in different countries are shown in …

Figure 5.

It is worth noting that access and utilisation criteria relate closely to aspects of the two dimensions outlined above, for example in helping to ensure the infrastructure supports scientific excellence (through being widely accessible), and in ensuring that it is (financially) sustainable in the longer term (through having in place appropriate access policies and charging plans, as well as optimised usage).

…

Figure 5 Examples of appraisal criteria relating to access and utilisation

Broad / open access beyond the host institution

- Developed on a collaborative, national, non-exclusive basis, serving the R&I system broadly, not just the host/funded institutions. (AU)
- The business case should address user-related operational procedures such as the user access plan and outreach. Access guidelines should ensure that there are as few barriers as possible to accessing major infrastructure for those undertaking meritorious research. (AU)
- The accessibility of the research infrastructure for researchers outside of the receiving institute and the quality of the access arrangements. (BE)
- The origins of user groups as well as modalities that regulate the access to the research infrastructure. (DE)
- To be open for access (as in non-exclusive consortia) for all interested researchers, no matter their research institution. (DK)
- Intra- and inter-institutional usage and access (IE)
- Relevance of investment to industry and proposed use by industry (from SMEs to MNCs). (IE)
- Quality of sustainability and management plans, including access charge plans. (IE)
- Be open and easily accessible to researchers, industry and other actors, ensuring broad utilisation. Access may require approval of a research plan and reasonable user fees as a compensation for the maintenance, user support and other services. (FI)
- Accessibility (NL)
- Accessibility, communication and user support towards current and new users. (SE)

Maximising utilisation

- The extent to which the research infrastructure can generate a large stream of new projects (BE)
- The infrastructure is optimally used within and among institutions, sectors and disciplines. (CA)
- The size of user groups (DE)

- Scope of potential user community, with a long-term plan for utilisation. The research infrastructure is continuously used by excellent researchers and research groups (FI)

…

Wider strategic fit and benefits

Many countries include criteria within appraisals that relate to the wider strategic fit, alignment and benefits of the proposed infrastructure.

These include consideration of relevance and alignment with national, agency or institutional research strategies and priorities. The Finnish national RI roadmap also notes that "building and operating an RI requires a long-term commitment from the research infrastructure itself and the host as well as other contributing institutions". It therefore also includes criteria relating to the 'commitment to the project by the organisations involved'. Similarly (but outside of the appraisal criteria), proposals in Denmark must be submitted from the management of a university / institute in an effort to encourage internal assessment of proposals pre-submission and ensure alignment with institutional strategies and policies, as well as "buy-in" to the proposed RI. The Danish assessment criteria then also include 'that the infrastructure will be co-funded by the research institution'.

More generally, criteria in some countries consider the relevance and appropriateness of the proposed investment within the wider context of national needs and the existence of other similar facilities or initiatives nationally or internationally (i.e. considering issues of coherence and potential leverage).

Several countries also include criteria relating to the contribution of investments to enhancing the visibility and reputation of the national research community at an international level, including opportunities to enhance international engagement and participation in related initiatives.

Specific examples are shown in Figure 6.

…

Figure 6 Examples of appraisal criteria relating to wider strategic benefits

Alignment with national research priorities / strategies and needs

- Aligned with key government priorities and initiatives. (AU)
- Strategic significance of the research infrastructure for Finland. (FI)
- The proposed research infrastructure's relevance to Germany. (DE)
- Alignment to 14 National Research Priorities. (IE)
- Of national importance (NO)

Fit within the mission and strategic plans of the NSF and the sponsoring Directorate or Division. (USA)

Alignment with national research needs

- To be of national interest. (DK)
- The importance of the research infrastructure for the research within the concerned scientific discipline. (BE)
- The infrastructure is necessary and appropriate to conduct the research or technology development activities. (CA)
- The strength of the justification of need (IE)
- Be of broad national interest and (timely) scientific significance. (FI)
- The importance and urgency of the investment for science (NL)

Alignment with institutional strategies and priorities

- The extent to which the proposal can be fitted within the strategic research policy of the involved institute or institutes. (BE)
- To support the research institution's strategies. (DK)
- The project's links to the research strategy of the host organisation(s). (FI)
- Contribution to the overall research strategy of the research body(ies) concerned. (IE)

Alignment / coherence with other infrastructure and initiatives

- The extent to which the proposal is aligned with initiatives at home and abroad and with research infrastructures within the specific research field. (BE)
- Planned, as well as existing potentially competitive and complementary research infrastructures (DE)
- If relevant, a linkage with international research infrastructure. (DK)
- The RI provides added value at the national and / or international level. (FI)

…

Socio-economic impact

Similarly, many countries include one or two criteria that seek to assess the potential socio-economic impact of research infrastructure. For instance, covering aspects relating to:

- The scale of economic benefits anticipated from design / construction and use

- Support for innovation and industrial competitiveness in design/construction or through the research and development enabled through the infrastructure
- Contributions to tackling wider societal and environmental challenges.

It is evident reading across the country examples that such socio-economic criteria are still the least common and often the least well developed in terms of the specificity of their wording (this again may in part reflect the need for flexibility in applying the criteria to a range of situations). Nevertheless, the examples identified of such criteria are listed in Figure 7.

…

Figure 7 Examples of appraisal criteria relating to potential socio-economic impact

Economic benefits

- Maximise the capability of the R&I system to improve productivity, foster economic development and serve the national interest (AU)
- National employment (NO)

Innovation and industrial competitiveness

- The innovative technological character of the research infrastructure. (BE)
- Technological and other advancement of the infrastructure. Introduction of new cutting-edge technology (if relevant) (FI)
- Contribution to strengthening the capacity for innovation and enhancing international competitiveness (CA)
- Societal impact of the research infrastructure in industrial-commercial terms or the common good either in the short (e.g. construction stage) or long term (e.g. utilisation of results) (FI)
- The importance for industry (NL)
- Commercial relevance (NO)
- The non-academic impacts of the infrastructure, including contribution to innovation and possibilities for industry. (SE)
- *Proposals are asked to detail potential industrial benefits from investment (though this is not a formal criteria) (DK)*

…

Other criteria

Finally, a small number of other criteria are found in individual countries, that do not fit well within any of the main groupings outlined above. These include: the RI role in researcher training (FI); ethics and ethical considerations (NO, SE); environmental consequences (NO); data management plans (FI); cooperation with other infrastructures (SE); collaboration and co-investment (AU, DK, NO, USA).

3.2.2 Approaches to scoring and weighting

In almost all cases, appraisal panels are required to **score individual proposals** on each of the specified criteria discussed above (Denmark is the exception, using a wholly qualitative process). The scoring system employed is typically a Likert scale, of e.g. 1-7. Some countries (e.g. Sweden, Ireland, Finland and Canada) explain in their publically available information what the different scores mean, but this is simplistic (see examples in Figure 8), providing little insight into the assessment process.

…

Figure 8 Examples of scoring scales employed for ex-ante appraisal against criteria

For the Canadian innovation fund, the following assessment scale is used by the expert committee for the assessment against the 6 criteria:

1. Does not satisfy the criterion due to major weaknesses
2. Partially satisfies the criterion with some significant weaknesses
3. Satisfies the criterion with only a few minor weaknesses
4. Satisfies the criterion
5. Significantly exceeds the criterion

For the Irish RI Fund, certain criteria are assessed against the following scores:

1. Very low potential
2. Low potential
3. Good potential
4. High potential
5. Outstanding potential

The Swedish Research Council use a 1-7 or a 1-3 scoring system for different criteria, where:

1. Poor
2. Weak
3. Good
4. Very good
5. Very good to excellent
6. Excellent
7. Outstanding

1. Insufficient
2. Sufficient
3. Excellent

Finland applies the following scoring system

1. Weak: severe flaws intrinsic to the proposed infrastructure project or the plan
2. Unsatisfactory: in need of substantial modification or improvement
3. Good: contains elements that could be improve
4. Very good: contains some elements that could be improved
5. Excellent: extremely good in international comparison – no significant elements to be improved
6. Outstanding: exceptional novelty, innovativeness and enabling of renewal of science at a global level

…

The guidelines for expert committees assessing proposals under the Canadian Innovation Fund go a little further[9], in discussing the aspects that must be addressed under each criterion (and that should therefore be considered in providing a score). However, these are little more than restatements of the proposal instructions. For example, the criterion “the research or technology development activities are innovative, feasible, have the potential to lead to breakthroughs, and will enhance international competitiveness” should be assessed and scored based on a consideration of three aspects that proposals should have fully addressed:

- Present the principal users’ track records, including their most significant contributions and relevant measures of output.
- Highlight team members’ scientific and/or technical contributions to the proposed program.
- Describe collaborators’ and partners’ contributions to the proposed program.

In all countries, peers score proposals *independently* in the first instance and then *as a panel*, where they discuss and look for consensus across any differing

[9] See Appendix 2: https://www.innovation.ca/sites/default/files/Funds/2017_guidelines_for_expert_committees_final.pdf

perspectives, such that the panel can agree on a final score / set of scores for each proposal along with a qualitative explanation of each score. A panel will then produce a final **ranked list of applications**, based on individual proposal scores (sometimes adjusted as the appraisal progresses and the scores / grades are calibrated by the overall set of applications) with a qualitative commentary on its priorities (and perhaps the individual scores) for use by the programme board or ministry in reaching / approving a final decision.

In several countries, early appraisals and **feedback** may be shared with bidders in order to allow them to strengthen their proposals (re-submissions) – though this typically only applies to those proposals judged to be of sufficient quality. For example, in Denmark there is a period of interviews and site visits with a selection of proposals, to ask for further details and seek further clarifications and explanations, which may then result in adjustments to rankings.

We have not identified any use of explicit **weighting** in the scoring and ranking systems employed as part of the appraisal process. However, there is often some implicit weighting within the choice of criteria used as the basis for assessment, or in the approach to appraisal. For instance:

- In some cases, while scientific excellence and feasibility are covered by core criteria, additional aspects (such as socio-economic impact or innovation) are only to be ‘considered’ as part of the assessments. For example, in Denmark, proposals should meet five criteria and “in addition, proposals are asked to detail potential scientific, industrial and societal benefits from the investment”. Similarly, in Finland, decisions on funding are based on consideration of four criteria (that relate to scientific significance and added value, links to host and national strategies and openness in use), while “attention is also paid to: systematic and broad utilisation of the infrastructure, quality and scope of the potential user community, technological and other advancement of the infrastructure, and economic capacity and stability during its lifespan.”
- In others, these wider considerations are assessed separately, resulting in findings and recommendations that are advisory (i.e. to be taken into account, but not formally part of a scoring/ranking process). This, for example, is the case with the second review of proposals by the strategic investment committee in Flanders, where the board may reject their recommendations, turn these into funding conditions, or ask for amendments to proposals on the basis of the comments provided. Similarly, in Germany, a ranked table of proposal scores is produced based on the science-driven evaluation, while a separate cost and risk assessment is also provided “for further consideration”.

In a recent working paper, Pancotti et al (2014) reviewed international practices in RI selection and appraisal processes and they noticed a general trend away from purely science-based considerations towards "more formalised, systematic and possibly quantitative approaches to RI selection and appraisal". The changing role of RI facilities, they concluded, and a growing expectation that they should tackle important socio-economic challenges means that these challenges were increasingly factored into the assessment and appraisal process.

Our review across selected countries also suggests that the science case is still generally the most important, and in most countries the appraisal of proposals is primarily done on the basis of 'scientific merit', often using a peer review approach. There is, however, a growing emphasis on (or at least consideration of) other aspects (the innovation case, the economic and societal impacts of investments, and alignment with grand challenges) – either through specific project appraisal processes and criteria, or through the wider associated strategy and roadmapping processes. There is also growing attention paid to the economic analyses regarding large RIs, by which we mean the assessment of the whole life cycle of infrastructures, including the risks and feasibility of the construction phase, the costs of exploitation and maintenance, the use of the facilities by external parties, and the cost of / need for upgrading or decommissioning. However, while such elements are increasingly a formalised and systematic part of criteria, they are mostly assessed through the same (mainly qualitative) peer review process, alongside more science-based considerations.

3.2.3 Carrying out the appraisal

The majority of comparator countries operate a tiered appraisal process, with two or sometimes three layers of assessment. This tends to follow the following overall structure:

- The process begins with an assessment of **individual proposals** by panels of independent experts, always including eminent (and usually 'foreign') scientists, as well as (sometimes) industry experts and other specialists. For example, there are examples of efforts to include those with experience of utilising research results (Canada), managing research infrastructure (Ireland) or assessing risk (technical consultants used in Belgium).
- This is generally followed by a review of individual assessments **at the portfolio level**, identifying the best proposals based on the panel advice and consideration of strategic issues / financial guidelines (e.g. the Netherlands works with top-down specification of budgets for different areas). In some countries (e.g. Canada), this portfolio analysis is split into two steps, with the first considering a sub-set of the portfolio that are of similar size and complexity. Others undertake a first 'area-based' portfolio assessment.
- There is then a **final review** of the recommendations from the 'technical' appraisal process, which is carried out by research councils or internal policy teams within a science ministry. In all cases the **final decision** is then taken by a ministry (the minister) or the board of an executive agency with the mandate of the minister – based predominantly on the recommendations of the appraisal

process, but usually with the ability to adjust the selection to take account of e.g. policy priorities or budgetary constraints (though this step is often something of a black box). Interestingly, the relevant board of Directors in the Netherlands either accepts the ranked list of its scientific evaluation committee, or rejects the list in full and returns it to the assessment committee for further consideration.

It is also worth noting that there are several countries that use **RI Roadmaps** to help manage bottom-up demand, with expressions of interest being used to help governments arrive at a list of priority topics, which can then be bid against in the subsequent open calls (Sweden's inventory of needs is a case in point). The extent to which the roadmapping process integrates some of the ex-ante appraisal of individual projects varies by country. Some roadmaps identify broad needs and ideas, while others get closer to selecting individual investments and committing to funding some or all of these in the coming period. For example, there is a stated intention in Denmark to fund at least 15 of the 20 projects listed in the catalogue of proposals associated with its roadmap. Such situations shift at least some of the emphasis of appraising proposals to the roadmap development stage, rather than the point of final selection / funding.

3.3 Current state of the art

In recent years, there has been a growing interest in methodologies, tools and indicators for the evaluation of science capital investments, in order to inform ex-ante prioritisation/ decision-making on new (and upgraded) infrastructures. The demand stems from funding agencies and policy makers, as well as infrastructure managers, administrators and user communities. Across the case study countries, we see a number of recent changes and developments in the approach and details of the appraisal process, which reflect ongoing learning and an expansion in the recognised role of RIs.

Looking across the different approaches and aspects of the appraisals currently employed in different countries, we would highlight a number of particular features that we see as strengths of these specific systems. These include:

- The use of a **tiered appraisal approach**, involving an initial scientific and technical review of individual bids (by individuals and then panels of expert reviewers), and concluding with a more strategic review across the portfolio of all (or the best) proposals, carried out by funders / ministries, which is largely (though not entirely) based on the outcomes of the assessment process
- The use of **multiple peer review panels,** which avoids the need to appraise a research data centre against a light source or research ship
- Similarly, the **simplicity of assessment criteria**, which allow these to be applied flexibly across a portfolio of widely different infrastructure proposals over time
- Involvement of **international experts** with a broader view of the international state of the art, as well as (increasingly) experts with additional expertise in e.g. RI construction or management

- A **willingness to share feedback** with (some) applicants to allow refinement of proposals, in recognition of the effort invested in preparing applications
- The use of **numerical scores accompanied by written explanations** of those scores, which is helpful to panels in their deliberations and to agencies responsible for making and providing feedback on final decisions

3.4 Outlook on future developments

The robustness of appraisal procedures for science capital investments has often been found not to be aligned with the size and complexity of those investments. For example, in 2010 the European Court of Auditors concluded that the criteria for the payment of EU funds under the construction of new infrastructures scheme (ERDF) were insufficiently specific.[10] In 2013 the Dutch advisory council for Science Technology and Innovation stated that "there are no systematic evaluations of the effectiveness and yield of research infrastructures" and there is a lack of transparency with regard to investments.[11] Similarly, in the UK, the National Audit Office published a report criticising the appraisal (and evaluation) of research infrastructure projects and emphasised the need for a more structured, consistent and systematic approach for prioritising projects.[12]

There is therefore a widely-recognised need for a more structured, consistent and systematic approach to evaluating research infrastructures, including ex-ante (i.e. prioritising projects, assessing business cases and technical issues). This is an area that is a focus of some considerable developmental activity in many of the countries we have looked at, but is also an ongoing process, and there would appear to be outstanding weaknesses in current approaches (at least based on the information publicly available). For example:

- **It is unclear how one scores some of the criteria specified**, and in particular those relating to anticipated future socio-economic benefits (impacts) of what may be quite fundamental research that could take very many years to result in applications on the ground.
- It is unclear how one appropriately adds up the scoring of very different kinds of criteria. There is **no evidence that any formal weighting system is applied** – at least within criteria that are formally scored. There is some use of 'other areas of consideration', whereby additional factors (beyond those covered by core criteria) may be taken into account in the assessment/decision process. However, this appears to risk reducing the transparency, or at least the consistency, of the overall appraisal processes.

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[10] European Court of Auditors, *The effectiveness of the design studies and construction of new infrastructures support scheme under the sixth framework programme for research* (2010).

[11] AWTI, *Size and suitability. Investing strategically in large research infrastructures* (2013)

[12] National Audit Office (NAO), BIS's capital investments in science projects (2016)

- The final decision is typically exercised by a programme board or senior policy makers, based on the advice of international experts and set against strategic priorities. It is **unclear how far this final decision is able to be explained and made transparent** – and the extent to which the panel reviews, scores and rankings are 'over-ridden'.
- It is unclear how past evaluations feed forward into ex-ante appraisals, allowing peer reviewers to score non-scientific criteria more confidently (i.e. **learning from past experience**).

Finally, from the academic literature, Pancotti et al (2014) concluded that peer review, while widely used and useful for assessing the science case of the RIs, is not the best appraisal method in the context of multifaceted RI systems and "does not account for the nature and pace of scientific discovery". As a result, the authors looked further into the possibility of adopting **cost-benefit analyses** as a method which can potentially take into account the socio-economic effects of RIs. Changing the needs and expectations towards large RI facilities have also led to wider examination and piloting of cost-benefit analysis (CBA) within the appraisal process.

3.5 Some reflections on implications for the UK

The UK's appraisal arrangements for research infrastructure are broadly in line with the approaches we have identified and explored through this international research.

The appraisals are typically science-led, with three groups of assessment criteria in use – science first, technical feasibility second and economics third – and with decision-making being led by leading domain scientists and overseen by scientific administrations with the support of technical and financial specialists. The comparator countries tend to make greater use of international experts.

The appraisal criteria and process are developing in all countries, with societal benefits and strategic interests beginning to weigh more heavily in the process overall.

It is helpful to think in terms of medium-scale and large-scale infrastructure, with the former more likely to be identified and supported through calls for proposals, which may give some thematic direction – challenge focus – and then rely on scientific panels to choose amongst the best. The individual panels will consider technical questions as well as impact in their preparation of the lists of stronger proposals. The thematic panels will typically be guided by an overarching committee with a broader strategic mix of members, from research and user communities, as well as major funders and policy leads. The competitions may have a second round, inviting applicants to address any questions raised – scientific, technical or economic – before being re-submitted to be looked at again by the thematic panels and then finally by the overarching panel to finalise decisions. Even at this stage, the scale and importance of the individual capital investments is such that there is still likely to be some extensive negotiations with funders; in essence, the more money invested, the closer the commissioning process comes to a negotiated procedure. The use of challenge funding has become more common, in part as a response to the criticisms by financial authorities that the appraisal of research infrastructure lacks the precision and consistency one would expect to find in a grants programme. The NAO has made similar observations in the UK.

The biggest RI investments are still subject to more political influences, with strategic issues weighing heavily in both the appraisal and the conditions attached to the approval. Co-financing and industrial leverage are also important contributory factors. There is also an ongoing challenge as regards the amount and quality of evidence available on the social and economic impacts of large research infrastructure, which means appraisals must work with rather broad brush views of the likely potential benefits to science or society. It is not clear for example, that evaluators will have been briefed on the concrete achievements of similar investments elsewhere, nationally or internationally, and provided with comprehensive guidance material that cross-references past studies. Given the state of the art in ex-post evaluation, there is wariness on the part of funders about the over-specification of the appraisal tests, and the potential loss of credibility in the eyes of the international experts they depend on critically to review proposals. The good will of these domain specialists and the wider community is necessary in order to be able to carry out the reviews, formulate feedback and expect that advice will be adhered to.

4 Monitoring and evaluation of science capital investments

4.1 Introduction

Investments in research infrastructures can have effects along different dimensions. For this reason, comprehensive evaluation approaches for RI are challenging endeavours with considerable measurement and attribution problems[13].

In broad terms, our literature review shows there are mainly three categories of effects which are considered in the monitoring and evaluation of science capital funding:

- The **scientific value** of the RI: effects on research activities, as well as training of (early career) researchers and scientists and opening the RI to other stakeholders (access and utilisation)
- The **economic value** of the RI: effects that arise from economic activity that takes place in the context of infrastructure development, and the procurement of related goods and services, or effects resulting in innovative products or processes connected with the research in the RI
- The **societal value** of the RI: the added value for society, e.g. by contributing to addressing societal challenges like climate change, the ageing society or sustainable agriculture, or through higher acceptance of research activities in society (e.g. by RI public engagement activities)

Additionally, the financial, economic and technical feasibility of RI projects themselves is regularly monitored, given the considerable investments made in many cases and the potential risks involved.

There are several established approaches for project control monitoring (e.g. risk-profile analysis, milestone trend analysis, cost trend analysis, Earned Value Analysis, target/actual-comparison etc.). However, the development of a standard methodological approach for the measurement of socio-economic effects (impacts) is still a work in progress.

There are several research agencies, research groups and expert committees working in parallel on the development of more comprehensive and robust approaches to RI impact assessment. For example:

- The OECD Global Science Forum Expert Group on RI policy, which has been undertaking various activities in preparation for the development of a reference framework for assessing the socio-economic impact of research infrastructures[14]

13 This term refers to the challenge of establishing a clear causal, robust link between the RI and effects linked to it.

14 The OECD Global Science Forum activity to establish a reference framework for assessing the socio-economic impact of RIs began in 2015. In the first phase of the project the forum collected and compiled an extensive bibliography on methodologies

- FP7 projects such as “RIs: Foresight and Impact (RIFI),” which published a full guide to assessing the socio-economic effects of RIs and EvaRIO (Evaluation of Research Infrastructures in Open innovation and research systems), which develops the “BETA approach” to the evaluation of research infrastructure (BETA is an economics institution at the University of Strasbourg)
- The project “Cost/Benefit Analysis in the Research, Development and Innovation Sector” by the Departments of Economics, Management and Quantitative Methods (DEMM) and Physics at the University of Milan and the independent research centre CSIL, financed by the European Investment Bank Institute under its University Research Sponsorship Programme (EIBURS)

There is a reasonable degree of interaction and sharing among these different groups, through conferences, events and informal networking, which is enabling some convergence around methods and tools. However, methodological challenges remain somewhat unresolved and will be a focus for ongoing debate. The development of a widely-agreed reference method still looks to be some way off.

The general need to strengthen the methodological toolkit for assessing the effects of research infrastructures can be illustrated by findings from the 2013 Technopolis study “Big Science and Innovation”, which analysed around 100 academic papers and grey literature on the topic of evaluating large research facilities and innovation outcomes. This analysis found no RI studies making use of cost benefit analyses or NPV [net present value] analyses for large research facilities, or a single example of an evaluation that had sought to identify, quantify and aggregate all types of economic benefits. An evaluation of the Synchrotron Radiation Sources was the only identified example that covered all broad classes of social and economic impact – however, this study did not attempt to “add it all up”. Finally, the study found few attempts to aggregate innovation impacts, and where this did happen, it focused primarily on the effects of the public procurement of cutting edge technologies.

4.2 Overview on the findings for the case study countries: similarities and differences

There are different logics behind monitoring and evaluation approaches. Monitoring efforts focus on steady progress of an RI project during construction and operation, and often concentrate primarily on financial and administrative aspects (e.g. compliance with the cost schedule). Monitoring arrangements during the operational

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and current practices, with two workshops held to exchange views and experiences on these issues. Information is now being gathered through surveys (of funders, policy makers and RI managers) on the diversity of indicators employed for various RI types, and on the way these indicators are collected and used. At its latest meeting (June 2017) the GSF discussed the objectives, limitations and possible structure of the planned reference framework.

phase do also address scientific or innovation-related outcomes, but often only simplistically, based on pre-determined and easily obtainable indicators and associated reporting requirements. A more detailed analysis of outcomes or impacts is usually only undertaken as part of one-off evaluations. Evaluations are conducted ex-post[15], i.e. after the RI has been established and running for a time. They do typically address the scientific, innovation-related and societal impacts of the RI, though with differing priorities depending on the country / RI concerned.

In addition, while RI monitoring is usually done internally, involving the ministry or government agency responsible for funding research infrastructures, RI evaluation is usually carried out by independent external evaluators (international scientific experts and / or evaluation professionals). Examples from case study countries are shown below.

…

Figure 9 Examples for actors involved in monitoring and evaluation processes in different countries

Examples for monitoring processes carried out primarily internally:

- DE: The monitoring/controlling for RI is carried out directly by a dedicated unit within the ministry (BMBF Controlling unit). It assesses project developments regarding costs, timing and progress. Furthermore, the unit assesses governance and management structures of projects, primarily during the construction phase. All RIs are subject to the oversight by the BMBF controlling unit. It is also responsible for other large-scale science projects valued over €15M.[16] Monitoring during the operational phase of the RI is also carried out by another BMBF unit.
- CA: Monitoring activities are carried out by the Canada Foundation for Innovation, an independent institution created by the Government of Canada to fund research infrastructures.
- DK: Each of the granted research infrastructures is obliged to report annually to the Ministry of Higher Education and Science in order for the Ministry to monitor progress.
- SE: In general, all funded researchers and research institutions need to send in annual financial reports (and in most cases scientific reports) to the Swedish Research Council. Granted research infrastructure projects need to report according to the general terms of reporting, which focuses on key numbers in terms of usage, national reach, equality and scientific results/impacts.

[15] For ex-ante assessments / evaluations see the previous section

[16] For larger projects (above €50n) the BMBF is also supported by external consultants.

Examples for evaluation processes with external involvement:

- BE: All agencies and institutes that are part of the Flemish government, including research infrastructures, are evaluated every five years by an external independent panel of experts.
- FI: Evaluations of RI are supported by two international expert panels, one focusing on the scientific dimension and another focusing on governance and impact

SE: In 2012, the Swedish Research Council released an interim evaluation of eleven national research infrastructures. This was carried out by three international expert panels

The above are Technopolis case studies for this project

…

There are exceptions, particularly for larger-scale RI. There is a certain "size effect" notable in the monitoring and evaluation requirements and approaches found in the case study countries, and there are several examples of countries where there is an explicit intention to undertake more rigorous monitoring and evaluation for larger investments. For example, in Germany, RI investments over €50m require an additional external project controlling structure to be established, rather than this being done internally. In addition, larger infrastructures are more likely to be subjected to an ad-hoc evaluation by the German Council of Science and Humanities. In Belgium, there are similar differences in the attention paid to investments in research infrastructure that are above €1m.

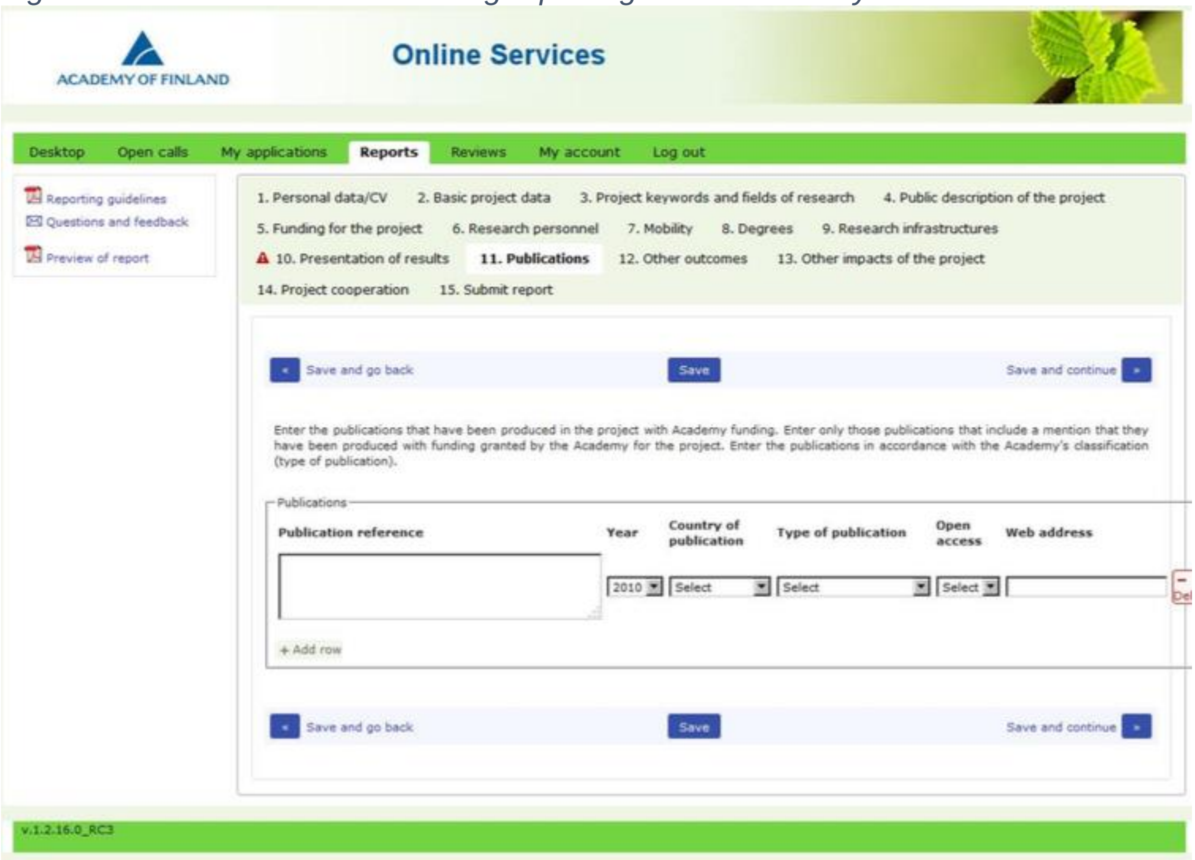
4.2.1 Monitoring arrangements

A common finding in the case study countries was that the managers, lead scientists or principal investigators of research infrastructure projects are required to prepare status reports at regular intervals. These usually served as a core element of the monitoring approach, but might also be used as the starting point for retrospective analysis in any subsequent evaluation.

There are different arrangements regarding the frequency of such status reports, although in most cases these are required on an annual basis. In Finland, monitoring is more frequent, with status reports required every quarter. In some countries, the frequency of reporting can also vary between different projects. This is the case in Canada, where the reporting frequency depends on previously identified risks in the project management of the RI (see the case study appendix for information on the "Tool for Risk Assessment and Management (TRAAM)" by the Canada Foundation for Innovation).

The monitoring reports are usually based on standardised reporting templates (see for example the Irish case study). In some cases (e.g. Finland) the reporting is organised via an online tool for the monitoring data collection (see screenshot in the following figure).

Figure 10 Online tool for monitoring reporting of the Academy of Finland



Source: Academy of Finland's How-to guide for the online services, available at http://www.aka.fi/en/funding/how-to-apply/online-services/ (accessed on June 8th, 2017)

Monitoring reports usually contain a mix of qualitative descriptions of the current status quo and outlook of the RI, as well as a set of quantitative indicators. The indicators tend to align with the three broad evaluation dimensions listed in the previous section: the scientific effects, the economic effects and the societal effects (as can be seen in the examples presented in Figure 11).

…

Figure 11 Examples for common indicators used in monitoring approaches (case studies)

- Scientific dimension
  - Number of publications connected with the RI (sometimes weighted by journal impact factor, citation rates) (generally used in all case study countries)

  - Number of users/access statistics to the RI as an indicator for openness to the scientific community (e.g. in FI, documented via a usage logbook in BE)
  - Attraction (number) and retention of researchers (CA), number of PhD candidates qualified at the RI, number of students studying/working at the RI (FI)
  - Academic collaborations with other national or international research groups
- Economic dimension
  - Number of direct and indirect jobs created (e.g. in FI)
  - Number of spin-offs and start-ups (e.g. in FI, IE)
  - Number of patent applications/filings or patents granted (e.g. in FI)
  - Number of industry engagement activities, number and funding of collaborative projects with industry, gained industry contracts (e.g. in BE)
  - Number of developed new technologies (e.g. in FI)
  - New products based on results from RI e.g. in (e.g. in DK)
  - Amount of co-funding from industry partners (e.g. in IE)
- Societal relevance
  - Number and kind of outreach activities to the general public (e.g. in AU)
  - Media appearances (e.g. in IE)
  - Regional Impact

…

Source: Case studies for this project

These findings correspond to a long list of possible indicators (shown below) that has been compiled by the OECD Global Science Forum. Current survey work by the forum is looking to understand which of these indicators are collected and how they are used by institutions in different countries.

…

Figure 12 Examples for common indicators used in monitoring approaches (OECD Global Science Forum)

- Scientific output and attractiveness
  - Publications –articles published (and co-authorship network), publications in high-impact journals, scientists who have published or co-authored, citations

of published articles

- Number of scientific users
- Collaboration with leading teams worldwide (top 10)
- Number of Nobel Prizes and other important awards linked to work carried out at the RI
- % of international scientific manpower within the RI
- Number of new scientists using the RI
- Access/use of experimental facilities: (available instruments & services (number, typology, capacities), number of user visits (on site), number of instrument-days, number of received & accepted experimental proposals, number of experiments performed, typology of users (academic research, industry, etc.), "fair scientific return" in member countries
- Access/use of research data / databases / collections & informatics resources: available resources (volume, type), number of users, typology of users (academic research, industry, etc.), more detailed statistics on the access to data / databases / collections / informatics resources, number/importance of the (re-)use of the resources

- Technological output and attractiveness
  - IP/Patents/licenses – Number/volume/importance of: international patents, national patents, co-patenting with companies, citations of patents (bibliometric analysis), patents making use of the results generated by the public research programmes of the RI, copyrights, licenses, background IP used for design/construction/upgrade
  - Number/volume/importance of: prototypes and innovations generated, technology transfer (activity of the TT Office), co-development with industry, co-development with other RIs, co-development with research & technol. organisations
  - Availability & access to dedicated technology platforms
  - Data on the proprietary (commercial) use of the RI by industry
  - Distribution of specific products (e.g. animals, plants, software/hardware, etc.)
  - Involvement of industry in the financing of academic research at the facility
  - Involvement of industry in academic collaborations making u=-099-;/se of the facility
  - *Involvement in standardis*ation bodies

- Direct economic impact
  - Basic data: total budget of the RI (incl. investments and salaries), total number of FTE

- Number/volume of public procurements and contracts
- Purchases and industrial/commercial contracts in the various partner countries
- Suppliers of the RI: total number, regional dimension, revenues
- Firms using the RI (access to experimental facility or to data/collections and informatics resources): total number, regional dimension
- Number of R&D projects commissioned by companies
- Volume of funding of R&D projects commissioned by companies
- Volume of funding through collaborative projects
- R&D time spent in industry using RI provided data
- Dedicated economic impact studies (incl. central hub and nodes for distributed RIs)

- Indirect economic impact
  - Innovative projects based on RI outputs
  - Number of medium- to long-term collaborative contracts with industrial partners
  - Number of start-ups around the RI
  - Number of spin-offs generated by the RI
  - Number of PhDs and engineers (from the RI) employed by industry
  - Job creation in the economy: indirect (generated by the RI purchases), induced (generated as a result of the high-tech requests of the RI to industry)
  - Statistics on IP created by graduates / past collaborators / past students from experiment collaborations and access to data resources
  - Impact of the RI on the creation/development/ strengthening of a local/regional ecosystem of innovation / Integration of the RI in this ecosystem
  - Local/regional impact of the RI on: the environment, energy production and consumption
  - Economic impact on tourism

…

Source: OECD Global Science Forums Questionnaire to identify a common and consistent set of core generic indicators for baseline impact assessment

Monitoring approaches also refer to project management metrics, since part of their aim is to assess the progress of projects under development/construction. For example, in Germany the following **Key Performance Indicators (KPIs)** (see …

Figure 13) are used to monitor progress in RI construction.

…

Figure 13 Metric/KPIs used for monitoring of RI construction processes in Germany

- Schedule Performance Index (SPI): “Earned Value/Planned Value”, in order to assess the relationship between the value of the work done and that of the planned work.
- Time Estimate at Completion (TEAC): “Time at Completion/Schedule Performance Index”, in order to estimate project duration.
- Cost Performance Index (CPI): “Earned Value/Actual Cost”, in order to determine whether the project’s cost planning meets its targets.

Estimate at Completion (EAC): “Budget at Completion/Cost Performance Index”, in order to perform a revised cost estimate at a given date.

…

Source: Country case study for Germany for this project

4.2.2 Evaluation arrangements

Our case studies suggest that in all countries some kind of evaluation approach for RI is in place. However, we see a considerable heterogeneity of the specific approaches taken. Broadly, these include the following categories:

- For countries such as Australia and Belgium, the case studies suggest that it is standard practice that all infrastructure projects are evaluated at some point. Also for Norway we found that all funded research infrastructures were evaluated in an overarching evaluation to gain an overview of effects/impacts achieved through all investments in research infrastructures (portfolio view on research infrastructures). In some cases there are regular evaluation exercises for research infrastructures every 4-5 years (e.g. in Canada in 2010 and 2015).
- In other countries ad-hoc evaluations of research infrastructures take place, but not on a regular basis. This is for example the case in Germany where the Ministry for Education and Research usually asks the evaluation committee of the German Council of Science and Humanities for its view on specific research infrastructures when the need to do so arises.
- In other cases, RI projects with a funding volume over a certain threshold or with particularly high project risks (CA, IE) are evaluated, whereas for other RI projects the standard written monitoring tools are seen as sufficient to assess the effects of the RI.

Evaluations of RI are usually carried out in cooperation with the responsible ministry, with external scientific experts and/or evaluation experts in the area of science policy[17] for at least two reasons:

- The assessment of scientific achievements made possible by the RI needs in-depth knowledge in the respective scientific area. This can usually only be provided by scientists working in the same area. In order to get a more neutral and broader view, there are often international scientific experts involved in the evaluation (e.g. BE, CA, SE, FI)
- Evaluation practitioners bring a detailed knowledge of required evaluation procedures and specialist methodological skill sets (e.g. for cost-benefit analyses or bibliometrics), as well as provide the staff numbers to carry out comprehensive reviews within a reasonably short period.

…

Figure 14 Examples for the involvement of external parties in evaluation in the case study countries

- AU: A 2010 evaluation was carried out by an internal evaluation team from the then Department of Industry, Innovation, Science, Research and Tertiary Education (…). In 2014, an external evaluator was then commissioned to undertake an independent "efficiency review" of the 27 research infrastructure projects funded under the NCRIS.
- FI: The evaluation combines several approaches. The evaluation will be supported by two international expert panels, one focusing on the scientific dimension and another focusing on governance and impact.
- SE: In 2012, the Swedish Research Council released an interim evaluation of eleven national research infrastructures (…) The interim evaluation was carried out by three international expert panels.

IE: One or two of SFI's programmes (including the RI programme) are evaluated each year by an external contractor, with the results reported to the Board.

…

Source: Case studies for this project

[17] An example of the involvement of external contractors for impact assessment in the UK is the Lifetime Impact Study of the ISIS Neutron and Muon Source at the Rutherford Appleton Laboratory by Technopolis in cooperation with the Council of the Science and Technology Facilities Council (STFC) from November 2016.

In several case study countries, there are dedicated evaluation units within the funding organisation (e.g. the Evaluation and Outcome Assessment team in the Canadian Foundation for Innovation[18] or the controlling unit and evaluation unit in the German Ministry for Education and Research). These internal teams tend to advise budget holders on their evaluation requirements, helping with the drawing up of individual specifications and overseeing the methodological robustness of the evaluation proper. They may also help to commission evaluations, where they are outsourced. Science ministries and research councils tend not to maintain the size of staff necessary to implement the evaluations, given the variability in workload and thematic focus over time.

External providers may be specialist consultancies, economics research institutes or independent expert panels, but not always. In Germany, the research ministry can draw on the capacity and expertise from its project management agencies (e.g. Projektträger Jülich or the German Aerospace Centre's Project Management Agency), which in general assist the ministry in organising the entire monitoring and evaluation process and are often also responsible for the economic review of individual RI facilities (especially the ex-ante impact assessments).

The **evaluation dimensions** addressed by ex-post evaluations are similar to the impact dimensions described in the section on monitoring above. This means that the following aspects are usually analysed (in more or less detail):

- Scientific impacts
- Technological impacts
- Direct and indirect economic impact,
- Social and societal impact

It is therefore clear that both economic and non-market impacts are considered in the evaluation frameworks in the case study countries – both of which are of particular interest to BEIS.

Looking at the evaluation dimensions and their operationalisation through indicators it becomes clear that among the most important dimensions are the scientific impacts (as one dimension of non-market impacts). A second prominent non-market impact dimension in many countries is societal impacts. However, while there are standard indicators for scientific impacts (e.g. counts of peer-reviewed journal articles, journal impact factors, field normalised citation rates, etc.) we find no such standard indicators for assessing societal impacts.

[18] The Evaluation and Outcome Assessment (EOA) team in the Canada Foundation for Innovation (CFI) analyses the outcomes of the CFI investments to ensure the most appropriate policy and programme design. The EOA team also tracks the economic and social outcome of the CFI's investment to ensure the organisation's accountability against its stakeholders.

The OECD forum looking at the assessment of socio-economic impact of RIs has identified societal impact indicators such as the number of consulting projects, the number of visitors to the RI, the number of people engaged with the RI for educational and outreach activities, and the number of media articles. These approaches are attempts to find quantitative approximations of difficult to measure constructs referring to social or societal processes.

It becomes clear from the case studies, however, that the majority of approaches taken in the countries to assess these non-market effects are of a qualitative nature. For illustration purposes, the findings from the Irish case study can be mentioned. In Ireland, awardees of funds of the RI programme are asked to comment on a pre-defined set of impact declarations regarding their RI project:

- "The research conducted through my award has resulted in a new policy being implemented and/or an improvement to the delivery of a public service" (Public Policy and Services)
- "The research conducted through my award has enhanced the quality of life and health of Irish citizens" (Health & Wellbeing, Societal Impact)
- "The research conducted through my award has improved the environment and/or the sustainable relationship between society, industry and the environment" (Environmental Impact)
- "The research conducted through my award has increased the knowledge, appreciation and understanding of science, engineering and technology amongst the general public. The research conducted through my award has developed the country's international reputation" (Societal Impact, International Engagement)

It seems from the country case studies that – besides standard bibliometric indicators – in many cases the evaluations concentrate on user surveys, case studies (e.g. describing effects of a cooperation of companies with RI), qualitative assessments by peer reviewers based on site visits or interviews with RI stakeholders, or the appraisals of field experts based on reports from the RI managers. In general, the use of the full methodological toolkit of quantitative and qualitative methods theoretically available for evaluations is quite limited in practice. This can be illustrated by a quote from a Norwegian expert on RI evaluation stating that "it is difficult to [quantitatively] confirm the spillover effects and there are no standardised instruments yet for evaluating (them)". Similarly, for Denmark we found that the scientific, societal and industrial impacts of RI are primarily assessed through the analysis of a 1,000-word statement of the research infrastructure's impact written by the project director or PI and included in the final report or end of grant award. No quantitative evaluation system is in place in Denmark, according to our case study.

Our country case studies did not identify widespread use of approaches like cost-benefit analyses, the calculation of net present values for the assessment of RI or other possible quantifications of RI impacts. Thus, it seems that these approaches are used rarely and only in specific cases.[19]

4.3 Current state of the art

According to the empirical findings from our 11 case study countries, the current state of the art for **monitoring** research infrastructures includes the following:

- Standardised reports for regular ongoing monitoring of the status quo, progress and expected development of the research infrastructure project – with variation in reporting requirements and details, depending on the scale of investment.
- These regular reporting tools are partly of a qualitative nature (i.e. a description of the current situation, a description of upcoming difficulties or challenges and the planned actions on this), but usually are also complemented with quantitative parts (key performance indicators on financial figures, publication records, user number of the RI, etc.).
- There is an evident move towards reporting on non-scientific outputs that track back to national or federal strategies, with the selective use of case studies to illustrate notable innovations or other economic impacts.
- Monitoring arrangements are usually established between the RI project management team and the responsible funding organisation or ministry. In most cases, no third party is involved. There are, however, exceptions from this rule, for example when external project controlling experts are hired to monitor the construction phase of a large-scale infrastructure project.

In terms of the **evaluation** of research infrastructures, the current state of the art includes:

- Bringing in external expertise for evaluation, especially for larger infrastructures, is the norm. Often, internationally renowned scientific experts are invited to participate in a qualitative evaluation exercise with presentations of the RI managers, site visits, interviews with key personnel, etc. Outsourcing of more detailed impact assessments to external, specialised policy consultancy or evaluation firms is also common.
- Panel evaluations remain common, making use of the deep international expertise of members in the rendering of their judgement on an institution's leadership, research quality, skills development, etc. In most cases, the peer review process is informed by comprehensive background material – including financial and output metrics – and visits that allow peers to gather evidence first hand and without the support of the evaluation subject.
- Quantitative indicators are often used for the assessment of scientific achievements and other research outputs (publication records, citation rates for journal contributions associated with the RI, etc.). Economic impact assessments

[19] See the Technopolis report "Big Science and Innovation" for an overview of particularly relevant reports.

are less common, and tend to focus on the direct economic benefits of the capital and operational expenditure, and using case studies to selectively present examples of the kinds of wider economic benefits that derive from industrial users using facilities or supplying novel equipment and scientific instruments. Almost no evaluations attempt to quantify the benefits derived from the research-derived knowledge spillovers, and where they have been looked at, this has been through backwards tracking longitudinal case studies.

In terms of the strengths and weaknesses of these approaches, (semi-)standardised monitoring approaches like the ones described above have the advantage of being applicable to a wide range of different research infrastructure projects. Once there is a standardised reporting template for RI in use, there is only limited effort needed to carry out a regular monitoring. If there are many/several research infrastructure projects to be monitored and evaluated, this standardised approach is a feasible one.

In general, qualitative evaluation (peer review or expert panel evaluation approaches) have the advantage of avoiding the need to quantify the effects or impacts of an RI. A quantitative measurement of the many different potential impacts of a RI is a difficult task. For this reason, it is reasonable, especially if there are several RI to be evaluated, to rely on the expert views and qualitative assessments of renowned scientists, potentially enriched with basic standard indicators for publication efforts or with a larger number or different case studies illustrating the different effects of the RI in a descriptive way (e.g. effects for companies using the RI facilities, effects for supplier companies involved in the construction of the RI facility).

There are downsides to the prevailing qualitative approach. For instance, the fact that it is increasingly important to be able to "attach numbers" to the effects of an RI, speaks in favour of quantitative approaches. A quantification of effects makes it easier to communicate the many different potential benefits to different stakeholders. There are methodological instruments to realise this quantification, but this often requires substantial efforts. In our country case studies, these full-scale impact assessment exercises were not prominently mentioned by our interviewees as standard practice. However, we identified occasional detailed impact studies in the UK and in other countries. This includes the Lifetime Impact Study of the ISIS Neutron and Muon Source at the Rutherford Appleton Laboratory by Technopolis (2016) in collaboration with the Science and Technology Facilities Council (STFC), the STFC social and economic impact study of the Daresbury Synchrotron Radiation Source (1981-2008) from 2010 and the "Analysis of organisational and technological learning and innovation benefits that occur in the relationships between CERN and its individual supplier companies" by Erkko Autio et al (2003).[20] These studies partly make use of concepts such as the analysis of input-output tables and economic multipliers and are therefore more advanced from a methodological point of view.

[20] The Technopolis report Big Science and Innovation shows a concise assessment of 11 studies on research infrastructure impact assessments (see Attachment E.1 of this report).

These more advanced studies have the strength of attempting a quantification of RI effects. There are of course limitations to this quantification as many effects are hard to express in monetary terms. A considerable weakness of full impact studies is the substantial effort in time and monetary terms associated with them. Apart from their other methodological limitations, this means that they seem to be used only on a limited and ad-hoc basis.

4.4 Outlook on future developments

In the introduction we pointed out that there seems to be untapped potential in fully exploiting the methodological toolkit available for evaluating effects and impacts of research infrastructures. More specifically, the use of instruments such as cost-benefit analyses or calculations of the (societal) net present value for RI seem not to be commonly used.

However, there are i) rising needs to demonstrate the (social) return on investment for publicly funded projects and thus also research infrastructure projects, as well as ii) a number of activities going on to further foster the use of more advanced quantitative methods (expert working groups, research projects). As a result, one might expect that the use of cost-benefit analyses or other quantitative approaches might be used to a larger extent in the future.

Nevertheless, currently prevailing approaches such as qualitative expert assessments of the achievements of research infrastructures also have their merits and will surely continue to dominate many evaluation approaches to RI in the short term.

Future developments might point towards more standardised or harmonised sets of impact indicators used for evaluating the effects of RI. One step in this direction is the survey currently being run by the OECD Global Science Forum to collect information on which indicators for different impacts of RI are being used by RI managers in different countries. The forum plans to use this as the basis for the development of a reference framework for assessing the socio-economic impact of research infrastructures, which might include a common set of (core) indicators for use in RI assessment.

The evaluation of effectiveness and efficiency is also likely to become a little easier to do robustly as monitoring systems improve and research information systems become more sophisticated. The creation of more comprehensive and readily accessible (digital) databases and repositories will allow evaluators to do far more to trace the movement and effects of people, organisations and knowledge, such that one can more easily link specific activities with longer-term impacts.

A potentially interesting approach to analyse qualitative information in a more sophisticated way might also be the use of novel techniques such as text mining. Our Finnish case study mentioned plans by the Academy of Finland to use text mining techniques for analysing the free text impact descriptions of RI. These approaches are of course still far from being standard practice. However, the

Academy of Finland already has some experience in using text mining techniques for their work and they are considering this approach also in processes related to RI. Future developments in this area might be interesting to take into account.

A last interesting, although somewhat marginally important finding from the country case studies does not concern the collection of evaluation data for RI, but the communication and visualisation of results. In the Canadian case study it was mentioned that the Canada Foundation for Innovation "has started to use a shorter and more visual format of presenting the outcomes and impacts of the CFI. One example of this is the recently adopted approach to provide brief one-page overviews giving a graphic presentation and enumeration of one or more KPIs relating to the agency's mission, be it networking effects, skills and expertise or knowledge advancement targets on the level of outcomes or the impact level outcomes of innovation supported or general social, economic and environmental benefits of the activities of the CFI. This kind of visualisation provides key stakeholders with an attractive and instantly accessible view of an institution's performance. This serves well the Board of Directors of the organisation who are able to grasp the most important aspects easily and quickly, pointing out the specific fields themselves where more information is needed. There are currently rapid developments in visualising data of all kinds (interactive graphs, infographics, maps, monitoring dashboards), and these developments might also be relevant in the context of monitoring and evaluating research infrastructures.

4.5 Some reflections on implications for the UK

The UK appears to be doing more evaluations than all of the other countries we researched through this international comparison, especially with regard to ex-post evaluations and the quantification of wider social benefits.

We were unable to find any examples of countries with an overarching evaluation strategy for research infrastructure, which describes the principles used to determine what is evaluated, when and on what terms. There is an arbitrary quality to the mixture of published studies we identified, at least when looked at from the outside, which suggests studies are triggered by other factors or events.

Panel-based peer reviews continue to dominate in numerical terms, however, there is a growing concern with the question of impact, which is evident everywhere in research policy and is also increasingly reaching the area of research infrastructure. The state of the art remains a work-in-progress, with very much less sophisticated techniques being deployed than in other areas of economic impact assessment, in recognition of the highly particular nature of most RI investments and the long-run and diffuse impact they tend to produce (as a class of investments). So far it seems no one has yet managed to find an intermediate solution between the macro-economic models that have been used to estimate the impact on TFP of additional investments in the EU RTD Framework Programme (e.g. Nemesis model) and the deeply qualitative and backward looking case study of the EU RTD FP's contribution to the state of the art in vehicle-related batteries (FP4-FP7). Nemesis is unable to distinguish between investment in the ERC as compared with drug discovery or large-scale research infrastructure. The case study approach is slow and rather costly, and somewhat impractical when attempting to cover an entire FP within the terms and timescales required of the financial regulations.

The European Commission has funded methodological studies regarding the evaluation of research infrastructure and its wider societal benefits, and this work has produced several evaluation design guides (e.g. the FP7 project, Foresight-enriched Research infrastructure Impact Assessment Methodology [FenRIAM]). These toolkits are broadly similar in the types of benefits they anticipate, and the methods they propose. They look similar to the sorts of development work underway in the UK: They are essentially micro-economic studies working within a CBA framework, with qualitative research (case studies) being used to capture and value some fraction of the knowledge spillovers.

These emerging codes of practice are not obviously being adopted or further developed by funders or administrators, so they remain rather more generic and partial than the equivalent official guidance on investment appraisal (e.g. HM Treasury Green Book).

There are examples of individual economic impact assessments, however, these have tended to focus on quantifying the direct benefits of spending money on science infrastructure and then modelling the indirect and induced effects of those capital and operational budgets using input-output tables. These economic studies tend not to consider the research-enabled benefits that justify public investment in research infrastructure, and use the same methods and data (e.g. capital spend, salaries, purchases and regional or national IO tables) that one would use to evaluate the economic impact of a capital investment in almost any capital project, whether it is a new synchrotron or an airport. These economic studies have been most common in North America, however, it is an approach that is now replicated by others, including for example the European Space Agency (ESA).

One or two major international scientific organisations, like CERN and ESA, have begun to invest in the development and use of economic impact assessment methodologies. ESA is under growing pressure from its member states to demonstrate the economic returns from its missions and very large budget. Having commissioned methodological studies to work out its options for conducting evaluations, ESA concluded that the only pragmatic and affordable approach was to combine a conventional economic impact assessment (money in, money out) with a more descriptive and qualitative view of technological achievements. The former provides a positive return on investment to re-assure finance ministries, while the latter provides the insight that science and industry ministries look for. ESA has used this approach for its recent (2016) evaluations of the International Space Station and its launchers programme.

5 Concluding remarks

This report has presented a review of international practices in the governance, appraisal, monitoring and evaluation of science capital funding for research infrastructure (RI), based on a review of publically available sources and interviews with key stakeholders in eleven comparator countries. It provides an overview of international approaches, illustrated with examples of observed practices in individual countries, combined with reflections on the current state of the art and future challenges.

The aim was to collect, review and compare information about current international practices, and not to develop a new approach for the UK. Nevertheless, in all three thematic areas (governance, ex-ante evaluation, and monitoring and evaluation) we have presented some reflections in relation to the UK.

Generally, we found that the processes in place in the UK are broadly in line with what we found in other countries. Specifically:

- For governance mechanisms, we concluded that there are no obvious policies or practices identified in other countries which would immediately recommend themselves as improvements for the UK. However, specific aspects (such as a greater transparency in the priority setting processes in Denmark or the strong focus on strategic criteria in Australia or the greater involvement of international experts) could be aspects for consideration for BEIS.
- Similarly, we found that the UK's appraisal arrangements for RI broadly correspond to what we have found in other countries. The appraisals are typically science-led, with three groups of assessment criteria in use – science first, technical feasibility second and economics third – and with decision-making being led by leading domain scientists and overseen by scientific administrations with the support of technical and financial specialists. The comparator countries do, however, tend to make greater use of international experts. Also, it is clear that appraisal criteria and processes are continuing to develop across all countries, with societal benefits and strategic interests, in particular, beginning to weigh more heavily in the process overall.
- In terms of evaluation practices, the UK appears to be doing more evaluations than the comparator countries for this study. This is especially true with regard to ex-post evaluations and the quantification of wider social benefits. The state of the art remains a work-in-progress, however, with very much less sophisticated techniques being deployed than in other areas of economic impact assessment, in recognition of the highly particular nature of most RI investments and the long-run and diffuse impact they tend to produce. So far it seems no one has yet managed to find an intermediate solution between macro-economic models and deeply qualitative and backward looking case studies. The European Commission has funded methodological studies, and this work has produced several evaluation design guides. However, they look similar to the sorts of

development work already underway in the UK: They are essentially micro-economic studies working within a CBA framework, with qualitative research (case studies) being used to capture and value some fraction of the knowledge spillovers.

In this study and previous work on this topic, we identified examples of individual economic impact assessments, however, these have tended to focus on quantifying the direct benefits of spending money on science infrastructure and then modelling the indirect and induced effects of those capital and operational budgets using input-output tables. These economic studies tend not to consider the research-enabled benefits that justify public investment in research infrastructure, and use the same methods and data that one would use to evaluate the economic impact of a capital investment in almost any capital project. There seems to be no “silver bullet” for capturing the impacts of RI. Accordingly, the only pragmatic and affordable approach is to combine a conventional economic impact assessment (money in, money out) with a more descriptive and qualitative view of technological achievements. The former provides a positive return on investment to re-assure finance ministries while the latter provides the insight that science and industry ministries look for.

Appendix A Literature Review

This literature review provides a concise analysis of existing conceptual approaches and empirical research on science capital investments in research infrastructure. We cover the following four topics:

- The role of science capital investments and large infrastructures
- The governance process
- The selection and appraisal process
- Monitoring and evaluation approaches

We have used multiple sources to compile relevant literature. After an initial open search on the internet, using key words and phrases to identify 'grey literature' that reports on the approaches to evaluating science capital, we have targeted specific organisations such as ESFRI, OECD etc. to identify their evaluation protocols and operational manuals and tools. In addition, we have identified relevant academic literature using Google Scholar and Scopus, as well as by consulting specific academic journals. A complete repository of all documents included in this review is appended.

A.1 The role of science capital investments and large infrastructures as an emerging field

Research infrastructure (RI) is a core topic on the research policy agenda, both at the European and the national level.[21] The European Commission identified RIs as one of the major topics in Horizon 2020 and (according to the 2016 work programme) it is prioritising further developing infrastructures; facilitating researchers' access to the infrastructure in a fair, transparent and open way; deploying e-infrastructures; and fostering the innovation potential of RIs "with a focus on instrumentation and on reinforcing international cooperation with strategic third country partners."[22]

A significant milestone in Europe was the establishment of the European Strategic Forum on Research Infrastructures (ESFRI) in 2002. The **ESFRI roadmap** – published in 2006 – sets out a list of RI's of pan-European importance and represented the outcome of systematic consultations with scientists and other users (for example, industry, technology and education). Since 2006, this roadmap has

[21] In the context of this study, we use the term "investments in research infrastructures" for investments (valued over € 1 m) in infrastructures used for scientific/research purposes. We focus on infrastructures themselves, not the financing of research institutes hosting them.

[22] European Commission (2016). Horizon 2020 Work Programme 2016 – 4. European Research Infrastructures (incl. e-Infrastructures). http://ec.europa.eu/research/participants/data/ref/h2020/wp/2016_2017/main/h2020-wp1617-infrastructures_en.pdf

been updated on a regular basis.[23] The ESFRI roadmap (as well as the ERA expert groups) raised the importance of RI's in the EU as a policy issue, and increased networking between researchers and policymakers through their involvement in international working groups, review boards or committees.

Many European countries have used, or are using, the ESFRI Roadmap as a blueprint when developing their own **national roadmaps.** This also lends to establishing national priorities, in regards to existing and future RIs. A growing number of countries have now prepared national roadmaps that seek to establish the prioritisation of national and pan-European RIs. Roadmaps also help to define national budgets, facilitate political support and allow long-term financial commitment. As a result, many countries have invested substantially in RIs over the last decade. The implementation of current roadmaps will require further significant investments in the future.[24] The MERIL database gives an overview of current European RIs of more-than-national relevance across scientific domains: from archives or statistical offices to biobanks, satellites and particle accelerators.[25]

Policy makers' expectations towards RIs have been changing. While previously, RI's have been understood as facilities that are primarily aimed at contributing to scientific research, they are increasingly expected to tackle socio-economic challenges. This is highlighted in a report by ESFRI which recognises the potential of scientific outputs by ESFRI RI facilities to have a "global impact" and "to tackle global societal challenges such as health, climate change and energy".[26]

Outside of Europe, countries such as Australia have also been drawing up road maps for investing in RI. For instance, in 2016 the National Research Infrastructure Roadmap was published, which sets out Australia's long term RI needs and proposes future areas of investment.[27] Similarly, New Zealand has also plans to set up a more structured roadmapping process in order to inform RI capability development over a ten-year horizon. The NZ roadmapping process will consider RI demands in priority areas as well as cross-cutting issues such as data infrastructures.

[23] https://ec.europa.eu/research/infrastructures/index_en.cfm?pg=esfri. The latest update in 2016.

[24] For instance, under its RI strategy, Australia has invested around £90mn in 2015/2016. New Zealand's Strategic Science Investment Fund is worth around £144mn p.a. The Canadian fund contributing to maintenance and operating costs of the Canadian RI has committed €280m for the 2017-2022 period. Leading in absolute figures, the United States intend to invest about €2.65bn in RI in 2017.

[25] https://portal.meril.eu/meril/. The MERIL (Mapping of the European Research Infrastructure Landscape) portal provides access to a database that stores information about openly accessible research infrastructures (RIs) in Europe, across all scientific domains, including the social sciences and humanities.

[26] ESFRI, 2011, *European Research Infrastructures with global impact; https://ec.europa.eu/research/infrastructures/pdf/esfri_brochure_0113.pdf*

[27] https://www.education.gov.au/2016-national-research-infrastructure-roadmap

Pancotti et al (2014) note, that "'grand challenges" such as climate change, health, energy and ageing populations seem to be best tackled by 'grand' RI's with adequate capacity (scientific, technological, managerial and staffing) to deal with them. Other objectives, such as economic growth and job creation, are also increasingly explicitly assigned to RI.

Pancotti et al (2014) further summarise the main expectations towards RIs as follows:[28]

- Contributing to the quality of scientific research;
- Serving socio-economic objectives or grand challenges, such as health, climate, energy or demographical change
- Contributing to more economic growth and job creation
- Contributing to innovation through different mechanisms – training scientists and engineers, facilitating the knowledge transfer;
- Enabling the pooling of financial and human resources, that are critical in times of budgetary constraints and economic instability

A.2 The governance of science capital funding and RI facilities

Most EU member states have established a national RI strategy or roadmap and have initiated public funding schemes for large RIs (usually specifically targeted). The formal coordination for implementing a roadmap and/or providing funding for large RIs within a country is generally the prerogative of the relevant national ministries of science and/or education. However, the **responsibility for operational tasks**, such as funding allocation and the assessment of proposals, is often then delegated to specific committees, funding agencies, or similar bodies. There are three common models:

- Special committees and initiatives for large RIs: in some European countries policy advice, roadmapping initiatives, assessment of proposals, etc. are delegated by ministers to special committees. Examples are the German Council of Science and Humanities (Wissenschaftsrat) in Germany, the FIRI Committee (Finnish Research Infrastructure Committee), the Dutch Committee on infrastructures and the French Haut Conseil de la Science et de la Technologie.
- Regular funding agencies: in many countries one of the regular funding agencies (i.e. the main agency in charge of allocating research funding to scientific projects) is given responsibility for funding large RIs as part of their wider funding portfolio. Examples include the National Programme for Research Infrastructure from the Danish Agency for Science, Technology and Innovation, or the support

[28] Pancotti et al., 2014, Appraisal of Research Infrastructures: Approaches, Methods and Practical Implications, http://wp.demm.unimi.it/files/wp/2014/DEMM-2014_13wp.pdf

schemes of the Deutsche Forschungsgemeinschaft (DFG) or Helmholtz-Gemeinschaft (HGF).

- Specific councils for investment in RIs: in some countries, a dedicated council for the investment in research facilities has been created. For example, in Belgium Hercules Foundation and in Sweden there is the Council for Research Infrastructures (RFI) (part of the Swedish Research Council). In some cases, the new council is incorporated in an existing agency/council, while in others it acts as a stand-alone organisation.

In addition, there are a number of inter-governmental scientific research organisations who are responsible for infrastructures and laboratories. Most member states of the European Union belong to such research organisations, often paying a membership fees. An example would be the EIROforum, which is a partnership between eight of the largest inter-governmental scientific research organisations: CERN, EFDA-JET, EMBL, ESA, ESO, ESRF, European XFEL and ILL.[29]

Outside Europe, governance is conducted more centrally. New Zealand invests in research programmes and infrastructure through the Strategic Science Investment Fund (SSIF), which was established in 2016. While the overall science priorities are defined via a process led by the responsible Ministry of Business, Innovation and Employment (MBIE), the SSIF provides a unified framework for strategic discussions between the Government and research organisations. Australia funds large RIs based on its National Collaborative Infrastructure Strategy (NCRIS). Similar to the NZ, this process is led by the relevant ministry (the Australian Department of Education and Training).

Kohler et al (2012) recognised the importance of **legal and governance structures** of large scale RI and set out several examples to illustrate different legal and governance schemes for pan-European RIs.[30] Such structures are required to conduct decision-making processes, allocate tasks and resources and manage the relationships amongst the various interested parties. Specifically, the authors claim that a dedicated legal and governance structure may:

- Foster multi-disciplinary research by having representatives of different communities deciding on joint programs;
- Better coordinate scattered communities, both geographically and thematically, increasing their cooperation;

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[29] CERN (Conseil europén pour la recherche nucléaire, i.e. European Organisation for Nuclear Research); EFDA-JET (European Fusion Development Agreement - Joint European Torus); EMBL (European Molecular Biology Laboratory); ESA (European Space Agency), ESO (European Southern Observatory); ESRF (European Synchrotron Radiation Facility); European XFEL (European X-ray Free Electron Laser); ILL (Institut Laue-Langevin, Grenoble).

[30] Kohler et al., 2012, Governance of Large Scale Research Infrastructures: Tailoring Infrastructures to Fit the Research Needs

- Increase innovativeness of research organisations;
- Leverage additional funding;
- Develop a strong identity and elevate international visibility for the communities served;
- Clarify responsibilities, accountability and authority.

A 2014 OECD report discusses governance issues specifically arising from international distributed RIs[31]. While partners in such RIs require governance to be characterised by simplicity, flexibility, transparency, informality and a general “emphasis on intellectual merit rather than bureaucratic authority”, funding bodies require operational effectiveness and accountability. The report discusses a generic governance structure of an international distributed RI, in which a governing body or general assembly represents all partners and defines the strategic direction and budget, whilst a director is in charge of implementing the decisions and executing the work programme, thus acting as a kind of general manager of the infrastructure. In addition, the OECD emphasises the need for a central facility/headquarters due to a distributed facility’s geographic dispersion.

Horlings (2008) notes that the governance system also determines how the planning, monitoring, evaluation and support is approached[32]. While in most cases the top-down approach is taken and a “one-size-fits-all” system is implemented, a bottom-up system may prove more useful in considering the different actors, interests, resources and ideas of the participants. In the following sections we discuss these approaches further.

A.3 The (ex-ante) appraisal of science capital funding and RI

The ex-ante appraisal of potential RI is a complex topic due to the various and evolving expectations for RIs (e.g. to be of national relevance, to create scientific synergies and to enable socio-economic impact). Appraisal and evaluation processes require methodologies that adequately respond to all of these challenges, and there is “a demand for credible principles, methodologies, metrics, procedures, and good practices for assessing RIs” (OECD, 2008)[33].

Roadmaps have emerged as a “standard term of art” to consolidate the different needs and expectations of the scientific community and the governmental authorities with regard to RIs. They serve as strategic plans that are elaborated jointly by

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[31] OECD, 2014. International Distributed Research Infrastructures: Issues and Options. https://www.oecd.org/sti/sci-tech/international-distributed-research-infrastructures.pdf

[32] Horlings, E., 2009, Investeren in onderzoeksfaciliteiten. Prioritering, financiering, consequenties, Rathenau Instituut, https://www.rathenau.nl/en/file/362/download?token=rJUhHEQs

[33] OECD (2008), *Report on Roadmapping of Large Research Infrastructures*, Paris: OECD. https://www.oecd.org/sti/sci-tech/47057832.pdf

scientists and policymakers and reflect the “consensus intentions of both the policy (funding agency) and scientific communities. The OECD defines roadmap processes as “strategic, long-range planning exercises” which help to understand and decide on the planning, funding and implementation of, in this context, large RIs. They take into account the science case of large RI facilities, while also often recognising the expected socio-economic impact of the infrastructure and other important objectives. The FenRIAM (Foresight enriched RI Impact Assessment Methodology) guide outlines a Foresight-based methodology for assessing (amongst others) socio-economic effects of RIs. The FenRIAM guide is presented in detail in section A.4 (monitoring & evaluation).[34]

Factors or topics in the socio-economic context include:

- Market conditions in the RI host region
- Key features of regional economy and competitiveness
- Key feature of regional innovation (in terms of education, existing research facilities, network and clustering

In several countries RI roadmaps serve as the starting point of their ex-ante appraisal procedure for funding RI. For instance, in Germany, the assessment process to determine inclusion in the National Roadmap implies a fundamental intention to provide subsequent funding of infrastructure listed.[35] However, a roadmapping based methodology can have its drawbacks – in particular the resource-intensive nature of the procedure, but also a tendency to ignore indicators of success (impact) within the process.[36] Horlings’s (2008) study, based on an assessment of seven case study countries, concluded that roadmaps could be a useful tool when they are updated regularly, have planned ahead for long-term financing of facilities, foresee transparent procedures and provide a solid framework of support, evaluation and planning.[37]

The quick scan shows that different **approaches to appraisal** of RI investments have emerged across Europe, but that these typically take into account four broad criteria:

- The science case - i.e. scientific merit;

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[34] Curaj A. and Pook K. (ed.) (2011), FenRiam – Foresight enriched Research Infrastructure Impact Assessment Methodology, produced as part of the “Research Infrastructures: Foresight and Impact”(RIFI) project co-funded by the European Commission. http://www.fenriam.eu/doc/FenRIAM%20full%20guide.pdf

[35] Federal Ministry of Education and Research (2016). The National Roadmap Process for Research Infrastructures – Investing in the Future of Research.

[36] Horlings, E., 2009, Investeren in onderzoeksfaciliteiten. Prioritering, financiering, consequenties, Rathenau Instituut, https://www.rathenau.nl/en/file/362/download?token=rJUhHEQs

[37] ibid.

- The innovation case – economic and societal impacts of investments in terms of innovation output
- The business/economic case – assessment of the whole life cycle of infrastructures in terms of the economic rationale,
- Societal relevance and socio-economic impacts

The science case is generally the most important, and in most countries the appraisal of proposals is primarily done on the basis of 'scientific merit', often using a peer review approach. There is, however, a growing emphasis on the 'innovation case': what are the economic and societal impacts of investments in large RIs? Alignment with 'Grand Challenges' has become more important, for example, in Australia the starting point for the roadmap on RIs were national priorities such as an environmentally sustainability, promoting and maintaining good health, and safeguarding.

There is also growing attention paid to the economic analyses regarding large RIs, by which we mean the assessment of the whole life cycle of infrastructures, including the risks and feasibility of the construction phase, the costs of exploitation and maintenance, the use of the facilities by external parties, and the cost of / need for upgrading or decommissioning. In Belgium the Hercules Foundation has a specific committee to assess the business plan of facilities (Hercules Invest). Also, in Canada and the USA the assessment of the project planning process and exploitation is a part of the review process.[38]

In a recent working paper, Pancotti et al (2014) reviewed international practices in RI selection and appraisal processes. They noticed a trend away from purely science-based considerations towards "more formalised, systematic and possibly quantitative approaches to RI selection and appraisal". The changing role of RI facilities and a growing expectation that they should tackle important socio-economic challenges means that these challenges are now factored into the assessment and appraisal process. They conclude that peer review, while widely used and useful for assessing the science case of the RIs, is not the best appraisal method in the context of multifaceted RI systems and "does not account for the nature and pace of scientific discovery". As a result, the authors look further into the possibility of adopting cost-benefit analyses as a method which can potentially take into account the socio-economic effects of RIs.

Changing the needs and expectations towards large RI facilities have also led to wider examination and piloting of **cost-benefit analysis** (CBA) within the appraisal process. In 2014, the European Commission published its s to cost-benefit analysis

[38] Technopolis Group (2013). Background study on national policies for research infrastructures

of investment projects,[39] this included a chapter specifically on RD&I projects. The guidelines specify the crucial steps in the appraisal of large-scale research investments as being:

- Context analysis;
- Defining project objectives;
- Project identification;
- Demand analysis;
- Option analysis;
- Financial analysis;
- Economic analysis;
- and Risk assessment.

The use of cost-benefit analysis in the appraisal of RI facilities was further examined in a paper published in 2016 by Florio et al. This paper presents both the results and lessons learned in applying the CBA approach. The paper also provides some adjustments to the proposed methodology, for example in capturing the social value of the investment using the contingent valuation techniques.[40]

A.4 The monitoring and evaluation of science capital funding and RI

The literature broadly encompasses three categories of effects/values that feed into the monitoring and evaluation of science capital funding and RI:

- Scientific value
- Economic value: from the economic activity that takes place in the context of RI development, and the procurement of related goods and services. This is beneficial for the local[41] and national economy. RI also contributes to economic innovation.[42]

[39] European Commission, 2014, Guide to Cost-Benefit Analysis of Investment Projects, http://ec.europa.eu/regional_policy/sources/docgener/studies/pdf/cba_guide.pdf

[40] Florio et al., 2016, Exploring cost-benefit analysis of research, development and innovation infrastructures: an evaluation framework, https://arxiv.org/pdf/1603.03654.pdf. The authors define “contingent valuation” as the method of “asking people to state the maximum amount they would be willing to pay to obtain a good or would accept as compensation to give way a good, contingent on a given scenario.”

[41] The EvaRIO report outlines factors of RI’s impact on the local economy, such as visitors, purchases and employee expenditure. However, interviews in the course oft he EvaRIO projects showed, that regional/local impacts are not easily revealed in a systematic and comparable way. The report found that stakeholders are not enough prepared „to collect and provide a complete set of elements allowing the evaluation of the local impact, and do not make a systematic review of the interactions“.

- Added value for society: RIs pursue a social mission useful for the society, and beyond this contribute to scientific education of the wider public.

The evaluation of the scientific value of RIs typically involves academic reviewers and committees. For instance, the 2012 evaluation of NORDSYNC and the Nordic membership of the European Synchrotron Radiation Facility (ESRF) largely involved interviews with stakeholders and scientific communities in Nordic countries.[43] In addition, the evaluation considered analyses of publication and citation rates in high-impact journals to complement the qualitative results.[44]

Some evaluations also now focus on evaluating and monitoring socio-economic effects arising from RIs. Recent infrastructure evaluations in the UK and elsewhere in Europe have begun to place much greater emphasis on capturing these social and economic benefits, doing much more than making an account of the scientific and skills-related advances that are also being delivered. For instance, in 2016, Technopolis conducted a Lifetime Impact study for the ISIS neutron and muon source, in close collaboration with the Science and Technology Facilities Council (STFC).[45] The study drew on an elaborate longitudinal case study methodology, to trace and estimate the social and economic impacts, such as nurturing scientific talent in the UK, providing valuable skills to industry and creating innovation impacts. In addition, the study team ran analyses of ISIS's financial and human resource figures as well as surveys to profile and characterise impact distributions among industry users and suppliers.

In recent years, there has been a growing interest in methodologies, tools and indicators for the evaluation of science capital investments. This has been useful in informing ex-ante prioritisation/ decision-making on new (and upgraded) infrastructures, ongoing/ interim monitoring and ex-post evaluation of existing infrastructures. This demand stems from funding agencies and policy makers, as well as infrastructure managers, administrators and user communities. In order to meet

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[42] As outlined in Technopolis' Big Science and Innovation report, innovation may result already in the construction phase of a RI (through innovative procurement, for example). In the operational phase, public-private partnerships (industry cooperation), HR capacity building (for example big data analytics skills) as well as other hard- or software related spillovers create innovations. Subsequently, spin-offs and/or joint ventures may result in R&D spillovers to industry.

[43] NORDSYNC is a consortium consisting of the four nordic countries Denmark, Finland, Norway and Sweden. The four countries assume their membership oft he European Synchrotron Radiation Facility (ESRF) through the NORDSYNC consortium.

[44] NordForsk (2012). Evaluation of NORDSYNC and Nordic membership of the ESRF.

[45] Technopolis Group, STFC (2016). ISIS Lifetime Impact Report.

this demand several initiatives were undertaken, such as the formation of workings groups (e.g. ESFRI working group on the socio-economic impact) and international conferences (e.g. in Hamburg[46] on socio-economic impact and the International Conference on RIs in Cape Town[47]).

Significant work was undertaken by the FP7 project "RIs: Foresight and Impact (RIFI)"[48], which published a full guide to assessing the socio-economic effects of RIs."[49] One conclusion was the need to focus on impact pathways in greater detail and substantiate them with empirical evidence. This has been recognised in more recent work, such as the FenRIAM (Foresight enriched RI Impact Assessment Methodology) guide which provides 'use cases'[50] for decision-makers and RI managers to conduct ex-ante estimations for developing a new RI. In addition, the guide also provides two use cases to perform an ex-post evaluation as well as an ex-ante evaluation of socio-economic impacts for an existing RI.[51] Thus, the guide enables clarification over:

- the scope of assessment and the roles and responsibilities of different actors in the process of evaluation;
- analysis of stakeholder networks;
- development of future scenarios for the RI in its environment;
- a structured exploration of the socio-economic implications of the RIs
- as well as to perform a detailed impact evaluation using templates provided in the toolbox.

Another similar attempt at developing a framework for assessment of RI impacts was made as part of the EvaRIO project (Evaluation of Research Infrastructures in Open

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[46] European Association of National Research Facilities (ERF) Workshop „The Economic Relevance of Research Infrastructures „ Hamburg, 31 May/1st June 2012 (http://erf.desy.de/workshop) .

[47] International Conference on Research Infrastructures (ICRI), Capetown, 3-5 October 2016.

[48] Rifi Project website: http://rifi.gateway.bg/page.php?c=14

[49] Curaj A. and Pook K. (ed.) (2011), FenRiam – Foresight enriched Research Infrastructure Impact Assessment Methodology, produced as part of the "Research Infrastructures: Foresight and Impact"(RIFI) project co-funded by the European Commission. http://www.fenriam.eu/doc/FenRIAM%20full%20guide.pdf

[50] In the context of the FenRiam Guide, Use Cases refer to different situations/interests where the Forsight and Impact Guide may be applied. Use Cases can be understood as "decision frameworks" or "decision guidelines".

[51] While the ex-post use cases draw on data collection and analysis methods such as interviews with scientists and secondary data analysis, the ex-ante use cases are characterised by a longer time horizon and thus greater uncertainty. Therefore, these use cases draw extensively on Foresight methdologies.

innovation and research systems)[52], funded under FP7. The resulting "Beta approach" is another framework which attempts to systematically present the effects of the RD&I programmes by outlining the direct effects, capacity effects, effects on performance of RI-related activities and indirect effects, categorised according to the RI Operators, RI Suppliers, and RI Users. However, one drawback of this approach is that it fails to allow for a comparison between the overall costs and benefits. As the EvaRIO final report notes, the Beta approach focuses on identifying benefits for each actor individually, and the benefits appropriated by said actor. However, the collective scientific benefit is generally higher than the sum of actor-specific individual benefits.[53]

In 2013, Technopolis conducted a study on 'Big Science and innovation'[54] The main aim of the study was to improve the UK government's understanding of the kinds of innovation and industrial benefits that might be expected to flow from a major public investment in a large-scale research facility. The study investigated both direct economic benefits that arise from designing, constructing, equipping or operating the facilities as well as indirect effects through lead markets / knowledge spillovers etc., on businesses' innovative capacity. The study also sought to critically review existing evaluation approaches and empirical research on science facilities. The resulting report detailed both the types of benefits one might expect and the types of measurement tools and evaluation methodologies best suited to capture those benefits. The study also offered recommendations for further methodological development work to strengthen the evaluation toolbox available to the UK government.

Notably, the study concluded that large facilities have rarely been subject to evaluation. The majority of economic impact assessments follow a broadly similar approach, in which evaluators focus on direct impact using input-output analysis and to a lesser extent on the quantification of indirect and induced effects. The evaluations fail to take into account second order effects and knowledge spillovers, that we know to be of particular relevance to scientific discovery. In general, such second order effects are studied only occasionally and often in isolation, for instance in the context of case studies. From a methodological perspective, there is a lack of comprehensive studies (capturing different kinds of effects), sound quantitative methods such as cost benefit analysis, counterfactual studies, the use of time series and a distinction between short-term, medium-term and long-term effects. For the evaluation of innovation outcomes, only qualitative methods are used (usually case studies in combination with desk study and supplier surveys). The study noted that more quantitative studies seem to be absent.

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[52] EvaRIO project website: http://evario.u-strasbg.fr

[53] EvaRIO (2013).Evaluation of Research Infrastructures in Open innovation and research systems. *Synthesis of results- Final Report*.

[54] Technopolis Group (2013). Big Science and Innovation.

Overall, the study noted that evaluations of RIs need to be more ambitious, reaching beyond the simple analysis of expenditures and regional multipliers and not focus solely on the obvious impacts. For instance, the impacts on innovation, on new markets and on local clusters are all worthy of closer investigation. There is also a need for broader use of data collection tools and analytical techniques and a time series with a range from short-term to long-term impacts. One of the most pressing challenges in this respect is cultural: to make RIs subject to (more comprehensive) evaluations and socio economic impact assessments more frequently.

In 2014, the Global Science Forum (GSF) set up an Expert Group to examine the potential to establish a reference framework for assessing the socio-economic impact of RIs. It concluded that traditional models and methodologies can only be applied to a limited extent and that other models and appropriate methodologies and indicators are necessary, such as assuring data openness and sharing as well as consistent attribution of scientific impact of RIs (e.g. by using bibliometrics). The group also stipulated the need for a set of indicators that derives from different objectives, a more tailored data collection process and better methodologies for cost assessment.

Nevertheless, comprehensive and methodologically demanding studies are still rare. Core aspects of RI benefits, such as their impact on human and social capital formation and innovation, are not extensively explored. For instance, to date, the existing literature provides insufficient evidence to support claims that investment in RI (even large-scale) attract and retain talent and promote innovation. Therefore, important socio-economic contributions made by RIs will remain poorly understood.

Appendix B Country Abbreviations

Table 2 Country abbreviations used in the report

Abbreviation	Country
AT	Austria
AU	Australia
BE	Belgium (Flanders only, unless otherwise indicated)
CA	Canada
DE	Germany
DK	Denmark
FI	Finland
FR	France
IE	Ireland
NL	Netherlands
NO	Norway
NZ	New Zealand
SE	Sweden
UK	United Kingdom
USA	United States of America

Appendix C List of interviewees

In this project, Technopolis conducted interviews with experts in the 11 case study countries on approaches to appraise and monitor/evaluate investments in research infrastructures.

The detailed interview questions were tailored to the individual country context. In broad terms, the interviews covered the following topics:

- quantitative/qualitative methodologies used for ex-ante appraisal and evaluation/monitoring of research infrastructures
- criteria used for appraisal of investments and scoring practices
- approaches to address downstream impacts of the research capital investments, spillover effects, local economic effects etc
- institutional responsibilities for carrying and overseeing out appraisal and monitoring processes
- advantages and disadvantages of different appraisal and monitoring frameworks

Interview partners were from relevant ministries in the case study countries, research councils, selection/evaluation committees or other relevant organisations. The following table lists our interview partners.

Table 3 List of interviewees

Country	Expert Name	Organisation	Date of Interviews
Ireland	Nicola Stokes (RI Programme Manager)	SFI	3rd May 2017
Netherlands	Kas Maessen (Member of Permanent Committee)	NWO	24th April 2017
Netherlands	Isabel van der Heiden (Policy Officer)	NWO	24th April 2017
Netherlands	Emmo Meijer (Chairman report *Size and Suitability)*	AWTI	18th April 2017
Belgium	Bart de Moor (former chairman Hercules Foundation)	KU Leuven	3rd April 2017
Belgium	Caroline Volkaert (Advisor RI)	FWO	7th March 2017 and 26th April 2017

Country	Expert Name	Organisation	Date of Interviews
Belgium	Bart van Beek (Science Policy Advisor)	FWO	7th March 2017
USA	Brian Midson (Programme Director)	NSF	21st April 2017
USA	Matthew Hawkins (Head LFO)	NSF	7th March 2017 and 21st April 2017
USA	Robert Hengst (LFO)	NSF	26th April 2017
USA	Graham Harisson (OISE)	NSF	7th March 2017
Canada	David Moorman	Innovation Canada	4th May 2017
Germany	Peter Wenzel-Constabel (Head of Unit)	BMBF	2nd May 2017
Germany	Dr. Elke Lütkemeier (Head of Department)	Wissenschaftsrat	2nd May 2017
Germany	Dr. Johannes Janssen (Head of Unit)	DFG	5th May 2017
Finland	Dr. Merja Särkioja (Senior Science Adviser)	Academy of Finland	20th April 2017
Sweden	Tove Andersson (Research Infrastructure department, Research Officer)	Swedish Research Council	1st March and 4th May 2017
Sweden	Susanna Bylin (Research Infrastructure department, Research Officer)	Swedish Research Council	4th May 2017
Denmark	Katinka Stenbjörn (Research Infrastructure department)	Ministry of Higher Education and Science	6th March and 4th May 2017
Denmark	Lars Christensen (Research Infrastructure department, office manager)	Ministry of Higher Education and Science	4th May 2017
Norway	Svein Stölen (Principal of UiO)	UiO	3rd May 2017

Country	Expert Name	Organisation	Date of Interviews
Norway	Tor Grande (Vice Dean for Research at Department of Materials Science and Engineering)	NTNU	2nd May 2017
Norway	Unni Steinsmo (former CEO of SINTEF)	SINTEF	3rd May 2017
Norway	Solveig Flock (Special advisor, Infrastructure)	The Research Council of Norway	26th April 2017
Australia	Dr. Cathy Foley (Science Director and Deputy Director)	CSIRO	24th April 2017
Australia	Prof. Andy Pitman (Director)	ARC Centre of Excellence for Climate System Science	21th April 2017
Australia	Ditta Zizi (Branch Manager)	Research and Higher Education Infrastructure, Research and Strategy Group, Australian Government Department of Education	26th April 2017
Australia	Prof. Suzanne Miller (CEO and Director)	Queensland Museum Network	4th Mai 2017

Note: Interviewees provided feedback on the case studies in all countries but AU, IE, FI and SE

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Appendix D Case Studies

The case studies are provided as a separate document.

Appendix E Additional country overviews

The country overviews are provided as a separate document.

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