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Impact of e-Infrastructures: Theories and practices of assessment methodologies

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This paper presents a brief overview of the theories and practices of assessment methodologies within the landscape of assessing the impact of e-infrastructures. The rationale and importance of doing such an assessment is a very relevant and valid topic, as now in a context of limited resources, the impacts associated to this financing requires careful assessment to be certain that the concrete goals set by the EU for the e-Infrastructures domain are achieved, if and how the financed initiatives contribute to these goals.
There are different constraints that are being revealed through some of the more recent initiatives, whom share the same concerns, for example there is very little information available to evaluate the achieved impact in comparison to the expected impact. These more recent projects have attempted to address the different concerns related to assessment, with the aim of preparing a widespread culture of impact assessment in the Research Infrastructures domain. This paper provides an overview of the work (methodology and results) carried out by these projects and an outlook on the next steps.

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1. Introduction

A major goal of e-Infrastructures is to facilitate scientific discoveries and technological developments, attracting excellent researchers around the world, building and enhancing the bridges between national research communities, scientific disciplines, research institutions and industries. These collaborations guarantee the creation of new ideas and knowledge, which then turns into innovation, ultimately supporting the creation of new jobs. As the goals and impact of e-Infrastructures is of great importance, the European Commission (EC) gives considerable support to sustain and evolve them. Therefore, being able to assess the impact of e-Infrastructures is a very relevant and valid topic, particularly nowadays during an economic crisis imposes a careful spending review of European Union (EU) budget.

Since 2009, the European Commission has financed ninety-one e-Infrastructure projects and there is very little information is available to evaluate the achieved impact in comparison to the expected impact. In a context of limited resources, the impact associated to this financing requires careful assessment to be certain that the concrete goals set by the EU for the e-Infrastructures domain are achieved, if and how the financed initiatives contribute to these goals.

During the last years some initiatives attempted to address how to measure the impact of e-Infrastructures through different actions and approaches, focusing on general purpose approaches - ERINA+ (Socio-Economic Impact Assessment for e-Infrastructures Research Projects - www.erinaplus.eu) and RI-Impact (Development of Impact Measures for e-Infrastructures - www.ri-impact.eu) - focusing on specific aspects - e-FISCAL (Financial Study for Sustainable Computing e-Infrastructures – www.efiscal.eu), OSIRIS (Towards an Open and Sustainable ICT Research Infrastructure Strategy - www.osiris-online.eu), and eNventory creating easy-to-use source of information (European and Infrastructures Observatory - www.enventory.eu). The aforementioned actions (projects) are co-funded by the EC with the aim to study how to develop a comprehensive methodology for a quali-quantitative impact assessment of the varied e-Infrastructures landscape. All these projects have openly discussed about their findings related to the impact of e-Infrastructures, supporting mutual understanding and suggesting areas of collaboration. They have presented the results of their surveys to representatives of e-Infrastructures projects and other entities involved in the European research landscape.

2. Importance and Rationale

Most of the ability of Europe's research to remain at the forefront of all scientific disciplines and technology relies on the support that they receive by state-of-the-art research infrastructures, including e-Infrastructures. The support of EU to the e-Infrastructures, therefore, is aimed at fostering e-Science, furthermore aiming at enabling the online circulation of knowledge in Europe, in order to assure the constitution of a solid European Research Area.

The importance of assessing the impact of e-Infrastructures and its goals are tied to the very same importance of e-Infrastructures themselves. Their positive impact is paramount and measuring it is essential to continue supporting them through suitable and opportune investments. The e-Infrastructures ecosystem needs to be kept healthy, also in this context of conscientious spending, as measuring and creating valuable information about the impact of e-Infrastructures, produces knowledge from the experiences and improves further decision making.

It is widely accepted that determining the impact of research advances is not so straightforward. The main reasons are essentially lack of raw data to be analysed and the temporal gap from the initial investment and the creation of a concrete impact. Moreover a fits-for-all methodology is not yet available, while a set of equally valid approaches can be adopted depending on the type of investment, type of Research Infrastructure and – sometimes – type of scientific discipline and expected impact.

More and more, the EC and all the actors and stakeholders involved are understanding that is not only possible to gain knowledge about the contribution that e-Infrastructures have on society through initiatives such as the ones mentioned above, but that it is an essential exercise to measure to be able to confidently move forward.

Theories and Models for Measuring Impacts

The majority of the approaches to the impact measurement focus' on the input, output, outcomes and impact model where:

- Inputs are the investments made in, or the resources required to, produce a product or develop/undertake an activity;
- Outputs are the products or services provided (e.g. number of grids/networks created, papers published, events held, etc.);
- Outcomes are the immediate changes resulting from an activity – these can be intentional or unintentional, positive or negative (e.g. employment, increased connectivity, etc.);
- Impacts are the net difference made by an activity after the outputs interact with society and the economy (e.g. transformational research enabled by the project which would otherwise would not have occurred or occurred as fast enabling EC funded researchers to be world-leading).

In the economic literature we can distinguish between: i) general studies focusing on the relation between growth, competitiveness, science and technology, and ii) studies aimed at better understanding such relationship with reference to a particular infrastructure. In the latter, we can distinguish impact assessment studies aiming at identifying expected impacts (ex-ante studies) and studies that measure and evaluate real impact during or after the end of a project or programme (monitoring and ex-post studies).

An ex-ante evaluation focuses on on-going and finished initiatives. The methodologies employed in ex-ante evaluation of programs and investment policies include:

- Foresight studies: this structured consensus building methodology based on experts judgements permits to anticipate social, economic and technological development opportunities in policy planning. These include:
  - Case studies for an in-depth analysis of real case, investigating for the expected results;
  - Broad surveys: asking a large number of experts, examining an issue in less detail;
  - Data collection methods: analysis of documents, interviews, questionnaires, peer reviews, focus groups, expert panels can be applied to the evaluation of economic as well as social impacts;
- Modelling and simulation through the use of Econometric modelling at micro (network analysis, statistical based model) and macro (Input/output tables, Social Accountability Matrices and General Equilibrium) level;
- Cost-efficiency techniques: this judgement methodology quantifies the costs and benefits associated with the policy intervention;
- Cost-benefit techniques: this judgement methodology compares in monetary terms all social and private costs and benefits of a programme to establish whether the benefits exceed the costs. The technique can be adapted to incorporate uncertainty and risk.

An ex-post evaluation focus' on: i) determining the efficiency and efficacy of the intervention; e.g. productivity studies), ii) providing a quantitative estimation of the impact of the intervention (e.g. microeconomic evaluation studies), iii) quantifying the various dimensions in which returns should be considered within a defined framework, iv) assessing environmental sustainability and wealth issues (e.g. cost-benefit analysis), organisational impact (e.g. case studies, network analysis, innovation studies), strategic impact (e.g. foresight).

The methodologies employed in this approach to evaluation[2] include:

- Statistical data analysis:
  - Innovation Surveys provide basic data to describe the innovation process, summarised using descriptive statistics.
  - Benchmarking allows to perform comparisons based on a relevant set of indicators across entities providing a reasoned explanation of their values.
- Modelling methodologies:
  - Macro-econometric modelling and simulation approaches allows to estimate the broader socio-economic impact of policy interventions.
  - Micro-econometric modelling permits to study the effects of policy intervention at the level of individuals or firms. There are mechanisms to control for the counterfactual by specifying a model which allow to estimate the effects on the participant outcome comparing this with the situation in which the programme does not take place.

[2] Fahrenkroget al. (2002)

  - Productivity analysis permits to assess the impact of R&D on productivity growth at different levels of data aggregation. This is particularly relevant to analyse the broader effects of R&D on the economy.
  - Control group approaches allow to capture the effect of the programme on participants using statistically sophisticated techniques.
- Qualitative and semi-quantitative methodologies:
  - Interviews and case studies use direct observation of naturally occurring events to investigate behaviours in their indigenous social setting.
  - Cost-benefit analysis allows to establish whether a programme or project is economically efficient by appraising all its economic and social effects. The approaches to quantify the socio-economic gains of a policy instrument include contingent valuation studies, simulating the existence of a market for a non-marketed good, such as for example the capacity to produce a genome mapping in less time. These studies generally adopt questionnaires incorporating willingness to pay schemes to try to infer the price a certain public good is worth to the respondent. Other approaches include the use of the conjoint analysis in surveys to determine the price users place on the attributes or features of goods and quality adjusted hedonic pricing for new or improved goods.
  - Expert Panels/Peer Review: measures scientific output relying on the perception scientists have of the scientific contributions made by other peers. Peer review is the most widely used method for the evaluation of the output of scientific research.
  - Network Analysis: allows to analyse the structure of co-operation relationships and the consequences for individual's decisions' on actions providing explanations for the observed behaviours by analysing their social connections into networks.
  - Foresight/ Technology Assessment: used to identify potential mismatches in the strategic efficiency of projects and programmes.

3. Work Done and Current Results

In the past Research Infrastructures and e-Infrastructures chose two distinct initiatives aiming at an initial exploration of the methodologies and models suitable for their respective domains.

The former DG-INFSO – F3 Unit, promoted the ERINA+[3] study (e-Infrastructure Research Impacts in key ICT Areas) aiming at developing an initial qualitative methodology to enable the evaluation of the positive impact brought by the e-Infrastructures in eGovernment, eHealth and eLearning research fields.

ESFRI[4] , in the light of constant attention to impact assessment, promoted RI-FI [5] that resulting in developing the FenRIAM (Foresight enriched RI Impact Assessment Methodology) framework.

[3] http://www.erinastudy.eu
[4] http://ec.europa.eu/research/infrastructures/index_en.cfm?pg=impact_studies
[5] http://www.rifi-project.eu/

While the cited studies provided the needed conceptual frameworks to support the assessment exercise they also revealed a set of barriers that could hinder the effective impact evaluation in the majority of cases.

The main concerns are the following:

- lack of impact assessment culture: often a simplistic qualitative impact analysis was performed with lack of concrete and measurable criteria and targets;
- un-ability to collect valuable data for subsequent analysis and reasoning;
- absence of any incentive in the Grant Agreement nor dedicated competences and effort in the project plans;
- unclear clustering of Research Infrastructures and e-Infrastructures supporting the re-use of best practices and lessons learned.

Some of the more recent initiatives exactly addressed these aspects, with the aim of preparing a widespread culture of impact assessment in the Research Infrastructures domain.

3.1 ERINA+

ERINA+, based on the previous experience of the ERINA study, has enhanced a quail-quantitative methodology to evaluate the socio-economic impact of e-Infrastructures projects, allowing for projects to perform a self-evaluation through a set of tools. The final assessment will consider both the efficiency (usage of time or effort with respect to the intended purpose) and effectiveness (capability of producing an effect in: competitiveness and excellence of research; innovativeness of research; cohesion) aspects.

The purpose of the e-Infrastructures' impact assessment exercise is threefold:

- To cultivate an ecosystem and assessment mentality: to identify what is the impact of any given project, any given program and any given investment in the context surrounding the e-Infrastructure ecosystem.
- To amplify the benefits of each single initiative at the widest possible level.
- To mitigate costs for carrying on research.

With above mentioned objectives, the ERINA+ project has explored the different dimensions of e-Infrastructure ecosystems and assessed the additional value produced by the e-Infrastructure projects and initiatives, as well as the benefits that e-Infrastructures bring to the general economy and social welfare. This analysis revealed an ambiguous use of the term project and e-Infrastructure that led to inconsistencies in the analysis; in fact while a project, an initiative based on a temporary contract needs to be analysed considering both the contractual obligations

and the short lifetime, an e-Infrastructure – as defined by ERINA+[6] - has a wider aim stated in a constituency statute, possibly evolving objectives and a long-term strategy.

Starting from analysing projects and developing a mapping among projects and e-Infrastructures ERINA+ has being able to enable the self-evaluation of the impact of e-Infrastructures projects and to evaluate the socio-economic impact of e-Infrastructures and related projects.

All the tools for the impact assessment of e-Infrastructures and projects will be embedded in the ERINA+ platform[7]. The ERINA+ platform will provide a dashboard for program managers and e-Infrastructure stakeholders.

3.2 Ri-Impact

The Ri-Impact project aims at developing a framework for evaluating and assessing the impact of e-Infrastructures. Through the projects goals: (1)To analyse the broader socio-economic impact of e-Infrastructures, (2) to identify the contribution of e-Infrastructure to ERA , (3) to identify the contribution of e-Infrastructure to the realisation of the EU policy aims, Ri-Impact performs the assessment of the e-Infrastructure program looking at its characteristics (accessible, efficient, sustainable, innovative, transformative).

The project provides the outline of a framework for evaluation of e-Infrastructure interventions and also a recommendation of a set of concrete actions to be taken at the European and Member States level to implement a robust monitoring and evaluation system. This is built upon an analysis of the socioeconomic impact of e-Infrastructures.

RI-Impact has analysed 21 of the 29 contacted projects gathering info on their accessibility, efficiency, innovation, sustainability and transformative character. Composite indicators have been built and have identified precise impact areas: research and innovation, human capital, economy, public authorities and international relations. As for the evaluation of projects, it is quite clear that, since there is no benchmark to refer to in this field, it's difficult to judge the quality – and even to compare projects among them - but, numbers collected form a baseline further for analysis and can be interpreted to have an idea of the overall behaviour of a project.

3.3 e-FISCAL

The e-FISCAL project analyses the costs and cost structures of the European High-Throughput and High-Performance Computing (HTC and HPC) e-Infrastructures. e-FISCAL will compare their costs and cost structures with similar commercially leased or on-demand offerings, namely cloud computing ones.

[6] A widely accepted definition is not yet available: at a first glance the difference among projects (developing or supporting an e-Infrastructure) are short-term and contractually based initiatives, while e-Infrastructures are long-term and entity based initiatives,

[7] http://platform.erinaplus.eu

Understanding the overall costs of these European research services is a prerequisite in planning their long-term sustainability. A quantitative analysis of the cost factors involved will help service providers and user communities to identify areas where the overall cost efficiency of ICT-enabled research can be optimised. The study will also analyse qualitative differences in service between HTC and HPC e-Infrastructures and their closest commercial counterparts.

In assessing costs across the e-Infrastructure market a method based on estimated capital and operational costs from e-Infrastructure centres was chosen to ease data collection and reasonably ask participants to gather it through questionnaires. After which, a simulation of annualised infrastructure costs is done to then estimate the annual Cost of Ownership and come up with metrics such as cost per core hour, CAPEX/OPEX ratio, cost per FTE, etc.

The main findings of the project up to summer 2012 have been the following [7]:

- State-of-the-art review: There is a lot of recent literature on the costs of individual "in-house" developed HPC or HTC centres and their comparison with commercial "on-demand" cloud services, and in particular the Amazon Elastic Compute Cloud (Amazon EC2). The majority of these studies use a price for core/hour which ranges from around 0.015 Euros (Magellan report) to around 0.040 Euros (University of Washington) in the US; around 0.075 Euros in the UK (Hawtin et al. 2012 for JISC) and around 0.09 Euros for a sample of EGI centres in Europe (e-IRGSP2 small scale study in 2009).

- The sample for the e-FISCAL findings was relatively good; 26 answers from 14 countries. However, high-end HPC centres (such as the PRACE Tier-0s) or other high-end HTC centres (such as the WLCG Tier-1s participating in EGI) are not included. This was mostly due to confidentiality reasons, particularly specific non-disclosure agreements between the vendors and those centres that do not allow for the publication of detailed cost information.

- The e-FISCAL median values for cost per core hour are around 0.05€/core in 2010 and 0.03€/core in 2011. This shows that the e-FISCAL initial findings for the related e-Infrastructure are in-line with studies reported elsewhere.

- The breakdown between CAPEX and OPEX in 2011 in our calculations is around 30%-70% (median) to 32%-68% (average). Around of 50% of total costs is dedicated to personnel.

- The average utilization rate used to calculate the average and median cost per core hour for the above results for 2011 is 62% and 74% respectively. This refers to a mixture of EGI, PRACE and other sites not integrated in these e-Infrastructures. As an example, for 2011, EGI reports an utilisation rate of 71.3%.

- Other interesting findings are the high numbers of depreciation rates for the hardware (average 5 years), the quite good rates of PUE (of around 1.5 median value) and the percentage of electricity cost (around 15% median value of all costs).

The information gathered about costs and business models of e-Infrastructure and commercial computing services will be used in order to generate information of interest to infrastructure providers and users in planning their usage and service provision.

Key project outputs that will be further produced include: an evaluation of the overall cost of the entire European HTC and HPC infrastructures and comparison with the closest commercial on-

demand offerings and the development of a generic cost model and related business models and sustainability outlook contributions.

3.4 OSIRIS

The field of ICT Research Infrastructures (RIs) is considerable and diversified, with widely varying collaboration models. In some cases there are functional similarities between them, but there are also significant differences. Also, the maturity of collaboration models is not comparable between different RIs, as in some domains there are already production-level infrastructures operational with well-defined governance (e.g., networks, DCIs), whilst in some other domains the picture is more fragmented (e.g., data infrastructures) or even still not defined (Future Internet). Economic sustainability and associated business models are still to be clearly identified for the majority of ICT RIs.

The main aim of the OSIRIS project initiative is to provide structured information and models for decision makers (European Commission, Member States, and Associated Countries) who develop cross border public-public partnerships and who establish a coordinated approach to future large scale investments in transnational European ICT research infrastructures. This will lead to complementary or common planning of investments and investment policies in order to obtain sustainable European ICT research infrastructures and it will allow the development of procedures, rules and management mechanisms for coordinated investments in large scale transnational ICT research infrastructures in Europe.

The ICT RIs considered by OSIRIS are:

- ICT infrastructures for research, i.e. grid / cloud, HPC, network, data RIs, as commonly understood, but also,
- infrastructures for ICT research, i.e. micro & nano electronics facilities and Future Internet / FIRE testbeds.

In the course of the project, the OSIRIS consortium has built up a wide set of information on ICT Research Infrastructures, most notably:

- an inventory of the existing cooperation between Public Authorities and ICT Research Infrastructures across seven main domains (network, grid/cloud, HPC, micro & nano technology, data RIs, ICT for Instruments, Future Internet) and several subdomains/cases: the analysis is based on technical documents and 40+ European reports on ICT RIs have been used;
- a report of the interviews with key people heading six ICT RIs: DANTE, EGI, IMEC, LETI, Lifewatch, and PRACE; several high-level statements regarding ICT RIs have been extracted;
- a qualified, hierarchical list of all non-technical aspects of ICT RIs, in order to better identify the business model behind them. The following key areas have been explored: governance, sustainability, access policy and operational principles;

- a large map comparing about 180 aspects of 25 selected ICT RIs. The detailed mapping process has resulted in a quali-quantitative spreadsheet-based approach to easily navigate across the different flavours of ICT RIs.

This information has been structured and made available for people in Public Authorities and existing and emerging Research Infrastructures in two forms:

- as document deliverables (D3.2, D3.3, D4.1, D3.4 respectively) in the OSIRIS project web site www.osiris-online.eu, where a final report (D4.2) will also be available;
- as a set of specialised interactive interfaces to the data collected on the web site www.ictresearchinfrastructures.eu. This is the outcome of the EP-hosted workshop that has been organised by the OSIRIS consortium on the role of ICT Research Infrastructures in Horizon 2020.

3.5 eNventory

The eNventory project targeted the formation of the European e-Infrastructures Observatory, a single-entry-point, one-stop-shop data warehouse, capable of representing e-Infrastructure benchmarks and exhibiting European e-Infrastructures achievements for networking, supercomputing and grids, while being expandable to emerging e-Infrastructures, through intuitive, interactive and user-friendly visualisation interfaces to allow for progress monitoring and impact assessment of e-Infrastructures at regional and national level across the European Union and beyond.

eNventory's aim is to carry out a design study that will set the grounds towards a European e-Infrastructures Observatory to monitor the status quo and evolution over time of electronic infrastructures, assessing their impact at regional and national level across the European Union and beyond. The European e-Infrastructures Observatory, through the collection and utilisation of appropriate indicators, will be able to monitor e-Infrastructures development and communicate all findings to related stakeholders but also to the public-at-large, in a seamless and impartial way.

The project will (a) identify of a core set of benchmarking indicators for the European e-Infrastructures Observatory that will be the baseline for monitoring e-Infrastructures development progress, (b) collect e-Infrastructures stakeholders' feedback and consensus on the proposed structure and functionality of the European e-Infrastructures Observatory, (c) European e-Infrastructures Observatory functionality demonstration through a prototype web platform that will be available to all e-Infrastructure communities and to the public at large.

4. Final Conclusions

Amongst the projects above described, there is still a general difficulty in gathering data for the analysis of e-Infrastructure domain as expressed earlier, as well as the difficulty of concluding a fits-for-all set of indicators. This implies that any guideline to assess the impact from the numbers collected need to be heavily tailored to the context of each project before being able to

interpret them; this difficulty even increases when dealing with the evaluation of indirect impacts of e-Infrastructures.

About the data collection perspective, three aspects are relevant:

- Structuring and evaluating the costs for running an e-Infrastructure. This is the aim eFiscal. The involvement of major stakeholders only reduced not avoided the issues in collecting a complete set of information.
- Monitoring the usage of an e-Infrastructure. eNventory focused on usage data, starting from the already available information from the Networking environment. Again, they revealed the lack of proper recording methods to collect and transmit relevant data.
- Evaluating the performance of an e-Infrastructure. ERINA+ developed a set of tools enabling the data collection from different sources (project owners, users, relevant stakeholders); this promising approach is under evaluation and results of the viability of the approach will be available late in 2012.

In regards to the best methodological approach, both RI-Impact and ERINA+ confirmed the suitability of the analysis of the gap between the ex-ante scenario (absence of or alternative investments) and the ex-post scenario (successful implementation of the initiative). However it is still to be validated how the micro analysis at project or initiative level may provide useful information at program or infrastructure level. ERINA+ and RI-Impact partners will work on this aspect during the coming months.

In general, it seems of paramount importance both the need for creating a culture of impact assessment in the Community of the Research Infrastructures and e-Infrastructures, as well as the need to conceive usable tools to monitor, assess developments, results and impact of the result EU funding in this domain. This needs to be done in a coordinated way and at a single project, e-Infrastructure and Program level.

Consensus amongst the projects is the idea to consolidate a long term strategy for defining the impact of e-Infrastructures, which could put together the major results of the work carried out by the projects - namely the framework from RI-Impact, the mapping from OSIRIS, ERINA+ and the eNventory tools, along with the findings from eFiscal. This could be very interesting since many of the actors and stakeholders, EC included, see the value in knowing what happens with its funding, and the e-Infrastructures and project themselves are interested in assessing their impact either during their preparation phase (*a-priori* analysis), during their life-time (continuously monitoring) and at the end (*a-posteriori* analysis).

These initiatives highlight both the importance and the challenges in assessing the impact of the EC investments in the e-Infrastructures landscape. Experiences, know-how and best practices provide the right direction. It’s the right time to set-up a comprehensive and coherent framework for enabling actual impact assessment at each level.

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