Sustainability of e-Infrastructures (for the Social Sciences)

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Abstract. This paper discusses the issue of achieving sustainability in e-Social Science and e-Science more generally. We aim to examine what is meant by sustainability and present a conceptual model that can help to illuminate what constellations of technical and social infrastructure underpin current usage and in what areas interventions may be needed to sustain future operation and usage of an e-Infrastructure. We then turn to a discussion of features of different national contexts and look at sustainability of the e-Infrastructure for the social sciences currently being developed in the UK.

Introduction

This paper presents a review of work on achieving sustainability in e-Social Science and e-Science in general. It reports on discussions at a number of workshops that have taken place on the subject over the last year, in the context of the UK e-Science Institute (Voss *et al.* 2007), the UK National Grid Service (Geddes *et al.* 2007), the UK National Centre for e-Social Science (Hewitt 2006), the German D-Grid initiative (Baun *et al.* 2006) and the EU e-Infrastructure Reflection Group (e-IRG 2007, Procter 2007). The comparison between these different contexts will help us to better differentiate between issues arising from particular national conditions and approaches, issues that are specific to particular communities or research areas (such as the social sciences) and issues that are of wider relevance to the wider international project of e-Science. The paper is therefore of relevance as a study of the social factors affecting sustainability but also of practical interest to those currently undertaking the development of e-Infrastructures (for the social sciences and other domains).

Understanding Sustainability

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

[1] Of course, people might simply wish that the funding programmes be sustained but that seems neither a realistic option nor one that maximises overall benefit to society.

However, in order to reason about ways of achieving this aim, we need to examine exactly what it is that we wish to sustain, why we want to do this, what the expected costs and benefits are and for whom these will be relevant. Once we have defined these more specific aims we can think about the issues involved and risks to sustainability as well as their potential impact and likelihood of occurrence. The nature of these issues and risks will then define the candidate interventions that will help overcome or mitigate them. The costs of interventions will need to be taken into consideration in relation to the benefits of the sustainability aims as well as the impact of sustainability issues and risks (as well as their likelihood). This paper will provide a conceptual framework for an analysis of sustainability issues, a set of general dimensions and examples drawn from the e-Infrastructure for the Social Sciences currently being created in the UK (Daw *et al*. 2007, this volume) and a discussion of sustainability in relation to different national contexts.

Sustainability and Uptake

There is a close relationship between the issue of initial uptake and eventual sustainability of e-Infrastructures. However, all too often this relationship is ignored and, even worse, both aspects are often treated as afterthoughts while technical issues are emphasised. There remains a predominant mentality that emphasises technical concerns and portrays the creating of an infrastructure as a construction process. In contrast, Edwards *et al*. (2007) have suggested that "effective infrastructures are rarely 'built' in an entirely top-down, orderly, and blueprint-like way" (ibid, p.2) and that use of technologies, and in particular infrastructural ones, is often deeply embedded in a complex web of socio-material relations.

The concept of *mutual shaping* (Williams and Edge 1996) emphasises this by pointing to the various ways in which technological development and social organisation emerge together over time whilst influencing each other. A working infrastructure is more than just a configuration of technical elements that might be described by some sort of wiring diagram. Instead, we need to understand infrastructures as socio-technical arrangements involving complex relationships between stakeholders of various kinds, intra- and inter-organisational arrangements, technical configurations, other resources such as skills and knowledge, aspects of the problem domain and the wider socio-political context. Moving away from simplistic accounts of technology uptake also has wide-ranging consequences for our understanding of sustainability issues.

Sustainability as Contested Ground

We might distinguish a number of groups that are involved in e-Science and may have an interest in its sustainability: funding agencies may wish to shift their focus on to new objectives; users may want dependable, usable, useful and affordable services that can be expected to be available in the longer term; technology developers may wish to see their products become part of an established e-Infrastructure so they can develop new technologies to add value to the installed base and infrastructure providers may want to be able to reliably plan service provision and have a stable source of income to finance the service delivery.

We would argue that because of the number of interests involved, we cannot treat sustainability as a simple aim shared by all but need to see it as a (potentially) contested landscape of partially conflicting aims. Practically achieving sustainability will then involve fostering *socio-technical constituencies* (Molina 1995, 1997), by bringing about *alignment* between technical components, standards, etc. (the 'technical infrastructure') on the one hand and stakeholder interests, working practices, organisational structures, etc. (the 'social infrastructure') on the other. Consequently, a lack of alignment, either in the form of *misalignment* (indicating tension) or *non-alignment* (indicating lack of awareness and coordination) may be seen as a generic cause of a lack of uptake or a treat to sustainability.

In order to reason about sustainability there first needs to be an understanding of the current state of affairs and what socio-technical constituencies have emerged that are underpinning the *status quo*. Only then can one reason about ways to either aim to preserve these constituencies or make targeted interventions in order to bring about different forms of alignment that are more likely to be sustainable.

Examining Sustainability

We now turn to our initial collection of specific sustainability aims based on a review of project documentation and workshop reports. It provides a number of examples of different aspects that might be categorised under the three headings of sustainability aims, risks/barriers and candidate interventions. At the end of this section, we will relate these findings to the conceptual framework outlined above.

Sustainability Aims

The following list illustrates what we might call sustainability aims, aspects of sustainability that we might want to realise. The list is not meant to be exhaustive, nor do we intend to suggest that these aims are independent of each other. The reasons why we would characterise these aspects as sustainability aims is because they are not merely instrumental, i.e., they are not simply means to achieve something else but have some inherent value that is an important factor in achieving overall sustainability of e-Infrastructures.

1. Dependable services and long-term availability of infrastructure
2. Independence of infrastructure from single providers or funding sources
3. Long-term added value through an established base that new activities can build on
4. Realisation of the benefits of investments made
5. Ability to effectively plan investments and activities
6. A growing body of knowledge shared throughout the community
7. Technical evolution that does not lead to legacy issues
8. Embedding of e-Infrastructures in everyday research practice
9. Users' needs are met and the costs of uptake are low enough
10. e-Science 'sells' and an increasing number of users are getting engaged

By negating the above we can derive a set of barriers to achieving sustainability and risks that threaten it. In the following, we will further elaborate these risks and make them more concrete on the basis of our observations of e-Science.

Sustainability Issues, Risks and Approaches to Mitigation

For each of the issues and risks identified, there are a number of candidate interventions that might address them. In this paper we can only give one example but this is not intended to suggest that the interventions we point to are either necessary or sufficient for any purpose or in any context.

State of Implementation: current implementations do not provide the well-defined, robust, useful and usable services required for wider uptake. **Response**: development of organisational structures that support the further development of software to meet commercial software engineering standards (e.g., OMII-UK).

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

Lack of availability of technical skills: relevant skills required to develop and operate e-Infrastructures and research applications are not widely available. **Response**: development of specific training programmes such as the Master in e-Science offered by the University of Edinburgh[2].

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

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

Lack of Standardisation: lack of standards in many areas that are mature, widely accepted and have interoperable implementations. **Response**: strengthening the role of organisations like the Open Grid Forum, developing certification programmes, improving dissemination activities.

Lack of Demonstrable Benefits: lack of adequate demonstration (quantification) of the benefits needed to secure further investment. **Response**: increase the degree to which activities are self-sustaining (i.e., the open source model); the fact that people are willing to invest effort and resources proves that there are benefits.

Lack of Critical Mass: lack of critical mass of active users and routine usage. **Response**: active support through user engagement, co-development of services and provision of education and training events aimed at researchers, e.g., versions of the ISSGC or Grid-Ka Summer Schools.

Unresolved Methodological Issues: in many research communities, use of information technologies raises methodological questions, for example, about the status of different sources of data (transaction data versus panel surveys). **Response**: discipline-specific initiatives need to engage with methodological discussions in targeted research areas (e.g., AHRC ICT Methods Network and the National Centre for Research Methods).

Licensing: licensing issues that prevent the usage of commercial software in grid environments. **Response**: negotiation of licensing arrangements suitable for the use of software and data in grid environments, at different levels: community, national and international.

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[2] http://www.ph.ed.ac.uk/postgraduate/degrees/msc_escience.html

Incompatible Open Source Licenses: existing established open source licenses differ to a large extent and are mostly incompatible with each other. **Response**: definition of an acceptable license or an acceptable set of compatible licenses for new developments.

Data Protection: securing privacy in a distributed e-Infrastructure is difficult. **Response**: strong auditing and monitoring mechanisms must be developed to guarantee a high level of privacy

Taking up Molina's notion of socio-technical constituencies, we might map the issues and risks (and, implicitly the interventions) to a number of different areas that bear upon the sustainability of e-Infrastructures. Figure 1 (below) demonstrates how the sustainability issues and risks identified above can be mapped to a number of areas of concern that an analysis of sustainability will need to consider. The graphical representation used here provides a convenient way to assess whether all the areas of concern have been covered in the analysis.

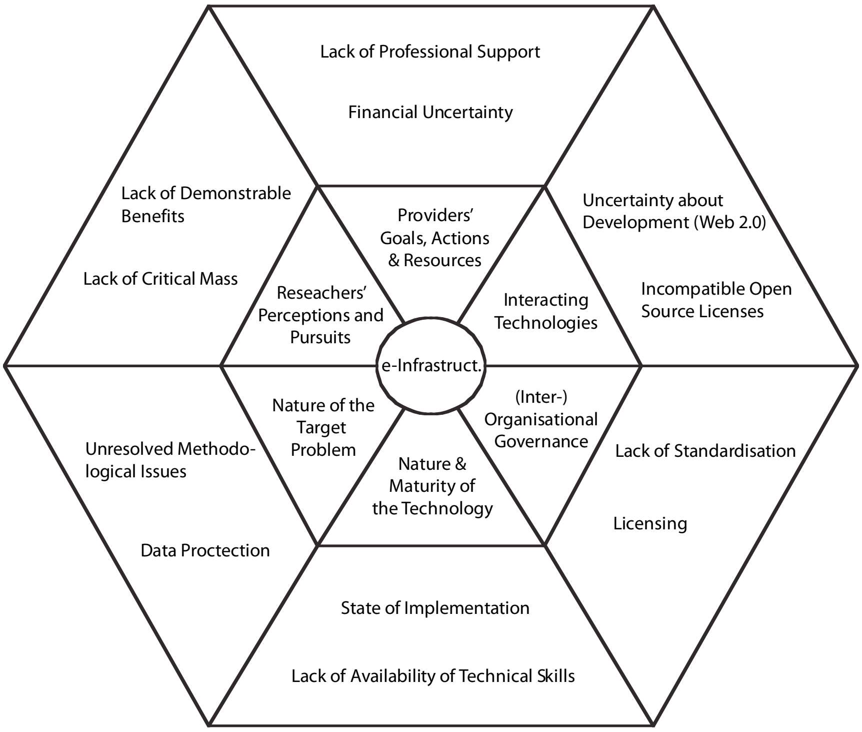

Figure 1: Mapping Sustainability Issues and Risks. Adapted from Molina (1997).

Discipline-Specific Issues in the Social Sciences

While the sustainability of national e-Infrastructures like D-Grid[3] and the UK National Grid Service (NGS)[4] in principle affect all disciplines that might make use of them, there are nevertheless specific issues to consider and we want to reflect on concerns of particular interest to the social sciences. The UK's National Centre for e-Social Science (NCeSS) has recently been awarded a grant by the Economic and Social Research Council (ESRC) to start building an e-Infrastructure for the social sciences (cf. Daw *et al*. 2007, this volume). While

[3] http://www.dgrid.de
[4] http://www.grid-support.ac.uk

this infrastructure will make use of the NGS for compute-intensive and/or data-intensive applications, there are various elements that will be provided through NCeSS, either at the NCeSS Hub in Manchester or at one of the NCeSS Nodes. Decisions about the deployment of this distributed infrastructure need to be made in the light of the longer-term prospect of service provision at each location. They will also be affected by discussions within the NGS and other service and data providers.

Social science as a discipline has not traditionally been 'pushing the envelope' of high-performance computing (HPC) facilities or other advanced information technologies. With the exception of the simulation and modelling community, awareness of the potential of HPC technologies and their potential application in the social sciences is generally low (cf. Barjak *et al.*, 2007, this volume). The social science community is, however, now beginning to grasp the potential benefits of e-Infrastructure for increasing access to, and re-use of, data. The potential range of research resources on offer to the social science community has never been greater. These include not only traditional research datasets in which the ESRC, for example, has invested significantly over the past forty years, but vast quantities of administrative, commercial and personal data now being captured in a variety of increasingly digital forms. Exploiting these resources to their full potential will not be possible without significant investment in e-Infrastructure and work to tackle the methodological and ethical issues involved (Anderson and Carlson 2006).

In common with the research community as a whole, the social sciences have been slow to get to grips with the sustainability challenges posed by the widespread adoption of e-Infrastructure. An important example is the impact of a potentially vast increase in both the numbers and types of research resources (data, services, learning objects, etc.). The accumulation, sharing and re-use of resources on a vast scale lies at the heart of the e-Research vision, however, it seems that responses to the support and financial issues this raises have yet to be factored into planning for e-Infrastructure sustainability.

A fundamental question that needs to be addressed is how resources originating in time-limited projects can be curated and managed so that they remain viable for re-use in the long term. In particular, where, in a landscape of multiplying, diverse and distributed resources, will the necessary effort and expertise come from and what funding models are most appropriate to pay for it? Funding bodies are concerned that escalating commitments to sustain resources will consume an ever increasing proportion of their budgets.[5] It seems that the existing social infrastructure as represented by service providers and the funding models that support them are in tension with the opportunities that the new technical infrastructure affords. At the very least, the time is right to consider whether a blueprint for a new social infrastructure, possibly with a greater number and diversity of service providers, is called for, but there are few signs as yet that the relevant stakeholders (existing or potential) are ready or able to explore and agree how to best exploit the options available to them.

The NCeSS e-Infrastructure project provides an interesting context for the study of these challenges. Its contributors – and hence the research resources they are providing – are guaranteed funding for the short-term only. If the project is to succeed in encouraging uptake of e-Social Science, its potential users must be confident that its resources will be sustained. Under current arrangements, new data resources resulting from the e-Infrastructure project would be handed over (strictly speaking, offered for 'ingestion') to the Economic and Social Data Service (ESDS). ESDS is the UK's national data service, funded jointly by ESRC and JISC, which provides access and support for an extensive range of key economic and social

[5] A recent example, is the decision by the UK Arts and Humanities Research Council to discontinue funding of the Arts and Humanities Data Service.

data, both quantitative and qualitative, spanning many disciplines and themes, and available to researchers free at the point of use.

It must be questioned whether the e-Infrastructure project would be sustainable under this model. First, as noted above, there are unmistakable signs that, in the future, UK funding bodies will expect institutions hosting research projects to absorb some of the costs of maintaining the research resources these projects create. This may, in turn, encourage host institutions to introduce charges for services provided, such as the micro-payments model adopted by many journal publishers. Second, the current sustainability model makes no provision for the sustainability of non-data research resources such as analysis services and community portals. These will require specialist expertise and the capacity to track their user communities' changing requirements. Third, and related to both the previous points, existing mechanisms for curating resources so that they are – and remain – fit to share seem unlikely to scale with the new resource landscape (proliferating, heterogeneous and specialised). Greater community engagement has a potential role to play but there are misalignments around research cultures, such as incentives and reward structures which must themselves be addressed.

Comparing and Learning from National Initiatives

Comparisons of national programmes provide an opportunity to contrast and compare different approaches to developing sustainable e-Infrastructures for research as well as to highlight features of particular approaches taken that might inform debates in other contexts. For example, the German D-Grid initiative aims to support three different middleware stacks whereas the UK National Grid Service operates exclusively on the basis of the Globus stack. Both approaches have their respective advantages and disadvantages. On the one hand is the risk that supporting multiple stacks will turn out to be too costly in the long run whereas on the other the danger is that a lack of support for different stacks may limit the potential user base, potential uses, the potential enrolment of new resources and the formation of inter-grids[6]. Other differences between the two initiatives exist in terms of the level of commitment to middleware development as well as the timing and scope of the initiatives (cf. Gentzsch 2007).

One important element to consider in any e-Infrastructure development and, in particular, in the development of national strategies is the scalability of the approach taken. If the ambitious aims are to be met and usage increased by an order of magnitude across all research areas then the question arises how providers can effectively cater for the increased number of users and their diverse needs. The US TeraGrid programme has been running a science gateway programme that has two related aims: to lower the barriers to uptake for researchers on the one hand and to make increased uptake manageable for resource providers on the other by clustering usage and devolving some of the day-to-day operational management (for example, the management of individual researchers' identities) to the level of research communities. In other national contexts, for example in the UK, different approaches may be taken to achieve the same aims. The UK is currently investing in the development of a federated identity management system based on Shibboleth under the UK Federation[7].

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[6] the linkage of different grid infrastructures, e.g., across national boundaries

[7] http://www.ukfederation.org.uk

In the UK, the Joint Information Systems Committee has implemented an e-Infrastructure Programme[8] to build on the UK e-Science Core Programme[9] and the OSI (Office of Science and Innovation) e-Infrastructure Roadmap initiative. The vision for the programme follows the initial five-year investment in the UK e-Science Infrastructure, which is being developed with other partners to expand the uptake and effective use of e-Infrastructure from early adopters and researchers across disciplines. A related programme on Virtual Research Environments[10] (VREs) is supporting the development of researcher-facing environments that provide access to e-Infrastructure through sets of integrated tools (often delivered through a portal).

As part of its e-Infrastructure programme, JISC has recently launched a community engagement strand to (a) address research community requirements and ways in which the community can be enabled to exploit e-Infrastructure services, tools, and resources to support new capabilities and research practices and (b) encourage the adoption of e-Infrastructure into new disciplines, groups and activities by engagement with both existing e-Science communities and new adopters. The two projects funded under this initiative are aimed at investigating and addressing barriers to uptake and sustainability and documenting good practice in e-Infrastructure usage (Voss *et al*. 2007a, this volume). They aim to widen the uptake of e-Infrastructure as well as to make e-Infrastructure provision and usage more sustainable by fostering an ongoing process of reflection in the communities, underpinned by a conceptual framework and baseline understanding developed through the establishment of a robust evidence base through the projects themselves.

The provision of training, outreach and support activities needs to scale to the wider research community. In the UK, the National e-Science Centre's Training, Education and Outreach team (TOE) have a remit to provide training across disciplinary boundaries and in cooperation with national service providers such as the NGS. In addition, discipline specific training events are run through institutions such as the National e-Social Science Centre (NCeSS) or the Arts & Humanities e-Science Support Centre (AHeSSC), usually in collaboration with the NeSC TOE team. As the uptake of e-Infrastructure increases, the emphasis will need to shift from end user training to 'training the trainers'. There will be a need to distinguish between generic training material that can be used in all contexts and can be provided through central repositories and dissemination mechanisms and discipline-specific material and events that need to be tailored to specific target communities. The e-Uptake project, funded under the community engagement strand, will develop a UK 'one-stop-shop' for training and support material as well as event and support information. The information contained will be made available through a central website but also through community-specific websites such as those of NCeSS and AHeSSC.

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

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8 http://www.jisc.ac.uk/whatwedo/programmes/programme_einfrastructure.aspx

9 e-Science Core Programme: http://www.epsrc.ac.uk/ResearchFunding/Programmes/e-Science/default.htm

10 http://www.jisc.ac.uk/whatwedo/programmes/programme_vre.aspx

There is an increasing recognition that in order to widen and deepen the uptake of e-Infrastructures and to develop sustainability models for their provision and use, it is essential that user needs be considered as a key concern in service development and provision. While experiences exist with various forms of engagement of users in the development of e-Science technologies, there is a lack of sharing of this knowledge and reflection on good practices (Schopf *et al*. 2006). The e-Science community urgently needs a forum where discussions of such methodological issues can find a home. There is also a need to develop reward structures that encourage methodological rather than just technical innovation. Fostering links with other research areas such as software engineering, computer supported cooperative work as well as science and technology studies may provide opportunities to develop these aspects of e-Science.

Conclusions

e-Infrastructures are complex socio-technical arrangements that emerge from a process of mutual shaping between different technical factors and social processes and structures. Consequently, those aiming to establish e-Infrastructures must understand the alignments that need to be brought about to establish stable socio-technical constituencies (Molina 1995, 1997) that underpin and sustain them. Sustainability is a crosscutting concern that needs to be considered in any decision making process. It is important to understand in any particular context just what the specific sustainability aims are, what issues and risks are involved and what possible interventions are available to overcome or mitigate them. We have provided a set of examples of these different aspects and integrated them into a conceptual framework for the analysis of the sustainability of e-Infrastructures. Finally, we have discussed sustainability aspects of the ESRC e-Infrastructure for the Social Sciences as well as various national e-Infrastructure initiatives.

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