Towards resource-efficient and service-oriented integrated infrastructure operation: Challenges and Opportunities

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The Land of the MUSCOs (LOTM) project aims to study and model alternative infrastructure operation configurations to determine how infrastructure systems could change to become: more centred on the end user, deliver efficiency improvements; and take into account multiple utility streams simultaneously.

End-users play a crucial role in determining the efficiency of infrastructure systems and provide a key point of integration between infrastructure streams. A closer integration of end-users into infrastructure operation introduces the need for appropriate feedback and related challenges. Infrastructure as a complex socio-technical system requires more holistic governance approaches than the current fragmented and marked-led approach, which is failing to accelerate the adoption of niche practices.

This briefing note describes the benefits and challenges associated with moving towards resource-efficient and service-oriented infrastructure. We first describe the benefits of having a more user centred approach to infrastructure operation and how MUSCos might overcome some of the challenges of engaging end users. Next we outline the essential role of data in supporting user engagement. We then discuss how governance and valuation of the infrastructure system would need to change to support emergence of MUSCos. We end with a discussion of the research needed to accelerate the way forward.

Introduction

Present infrastructure operation suffers from a number of challenges:

(1) Governance based on unmanaged growing demand is both inefficient and unsustainable.
(2) Current design and operation do not integrate the end-users in terms of the variety of their wants and behaviours and their crucial role in selecting and using technology.
(3) Separate and parallel delivery of different infrastructure streams prohibits the development of potential joint solutions, or substitutions, between infrastructure systems.

These characteristics of current operation act as obstacles to technical innovation and longer term sustainability. To address these challenges we need alternative infrastructure operation configurations which are: centred on the end-user and their demand for services; concerned with implementing resource efficiency improvements; and take into account multiple utility streams simultaneously. We call these alternative configurations Multi-Utility Service Companies or MUSCos.

Infrastructure as though the end-user mattered

End-users are fundamental to infrastructure operation; they define the ultimate requirements of the system (the level of demand); control the uptake of the most
cost-effective technologies for efficiency improvement and define to a large extent the ultimate efficiency of the system through their operation of technologies. Furthermore, the end-user provides a point of integration for infrastructure streams since certain services (e.g. hygiene, mobility) require a combination of infrastructure networks. Examples of end-user, or service, level integration are shown in table 1 below. A narrow focus on efficient supply neglects the crucial role of the end user in terms of their wants, behaviours and technical choices, which are critical to resource-efficient infrastructure operation [1].

Table 1: Integration of infrastructure streams for service delivery (Com. = communication, Transp. = Transport).

<table>
<thead>
<tr>
<th>Service</th>
<th>Infrastructure affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient temperature /thermal comfort</td>
<td>✓ (✓)</td>
</tr>
<tr>
<td>Illumination</td>
<td>✓ (✓)</td>
</tr>
<tr>
<td>Hygiene, food &amp; drink preparation</td>
<td>✓ ✓ (✓)</td>
</tr>
<tr>
<td>(sustenance), hot industrial process</td>
<td>✓ ✓ (✓)</td>
</tr>
<tr>
<td>water</td>
<td>✓ ✓ (✓)</td>
</tr>
<tr>
<td>Irrigation, cold industrial process</td>
<td>✓ ✓ (✓)</td>
</tr>
<tr>
<td>water</td>
<td>✓ ✓ (✓)</td>
</tr>
<tr>
<td>Entertainment</td>
<td>✓ ✓ (✓)</td>
</tr>
<tr>
<td>Mobility (i.e. personal access to work,</td>
<td>✓ ✓ (✓)</td>
</tr>
<tr>
<td>education, shopping, and daily leisure,</td>
<td></td>
</tr>
<tr>
<td>carriage of freight)</td>
<td></td>
</tr>
</tbody>
</table>

End-user level solutions, by necessity, involve multiple and diverse actors, and might therefore be more difficult to implement than a small number of large scale supply side initiatives. However, they may also enable more robust testing and deployment of resource-efficient technologies [1]. End-user attitudes, beliefs, habits or routines, personal capabilities, and contextual factors have been identified as barriers to the adoption of cost-effective technologies in studies across different infrastructure streams [2-4]. One proposal to overcome end-users’ efficiency barriers is to shift away from selling products or metered quantities of utility products (e.g. kWh of electricity, gas or litres of water), and towards selling “services” (such as thermal comfort, illumination and cleanliness): which can be defined as the ultimate goal of the product or utility product purchased [5].

Delivering Infrastructure Services

The resource consumption of a service can be defined by the end-users’ demand for the level of service as well as how efficient utility products are converted into the service required. The efficiency of such conversion itself depends on the conversion technologies in place (i.e. active appliances converting utility products into the service required), their passive context [6] and how end-users operate these technologies. Current efficiency initiatives either focus on changing end-users’ final demand (i.e. behaviour) or end-users’ conversion technologies: few consider the demand for services.

Service-oriented models would not only increase adoption of existing resource efficient and cost-effective technologies but could also bring about a change in the operation of these technologies, through contractual clauses concerning accepted modes of operation.

Bespoke quality

Utility products are provided to end-users at quality standards that have been established principally as a result of historical events, rather than practical needs, and are enforced by strict regulatory measures. Bespoke quality or multiple qualities would match the actual characteristics of services or resources needed, rather than conventional or arbitrary standards, and could lead to a reduction in resource consumption.

Technically, it would be possible to provide utilities at multiple bespoke quality levels better adapted to the needs of the end user: for example providing non-potable water or direct current power (Figure 1) to support appropriate services. Further examples for standards not matching final services they provide are, car usage by a single driver, small high temperature heaters, and 50°C hot water provision.

Key barriers to bespoke quality delivery constitute current regulation, safety concerns, reliability issues, and end-user practices. Pilot-level cases however show successful example jointly overcoming these barriers often driven by proactive consumers and/or local entrepreneurship.
Figure 1: Total 2011 UK domestic power consumption by different services and form of electricity (i.e. alternating current (AC) red arrows and direct current (DC) in yellow arrows), data source [7]

From data to wisdom
Integrating the end-user into infrastructure operation creates the need for an appropriate interface between the user and the infrastructure. Feedback given at this interface has the potential to radically reduce resource demand, by supporting resource efficient decision-making and catalysing change in the operation of technologies. Three key challenges to designing this interface are:

(1) The user-orientated, integrated infrastructure vision calls for an atypical use of feedback.

(2) It requires interoperability in a complex system of actors with competing interests [8].

(3) The large-scale adoption of smart systems has the potential to create a deluge of ‘big data’.

Design of user-infrastructure interface
To address these challenges, and the others likely to emerge when reconciling competing perspectives and interests (e.g. technological, ethical, security etc.), we propose the adoption of a whole system, socio-technical perspective which:

- Presents feedback at the user-infrastructure interface in an appropriate and context dependent form.
- Uses automated decision-making appropriately.
- Addresses the broad range of ethical, security and privacy issues raised by the flow of data, information and knowledge between the user and the smart infrastructure.

There is little doubt that pervasive ICT systems will underpin future infrastructure systems at the user-infrastructure interface due to their benefits on various levels. Coordination between ICT system and appliance manufacturers, service providers, and end-users on the other hand offers significant potential for a more
resource efficient infrastructure operation. This has to be facilitated by considering the complex interrelations between infrastructure streams, and through innovative governance and infrastructure operation schemes designed to overcome existing market and regulatory failures.

Complexity
The transition to a new, user-centric, approach to infrastructure operation requires a systemic approach to change. Infrastructure is a socio-technical system; it cannot be understood as a set of discrete technologies but must be seen as a complex, interconnected system of technology embedded in society and interacting with public and private institutions [1].

Understanding change, or transitions, as a co-evolutionary process “highlights the uncertain, path-dependent and cumulative nature of systems change” and helps to identify interventions that recognise the interconnectedness of infrastructure, with the potential for overcoming system lock-in [9]: hence the proposal of radically new arrangements, such as MUSCos, Multiple-Utility Service Companies.

Market and governance failures
Privatisation of infrastructure, intended to overcome public sector inefficiencies, has obliged government to regulate new types of market failure. The primary purpose of post-privatisation infrastructure governance was to introduce competition into the infrastructure system, to deliver greater economic efficiency and to protect consumer rights.

The current governance system is primarily market-led, which was fit for the purpose of driving cost efficiency and consumer protection, but it is unlikely to be appropriate to respond to emerging issues, like climate change [10]. Privatisation of utility sectors has led to the introduction of new actors responsible for the delivery, regulation and financing of utilities to correct market failures and protect customers. This has created a complex and fragmented governance structure [11].

The complexity and interdependence of infrastructure systems, both technically and socio-economically, requires that any action to intervene must recognize both the historic co-evolution of the system and the path dependency that could limit the potential of disruptive change [9]. Overcoming system lock-in requires systemic action that cuts across policy sectors, public and private institutional boundaries and state jurisdictions.

Innovative governance and operation
There are examples of promising alternatives of transformative changes at the niche scale (see box 1). The scale of efficiency improvements required would necessitate a step change in the rate of adoption of these alternative approaches and support in application at a larger scale. We need a more creative and systemic approach to governance which encourages and enables this step change and engages the right people at the right scale to deliver efficiency. This might include alternative problem framing and investment strategies as well as integrating infrastructure streams.

Box 1 promising alternatives
Direct intervention into service provision has been successfully implemented by Woking Borough Council, which recycles savings from energy efficiency into construction of low-carbon energy systems to provide affordable energy to residents. This initiative was made possible by a more integrated, outcome focussed approach to problem framing, which aligned strategies from several different policy sectors (e.g. climate change mitigation and housing renewal). The solution was delivered in partnership with a private company through a special purpose vehicle, which delivered value to residents, the council and the private sector company. This resulted in more effective intervention that reduces negative unintended consequences [12].

Infrastructure as though infrastructure mattered
There are many problems related to the ways in which infrastructure is valued, leading to challenges in investing in sustainable infrastructure, or operating existing infrastructure sustainably. In particular, the operational phase – i.e. post-installation and commissioning – of infrastructure is systematically undervalued. A cost is attached to the construction of infrastructure assets, such as road and bridges, and...
often to maintaining assets to ensure they continue to serve their original function, but not to the value generated by their utility in delivering a service to society.

In most charging schemes, the end-user does not pay for the service and well-being provided, but for some indirect or even unconnected measure thereof (e.g. gas, not heat; a flat-rate for water supply and waste disposal; vehicle excise duty, not miles travelled etc.). This focus on the physical infrastructure rather than the service it provides is unhelpful; however it arises because it is easier to measure cost/price than it is to measure value. An alternative approach to infrastructure valuation during operation would be to quantify the service delivered by the infrastructure, such as thermal comfort or access to employment, education and leisure, and charge end-users on the basis of these services. This might also include charges for the indirect services – the value provided by the other services enabled by this asset i.e. as a result of interdependency/interconnections.

There are some challenges associated with quantifying and monitoring the service and with defining monetary value. However there are additional benefits to an infrastructure valuation approach centred on services; the focus of investment is likely to move from new capacity to demand management, since this is where the most significant cost savings can be found and maintenance regimes are likely to become more active and consider the long term value of the infrastructure asset in delivering the desired service.

Getting there from here
The challenges described in this briefing note cannot be addressed in the current, throughput-based system of infrastructure operation. We need to accelerate the transition to alternative infrastructure operation configurations which incentivise resource efficiency. As described above, MUSCos, which are; centred on the end-user and their demand for services; concerned with implementing resource efficiency improvements; and take into account multiple utility streams simultaneously, could contribute to this transition.

The widespread adoption of a MUSCo configuration is currently constrained by a number of barriers including lack of trust and experience, lock-in to mainstream technologies and operation modes, high transaction costs associated with creating and monitoring contracts and the fragmented and entrenched regulatory and policy framework. There is need for action involving partnerships between academia, localities and industry, which addresses particular aspects of the challenge, but hopefully builds towards a system-wide transition. The academic side of the partnership should moreover be interdisciplinary, including expertise from social science (sociology, psychology, political science), economics, and engineering, as well as computer science, for example, and also integrative, so that the outcomes are not reflective of one single field, but rather bring together the different disciplines to provide answers to core research questions.

We recommend a multi-scale approach to understand how to overcome barriers and accelerate the adoption of MUSCos. Micro-level action, focusing on end-users, or specific technologies, should be conducted with a high level of detail, in order to bring out unexpected outcomes, and generate results that are reflective of the diversity of end-user behaviour even within a specific neighbourhood or industry sector. Meso-level action, at the community or industrial sector level, is important because it will highlight the crucial role of diverse actors, in terms of their relations, expertise and incentives, including contradictory incentives. It could also identify and develop unexpected new types of relations and collaborations which will be necessary for MUSCo infrastructure operation. Macro-level action, addressing infrastructure governance and policies (including procurement policies), is necessary to understand and remove constraints on service-based infrastructure from high-level policy and regulatory bodies. This action should be co-ordinated across Europe, in different national contexts, in order to develop a European strategy on sustainable infrastructure operation which maximises resource efficiency and prioritises service delivery over throughput volume.

Truly sustainable infrastructure operation needs to move away from the status quo based on provisioning unconstrained demand, and the action outlined above will chart and accelerate the way forward.
References


7. DECC, Energy consumption in the United Kingdom: 2011; Overall energy consumption in the UK since 1970, 2011, Department for Energy and Climate Change (DECC)


SuRe Infrastructure publications
(linked to pdfs on sure-infrastructure.leeds.ac.uk)

Land of the MUSCOs: Multi-Utility Service Companies

Conference papers
(1) Resource efficient an service oriented infrastructure operation, the role of multi-utility service companies in driving change towards sustainable and resilient urban infrastructure

Briefing notes
(1) Context and goals of the Land of the MUSCos project
(2) Identifying alternative opportunities; Technologies and operation modes
(3) Governance: Analysing Creative Intervention
(4) Agent Based Model typology

Undermining Infrastructure – Avoiding the Scarcity Trap

Conference papers
(1) Material Risks to Sustainable Urban Infrastructure Transitions
(2) Towards sustainable and resilient (SuRe) infrastructure: Material dependency and the analysis of local vs. global
(3) Critical materials for low-carbon infrastructure: the analysis of local vs global properties
(4) Enhancing Stocks and Flows modelling to support sustainable resource management in low carbon infrastructure transitions

Briefing notes
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