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Editorial

Modeling and evaluating the sustainability of smart solutions☆

ABSTRACT

Smart technologies provide diverse and promising opportunities to reduce energy demand and greenhouse gas emissions; they are increasingly expected to shift modern societies' patterns of production and consumption towards sustainability. However, the existence of a theoretical potential does not imply that every smart solution (application of a smart technology) will contribute to sustainability. Policy-makers are therefore in need of methodologies to evaluate the sustainability of smart solutions. This paper gives an overview of the current discussion in the field and the emerging methodological challenges. The challenges of assessing the *direct* impact of the ICT components and infrastructures are special cases of known issues in life cycle assessment methodology. The challenges of assessing *indirect* impacts are inherently interdisciplinary and call for integrated modelling approaches. The last two sections provide an overview of the papers assembled in this thematic issue that treat specific cases and general principles of modeling and evaluating the sustainability of smart solutions.

1. Introduction

Making the world smarter by adding computing, sensing and networking capacity to objects and infrastructures is a vision that emerged more than a decade ago from the field of ubiquitous computing. "Smart things" were envisioned with the ability to explore their environment and to communicate with each other, thus "enabling innovative products and totally new services to be developed" (Mattern, 2004, 155). "Smart environments" were designed, "able to acquire and apply knowledge about […] its inhabitants in order to improve their experience in that environment" (Cook and Das, 2007, 54).

"Smartness" became a metaphor for the integration of Information and Communication Technology (ICT) in formerly passive products and infrastructures to make them more responsive and give software more control over real-world processes. While some instances of this metaphor have become part of daily reality in some cases – such as the smart label[1] and the smartphone – others are still far from everyday practice, such as smart grids (as defined in EFC, 2003), smart cities (as defined in Caragliu et al., 2009; see also Kramers et al., 2014), or smart sensor networks (as described in Weber, 2009).

Although every application of smart technologies is designed and deployed to solve a specific problem, there is a discussion about the general trend towards "smartness" (or "smart everything", Koomey et al., 2013) and its potential to solve the predominant problem of modern societies: to shift from unsustainable towards sustainable patterns of production and consumption. Laitner subsumes smart buildings, smart appliances and smart grids under the generic concept of "smart energy solutions" (Laitner, 2010, 692).

Seminal studies have pointed out the potential of smart technologies to contribute to the energy productivity of the US economy (Laitner et al., 2001, 2009), to the abatement of greenhouse gas (GHG) emissions (GeSI, 2008, 2012) at national and global scales, and to strategies of "green growth" (Mickoleit, 2010), which the OECD defines as "fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies" (OECD, 2011, 4).

Although there is evidence from these studies that ICT has a high potential to reduce the energy and material flow through today's economies overall – and thus to mitigate the pressure on ecosystems and slow down climate change – there is no guarantee that this will actually happen. Every specific smart solution may or may not be sustainable, depending on the size of its own environmental footprint and on the *actual* reduction of environmental impact it brings about by improving other processes. The latter may differ from the *potential* reduction because the theoretical potentials may only materialize under specific conditions – or may be compensated by other processes that are enabled or increasingly demanded as a consequence of the specific smart solution. Assessing the sustainability of smart solutions usually requires accounting for the dynamics of complex systems and using multiple criteria in the methods of evaluation.

We hope that this thematic issue will contribute to the development of sound approaches to assessing the sustainability of smart solutions. The fundamental methodological challenges of such assessments will be addressed in more detail in Section 2 of this paper. Sections 3 and 4 will provide an overview of the papers assembled in this issue.

The idea for this thematic issue emerged at the first International Conference on Information and Communication Technologies for

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☆ Thematic issue on Modelling and evaluating the sustainability of smart solutions.

[1] Labels on product packaging or the product itself containing an RFID (Radio-Frequency IDentification) chip. The advantages and disadvantages of their application have been discussed broadly in the last decade, e.g. Wäger et al. (2005) and Oertel et al. (2005).

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Sustainability (ICT4S), held in 2013 in Zurich, where the self-critical question “How do we know if this solution is really sustainable?” has be addressed in many contributions (Hilty et al., 2013). Some of the papers gathered in this issue are expanded versions of papers presented at ICT4S, others were submitted in reaction to the open call for papers.

2. Smart solutions – sustainable solutions?

In 2008, the Global e-Sustainability Initiative (GeSI), an association of over 30 leading ICT companies, published the “SMART 2020” study. This report estimated that the GHG emissions from the ICT sector will represent 3% of total global emissions by 2020, but that ICT will help other industries and consumers avoid 15% of predicted total global emissions (or five times its own footprint) by enabling “smart motor systems”, “smart logistics”, “smart buildings”, “smart grids” and “dematerialization”[2] (GeSI, 2008). A recent update of the study titled “GeSI SMARTer 2020” extended this claim by estimating the greenhouse gas abatement potential of ICT to be “seven times the size of the ICT sector’s direct emissions” (GeSI, 2012, 19).

We will take these studies as examples to discuss methodological challenges. Their focus on GHG emissions will not limit the scope of the discussion, as the arguments can be generalized to other aspects of environmental sustainability. Neither should our remarks be understood as specific criticism of the GeSI studies; all studies in this field face essentially the same challenges (see Erdmann and Hilty, 2010; for a review of studies on ICT impacts on GHG emissions).

As other studies in this field, the GeSI studies basically estimate two types of impacts of ICT:

- The *direct* impact throughout the life cycle of ICT components, for example, the emissions caused by producing them and supplying them with power;
- The *indirect* impact of ICT by providing functions, for example, the emissions avoided by using a smart solution to increase the energy efficiency of some production or consumption process (also called enabling impact).

These two impacts are then compared to find the net impact of ICT, which is the indirect impact (avoided emissions) minus the direct impact (ICT’s own emissions). Proposals for more differentiated conceptual frameworks of ICT effects on sustainability are found in literature (see Hilty and Lohmann, 2013; for a bibliography). For the following discussion, it will be sufficient to note that the direct and indirect impacts are fundamentally different in nature:

- The direct impact is *real* because it occurs when ICT is produced, used and disposed of, and the emissions caused by these activities can be measured (at least in principle, not always in practice);
- The indirect impact is *hypothetical* because is it occurs when an activity is avoided that would otherwise have taken place and caused emissions; the emissions of an avoided activity cannot be measured – only modeled.

For example, to find out how much emissions are saved by videoconferencing equipment provided for virtual meetings, we could determine the direct impact by measuring the emissions of the production of the screens and cameras, the routers and switches etc. needed for the videoconference, and the emissions of providing them with electricity during use. To determine the indirect impact, however, we would have to know what would have happened if the equipment had not been available: Would people have traveled to the meeting by car or by public transport, by ship or by plane? Or would they have used the telephone instead, or had no meeting at all? Depending on the answer, the indirect impact could vary between zero and a multiple of the direct impact.[3]

The fundamental difference results in distinct methodological challenges for determining direct and indirect impacts, which will be discussed in the following.

For the direct impact, the challenges are those known in LCA methodology, in particular:

- Defining the system boundary, for example, whether or not end-user devices should be included in the system under study.[4]
- Collecting life-cycle inventory data and judging its quality. Example: How to deal with data referring to older components in a world of rapid change? How to deal with average values on phenomena with high variance?
- Dealing with allocation issues. Example: How much of the life-cycle-wide emissions of an Internet router are to be allocated to one specific use?

When assessing indirect impact, one is also faced with these challenges (because the avoided activities must be treated with an LCA approach as well), plus some more fundamental ones, which are more difficult to handle:

- Defining the baseline. Example: How much passenger traffic would be caused by people meeting for discussions if there were no further progress in technologies used for virtual meetings?
- Differentiating between potential and actual impact. Example: To what extent will smart meters with the potential to support energy saving in private households actually change consumer behavior?
- Anticipating systemic effects. Example: To what extent will smarter traffic management, if successful in avoiding congestion, attract more commuters to use private transportation, leading to additional emissions and new congestion?

We will briefly discuss the three fundamental challenges in the following subsections.

2.1. *Defining the baseline*

The challenge of defining the baseline is inherent to assessing indirect impacts because the concept of indirect impact is inevitably based on the concept of avoided burden. The baseline is a quantitative description of what is assumed to happen without the technological solution under study and can have various forms, from a simple number to the results of calculating a complex scenario (often called “business-as-usual” or “BAU” scenario) with a quantitative model.

Defining the baseline is critical, in particular if future projections of complex socioeconomic developments are involved. If we assume, for example, that fossil energy will remain cheap and transport will continue to grow, the potential to avoid emissions through videoconferencing, smart logistics and virtual goods will be much higher than in a world of high energy prices. In other words, the avoided burden can always be increased by defining a pessimistic baseline. The baseline may contain implicit assumptions having a large effect on the result, e.g., in a world of carbon-based electricity, a complex energy-

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[2] Dematerialization is defined in this context as replacing physical objects and processes with virtual alternatives, such as using electronic documents instead of printed ones or videoconferencing instead of traveling to meetings.

[3] See Coroama et al. (2012) for a study in which a survey was used to find out what users would have done if no videoconferencing had been available.

[4] See Coroama et al. (2013) for this specific example and Coroama and Hilty (2014) for a review of assessments of Internet energy intensity.