Smart Solutions, Energy Efficiency, and Sustainability – Updating the Research Agenda for Environmental Informatics

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Abstract

"Smart" solutions have considerable transformational power. From the perspective of Environmental Informatics, it is an open question whether a specific smart solution (e.g., a smart home application) is more energy efficient than a conventional solution and under which conditions even a more energy efficient solution is more sustainable. This paper provides ideas and arguments why we should take a broader perspective in research and development, taking into account the life cycle of ICT products, the dynamics of economic systems, and emerging risks for basic rights, and how these challenges can be integrated into the research agenda of Environmental Informatics.

1. Introduction

With this paper and keynote presentation, I would like to share some ideas for a future research agenda of Environmental Informatics. What are the challenges we are facing when we systematically develop and apply Information and Communication Technology (ICT) for environmental protection, sustainable development and risk management?

The 27th EnviroInfo Conference makes us aware of how the world of ICT has changed over the years. While in the beginnings of Environmental Information Processing or Environmental Informatics[3] we were happy to get enough computational power to evaluate some environmental data, we now have abundant processing power in our pockets and embedded in all types of infrastructures as well, making computing ubiquitous and our world "smarter". Huge investments are currently being made to develop "smart buildings", "smart cities" and "smart grids", just to mention the most popular buzz words using "smart" (see, e.g., Blumendorf 2013, Kramers et al. 2013, ETS Smartgrids 2013). Many of these technologies are connected to processes accounting for the largest blocks of our energy consumption, such as space heating and cooling, mobility, or operating electric appliances, and have considerable transformational power because they address infrastrucutres.

What does this development imply for the efforts of the Environmental Informatics community to use the power of ICT to solve environmental problems? Will smarter solutions be less polluting than conventional solutions, or maybe create additional environmental problems? How can smart technologies be systematically assessed with regard to their environmental opportunities and risks? These questions address the first of three issues that should be put on the research agenda of Environmental Informatics: methodologies for the environmental assessment of smart technologies.

The second (and connected) issue is energy efficiency, or more exactly: a too narrow focus on energy efficiency in the current "Green ICT" discussion. Most publications in this field reduce their scope to energy efficiency (or carbon efficiency with regard to energy-related carbon dioxide emissions). However, energy efficiency of ICT hardware has doubled every 1.57 years from 1946 to 2009 according to what is now called Koomey's Law (Koomey et al. 2011). This means that we can get 131'072 times (!) more

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[3] For the first efforts to explicitly structure the field see Avouris and Page (1995), Hilty et al. (1995) or Radermacher et al. (1994).

computing instructions done for 1 kWh than 27 years ago; in other words, since the first EnviroInfo conference was held, energy efficiency of computing has improved by at least five orders of magnitude (10^5) – if energy efficiency alone solved the problem of increasing energy consumption, we would have no "Green ICT" debate today. The issue here is to view technological energy efficiency in the context of economic systems and their dynamics, which include the growth of demand when some good can be produced more efficiently.

The third issue that should be put on the research agenda of Environmental Informatics is a focus on the impact of software products that are used by millions of people in everyday life. To develop environmental information systems – as we usually do – that are used by few people making conscious decisions relevant to the environment is of course important. However, software products for the mass market, such as operating systems, entertainment and office software may have large indirect effects on the environment by influencing hardware load and bandwidth use, by making functioning hardware obsolete and also by affecting user behavior. Is there a chance to define sustainability criteria for software products, as this can be done for wood or coffee?

The following sections will provide details on the three issues mentioned.

2. Smart solutions – sustainable solutions?

Let us define a *smart solution* to a problem as a solution that integrates computer support in a way that gives software more control over real-world technical processes, human decisions or human communication, than this has been the case for conventional solutions.

Many smart solutions are today designed with the intention to contribute to sustainability. Such claims include, for example, saving energy and reducing greenhouse gas emissions by more intelligent process control, finding the most sustainable alternative in a decision situation, or optimizing a process with regard to sustainability criteria. However, it is usually difficult to determine whether the potential net benefit of the smart or solution will materialize under real-world conditions (OECD 2010).

The following types of research are needed to meet this challenge (examples provided in the presentation):

- Models, methods and case studies for the sustainability assessment of smart solutions in their specific intended application context.
- Assessments of the effort necessary to implement a smart solution, in particular in terms of energy and material resources for the ICT equipment used over the whole life cycle.
- Technology assessment (TA) studies to detect potential areas of conflicting goals, in particular between smart infrastructures and privacy. There is a general trend from monitoring production processes and the environment to monitoring consumption and human behavior – without privacy-preserving solutions for future environmental technologies, this may become a serious obstacle for progress.

3. Energy efficiency and rebound effects

Whenever a unit of output can be produced with less units of input than before – which means to improve the efficiency of the production process –, this can lead to an increased demand for the output. This is known as the direct rebound effect, which can be explained by the fact that the price of a unit of output will usually decrease as a consequence of the efficiency increase. If the price is lower, increasing demand will lead to increased supply, thereby countering the potential savings of the input factor. If energy cost is a relevant part of total production cost, this is also true of energy efficiency.

"Price" in this context covers more than the monetary price. Many services require some time to be spent by the customer or other non-monetary contributions as well, so that the total price of a unit of service in fact amounts to more than the money paid per unit. For example, if passenger transport is made faster (i.e., the production of the service "transportation" is made more efficient with regard to time), it is likely that people will use the service more frequently or make longer trips because it became "cheaper" in terms of time, even if the amount of money to be paid per kilometer remains the same.

If it is not the demand for the same product that increases but the demand for other products because there is more of the budget left due to the efficiency increase (budget again in terms of money or time), this is called an indirect rebound effect.

The rebound effect materializes in a variety forms in the IT field, where energy efficiency is usually only a side effect of time efficiency. We all know from everyday life that faster data transfer makes us download larger files. Programmers develop less efficient software as computation and memory gets cheaper and smaller. Bureaucracy increases in large organization as the management can analyze more data in shorter time. Another example is the increasing number of power-guzzling vending machines (e.g., for cooled soft drinks) that became profitable just because of their smarter energy management.[4]

The well-known history of rebound-effects requires smart solutions to be analyzed and designed in the context of economic mechanisms, if the stimulation of additional energy or material resource consumption is to be avoided. The following types of research are needed to meet this challenge (examples provided in the presentation):

- Prototypes and applications of systems supporting not just efficiency, but measures that combine sufficiency and efficiency, such as cap-and-trade mechanisms (which can also be used as an intra-organizational coordination mechanism to manage any limited resource);
- Studies on and development of applications that support sustainable consumption (e.g., community platforms for intrinsically motivated collective action);
- Studies on macro-economic effects of ICT that address systemic effects of increasing efficiency (for a review of existing studies see Erdmann/Hilty 2010).

4. Sustainable software

Software is completely immaterial, but has growing influence on material processes in a "smarter" world. Software developers should therefore become aware of their responsibility for the consequences of the use of their software products. Responsibility in Software Engineering suffers from the problem of many hands, a concern that when responsibility for an artifact is broadly shared among many people, it may happen that no individual considers his or her own responsibility significant.

The *Ad hoc Committee for Responsible Computing*, a group of 50 computer scientists, has defined the following rule to address the problem of many hands: "The shared responsibility of computing artifacts is not a zero-sum game. The responsibility of an individual is not reduced simply because more people become involved in designing, developing, deploying or using the artifact. Instead, a person's responsibility includes being answerable for the behaviors of the artifact and for the artifact's effects after deployment, to the degree to which these effects are reasonably foreseeable by that person." (Ad hoc Committee for Responsible Computing, 2012, 1)

This principle can be applied to sustainability as well, but how can sustainability be interpreted in Software Engineering? Many conceptual frameworks linking ICT with sustainability have been developed over the last two decades.[5]

Naumann (2008) defines two aspects of sustainability in Software Engineering, the first one being "system-bounded sustainability", covering quality aspects of the software itself, and the second one being

[4] A general introduction to rebound effects in the ICT domain is given in Hilty et al. (2006). For the smart vending machine example see Hilty (2012).

[5] For an overview see Hilty and Lohmann (2013).

"overall sustainablity" or "system-unbounded sustainability", covering the interaction between the software and "ecological, economical, and social systems" (Naumann, 2008, 386).

Malakuti, Lohmann and colleagues (2013) introduce a distinction between "Greening in software" and "Greening by software", where the former "aims to reduce the environmental effect caused by the development, application and retirement of software" and the latter "aims at saving resources by the help of software such as substitution of processes by more efficient processes or by dematerialization." (Malakuti et al., 2013, 1149)

The participants of ICT4S 2013, the First International Conference on ICT for Sustainability, held at ETH Zurich in February 2013, endorsed at set of recommendations, which include to "use the power of software to reduce hardware energy consumption" by automating "energy-efficient behaviour of software systems" (ICT4S 2013, 284).

However, there is an emerging risk in automated demand shaping, which is the violation of the users' basic rights by the possibility of monitoring their behavior (Hilty et al. 2013). We should develop design principles that eliminate this potential conflict of goals in sustainability. Generally speaking, any ICT infrastructure installed must support and not threaten democratic basic rights in the long term.

Research in the field of Sustainable Software Engineering should therefore address the following issues (examples provided in the presentation):

- Solving the problem of defining functional units in the sense of Life Cycle Assessment (LCA) methodology for the services delivered by software products;
- Solving problems of measuring the energy consumption caused by running software, including client/server, Web-based and cloud applications; standardization of measurement procedures, usage patterns, allocation rules and other methodological issues to make measurements comparable;
- Methodologies for the assessment of the hardware-obsolescence effect of software products, e.g. indicators of "software bloat";
- Reflections on the ways of defining and establishing sustainability criteria as non-functional requirements in the software development process, including issues of privacy and the preservation of basic rights.

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