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The relevance of information and communication technologies for environmental sustainability — A prospective simulation study

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Abstract

Information and Communication Technologies (ICT) have relevant positive and negative impacts on environmental sustainability on various levels: First-order effects such as increasing electronic waste streams; second-order effects such as improved energy-efficiency of production; third-order effects such as a product-to-service shift in consumption or rebound effects in transport. In the simulation study described in this article, all known relevant effects on all three levels were modeled using a System Dynamics approach in combination with scenario techniques and expert consultations. The prospective study for the European Union with a time-horizon until 2020 revealed great potential for ICT-supported energy management and for a structural change towards a less material-intensive economy, but strong rebound effects in the transport sector whenever ICT applications lead to time or cost savings for transport.

Keywords: Information technology; Communication technology; Environmental impact; Sustainable development; Information society; Socio-economic modelling and simulation; System dynamics; Structural change; Material intensity; Rebound effect; Prospective technology assessment

1. Introduction

Information and Communication Technologies (ICT) have a great potential to support sustainable development. However, most of the ICT-related trends, such as the trend towards pervasive computing or policies for 'the information society', are not exploiting this potential (Som et al., 2004; Hilty et al., 2006). On the contrary, there is some risk that ICT will become counterproductive with regard to environmental sustainability (Hilty et al., 2004a; Köhler and Erdmann, 2004; Wäger et al., 2005; Widmer et al., 2005; Kräuchi et al., 2005). Systematic approaches to develop ICT and its application in view of the goal of sustainable development are therefore essential.

Political decisions made with regard to ICT or sustainable development (hopefully taking into account the interactions between the two fields) must be based on a prospective analysis of the positive and negative environmental effects of ICT. Such an analysis would be almost useless if it ignored the dynamics both of the development of ICT and of its impacts on the socio-economic system and its interactions with the environment.

For a prospective study in this field, it is therefore more important to analyse the causal structure of the system than to rely on time series from the past. Retrospective data, although quantitatively exact, may lead to incorrect results if simply extrapolated into the future without considering the causal relationships accounting for the dynamics of the system. Constructing a causal model creates at least the opportunity of being 'roughly right' in a medium to long-term perspective — as opposed to being 'precisely wrong' when no causal structure is in place.

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In a project commissioned by the Institute for Prospective Technological Studies (IPTS) of the European Commission, the authors developed a System Dynamics model to assess the impact of ICT on environmental sustainability in the European Union within a time horizon until 2020. It was clear from the beginning that it would not be realistic to try to *forecast* the development (i.e. to describe one most plausible development path). Instead, we explored possible, internally consistent development paths (scenarios) and showed how the development can be influenced. The final goal of the project was to formulate policy recommendations based on new insights about the relative relevance of ICT application fields for environmental sustainability.

Environmental sustainability was defined by the contractor with reference to the following set of environmental indicators, which had been developed in response to the conclusions of the European Council in Gothenburg and reported to the Spring European Council in March 2002 (see also Ruddy, 2005):

- greenhouse gas emissions,
- energy intensity of the economy,
- volume of transport to gross domestic product,
- modal split of transport,
- urban air quality,
- municipal solid waste landfilled or incinerated.

Some simplifications of this set of indicators were admitted during the project. 'Modal split of transport' was only taken into account for passenger transport, but not for freight transport. The former was done using a time-use approach in combination with known elasticities of demand, treating virtual forms of mobility (telecommuting, teleconferencing, etc.) as additional modes of transport. 'Urban air quality' was excluded because this was the only indicator which would have required relating mass flows to geographic space, a task which was unrealistic under the given budget constraints.

The basic idea of the model was to build a conceptual bridge from the use of ICT in a set of economic sectors to the environmental indicators listed above, accounting for the following three types of ICT impacts or effects (EITO, 2002; Köhler and Erdmann, 2004):

- 'First-order' or 'primary' effects: effects of the physical existence of ICT (environmental impacts of the production, use, recycling and disposal of ICT hardware).
- 'Second order' or 'secondary' effects: indirect environmental effects of ICT due to its power to change processes (such as production or transport processes), resulting in a modification (decrease or increase) of their environmental impacts.
- 'Third order' or 'tertiary' effects: environmental effects of the medium- or long-term adaptation of behaviour (e.g. consumption patterns) or economic structures due to the stable availability of ICT and the services it provides.

ICT use in each sector considered can, in principle, have first-, second- and third-order impacts.

Both ICT use in the sectors considered and ICT impacts are influenced by a number of external factors, such as gross domestic product, population, number of households, labor force, total number of desk workers, etc. The results of the model are therefore only valid with respect to the assumptions made about the development of these external factors. Internally consistent sets of such assumptions, called scenarios, were used as a framework to construct and run the model.

This article gives a condensed description of both the methodology used in the project and the main results that were derived. However, due to space restrictions, our description has to remain quite abstract, with a few exceptions where examples can be provided. The reader who is interested in a more comprehensive view is referred to the five original interim reports (Erdmann and Würtenberger, 2003; Erdmann and Behrendt, 2003; Goodman and Alakeson, 2003; Hilty et al., 2004b; Arnfalk, 2004) and the synthesis report (Erdmann et al., 2004) which are all accessible online. Since these reports add up to a total of 560 pages, the article at hand may also serve as a guide to the original material.

2. Methodology

The principle challenge of the project was to produce quantitative estimates of how environmental indicators might be influenced by ICT development and application in 2020 and to formulate policy recommendations on that basis. The time horizon involved a great degree of uncertainty, not just with regard to the type of ICT in use and the scale of penetration of ICT into everyday life in Europe, but also with regard to a wide range of other factors not directly related to the production and use of the technology.

Much of the uncertainty was addressed through the use of qualitative estimation and validation from experts. Specifically, the development of scenarios is a qualitative means of accommodating uncertainty, and in this case formed the basis for the construction of the simulation model.

The methodology applied can be described by the following steps, which were in practice not executed in strict sequential order because of various interdependencies:

1. Screening for relevance: Identify economic sectors in which ICT applications have relevant environmental effects and list the types of applications.
2. Data collection: Collect existing data about environmental effects of ICT in the selected sectors and for the identified application types systematically.
3. Scenario building and validation: Create the scenarios which the model should be able to simulate and test the plausibility of the scenarios with experts.
4. Model building: Identify the main parts and variables of the system and their basic causal relationships, design the structure of the conceptual model, refine the conceptual model, implement and test the model.
5. Model validation: Compare the output the model generates for each scenario with expert judgments and test the