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CO_2 Reduction with ICT: Prospects and Barriers

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Abstract

The challenge of climate change calls for a systematic effort to utilize ICT for CO_2 reduction. This paper shows that the effects of ICT applications on CO_2 emissions are manifold and demonstrates a systematic approach to deal with this variety. The approach combines a standard life-cycle approach with a classification of ICT effects in first- to third-order effects. It is applied to the fields of ICT application that are discussed in literature as candidate fields for ICT-related CO_2 reduction. High reduction potentials are identified in the following fields: data centers, mobile phone networks, electronic waste recycling, intelligent space heating, virtual meetings, and the organization of services where consumption is traditionally linked with product ownership. Finally, current barriers preventing the exploitation of these potentials are discussed.

1. Introduction

The application of Information and Communication Technology (ICT) to problems of environmental research and management – Environmental Informatics – has made considerable progress and contributes to sustainable development (Hilty et al., 2005, 2006a).

However, the challenge of climate change suggests a more comprehensive approach to utilize ICT for CO_2 reduction. Such an approach should consider all relevant direct and indirect effects of ICT use, leading to insights how positive effects (in terms of CO_2 reduction) of ICT application can be boosted and negative effects can be avoided as far as possible. This paper gives a prospect of ICT-related CO_2 reduction potentials and discusses some barriers that are to be overcome in order to realize the potentials.

2. Classification of ICT effects on CO_2 emissions

Many approaches to reduce CO_2 emissions by ICT focus on specific effects of ICT, such as potential optimization effects of ICT in the transport sector or the power consumption of ICT infrastructure. In order to obtain a comprehensive picture, we will introduce a general model of of ICT effects on CO_2 emissions. It is based on a life-cycle perspective, i.e. the whole life cycle of the involved products is taken into account (production, use, end-of-life treatment).

Figure 1 shows the basic scheme of a product life cycle. In the production phase, raw materials are transformed into the product. In the use phase, the product delivers the service it has been intended for. After its service life ends, parts of the product may be reused or recycled to recover materials. The rest leaves the system for final disposal or to be recycled in other product systems.

The design phase is included because of its impact on the material and energy efficiency of the whole life cycle. In the normal case, all phases of the life cycle consume resources (raw materials and energy) and produce residues in gaseous, liquid or solid state. Mass and energy are conserved, i.e. balanced beween input and output in the long run.

Figure 2 shows the specific case of ICT products, which does, for obvious reasons, not differ essentially from the general scheme. ICT products can be treated with LCA methodology like any other product –such as this book, a plastic bag or a business flight. It was difficult to perform LCAs for ICT prod-

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ucts for a long time because of lacking Life Cycle Inventory (LCI) data for electronics. This data gap is now being closed by the introductin of version 2.0 of the Swiss national LCI database "ecoinvent" (Frischknecht et al., 2005), released in fall 2007 (Ecoinvent, 2007).

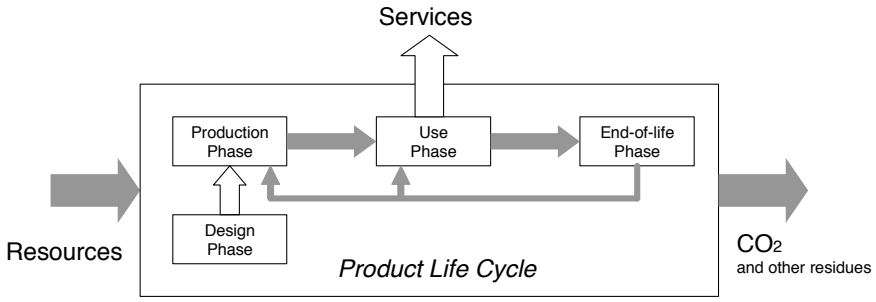


Figure 1: The generic life cycle of a material product that is produced, used and subject to some end-of-life treatment to provide a service during its use phase. The whole system consumes resources (raw materials and energy) and generates residues in gaseous, liquid or solid state

The analysis of the life cycle of an ICT product will only reveal what is called the *first-order effects* of ICT according to a widely accepted scheme (EITO, 2002; Köhler/Erdmann, 2004). The focus on first-order effects is suitable if the goal of a project is, for example, to choose betweeen different server hardware products for a data center: Which product will have the smallest overall CO_2 emission during its whole life cycle? What is the optimum point in time to replace a server by a new and more energy-efficient one? Such questions are classical problems for LCA. Many external parameters have to be accounted for, the primary one being the so-called electricity mix. If electricity is produced with a higher share of fossil power plants, the overall CO_2 emission attributed to the server is also higher, resulting in higher savings when it is to be replaced by a more energy-efficient device. Such considerations are treated by standard LCA methodology.

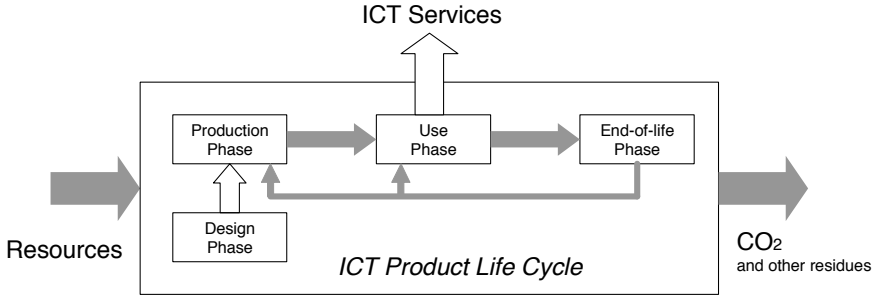


Figure 2: The life cycle of ICT products. ICT products such as PCs, servers, Internet routers, mobile phones, base transceiver stations, etc. can be assessed with standard LCA methodology

However, this classical approach does not accont for the role of ICT as an *enabling technology*. ICT applications can change the efficiency of processes in almost any sector. Such ICT consequences are also called *second-order effects* of ICT. By combining the specific with the general scheme we get the overall model shown in Figure 3. In this model, the ICT services provided by the ICT life cycle have effects on

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the life cycle of another product, which can e.g. be a dishwasher, a building, a transportation system or any other product that can be plausibly assumed to be influenced by ICT services in any of its life cycle phases. The ICT effects on this life cycle can be divided into *optimization* and *substitution* effects:

- Optimization (dotted arrows in Figure 3):
  - Optimizing product design with potential effects on all other phases (reduced resource consumption for production or use, longer service life, improved reusability or recyclability);
  - Optimizing the production process: improved process control and supply chain management with the potential to decrease resource consumption;
  - Optimizing the use: improved energy management, enabling shared use of products;
  - Optimizing end-of-life treatment: higher efficiency of recycling processes.
- Substitution (solid white arrow in Figure 3):
  - Replacing the services provided by the traditional product with ICT services. Example: Substituting an electronic message for a traditional letter or substituting a virtual meeting for a physical meeting.

It is obvious that optimization and substitution can change the resource consumption and CO_2 output per service unit.

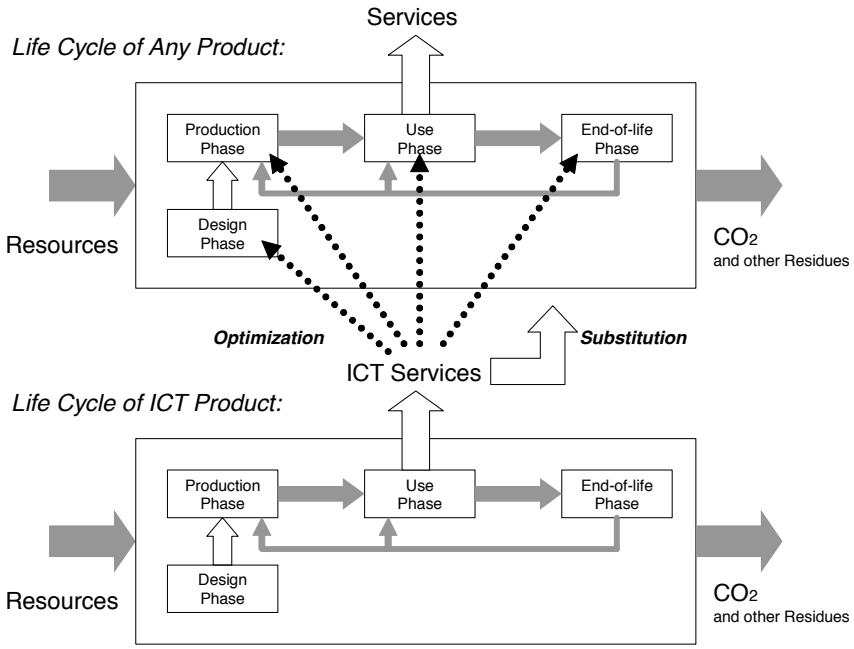


Figure 3: The potential effects of ICT on the life cycle of other products (second-order effects of ICT)

Even if we would fully understand how ICT and its applications develop and which first- and second-order effects this will have on the CO_2 emitted, we would still not have enough knowledge to decide how to influence this development with a view to CO_2 reduction. This is because any change in the resource consumption of the product life cycles involved may make a unit of service cheaper, faster or more convenient to consume, and this may in turn affect the demand for the service. In the long run, it may

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change economic structures and consumer behaviours. Such systemic reactions are called *third order effects*. If the reaction is against the intention behind the technological change, it is called a *rebound effect*. Example: If an ICT-induced increase in energy efficiency of a service makes the service cheaper, the demand can increase, leading to a situation in which roughly the same amount of energy is consumed as before, if not more.

For a broader discussion of ICT-related rebound effects see Hilty et al. (2006b). However, it is important to note that third-order effects of ICT are not undesirable by definition, i.e. not all third-order effects are rebound effects. For example, a structural change from a resource-intensive to an information-intensive economy is a necessary condition for sustainability (Hilty, 2007).

3. ICT-related CO_2 reduction potentials

The typology of ICT effects introduced above can be used as a framework to systematically ask questions and find partial answers concerning ICT-related CO_2 reduction potentials. Table 1 shows a simplified synthesis of the results of own research and literature surveys addressing these issues. Some of the fields (such as telework) have been discussed for decades as candidates for a substantial contribution of ICT to sustainable development, in particular the reduction of fossil energy use and the connected reduction of CO_2 emissions.

The table simplifies the situation in two respects. First, it makes a binary distinction between "high" and "low" potential where a continuous scale might be more adequate. However, the quantaties given in the literature are not comparable because of different time horizons and other incompatible assumptions.

Table 1:
Fields of ICT-related CO_2 reduction potential assigned to the dominating type of effect

Type of Effect		**High CO_2 reduction potential**	**Low CO_2 reduction potential**
1st order (ICT as part of the problem)	Use phase	Data centers	
	Use phase	Mobile phone networks	
	End-of-life phase	Electronic Waste	
2nd order (ICT as an enabler of solutions)	Optimization	Space heating	
	Substitution	Travel to meetings, conferences	
			Electronic media
3rd order (systemic effects)	Structural change	Services vs. ownership	
	Rebound		Intelligent transport
			ICT miniaturization

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Second, the table treats the three types of effects in a linear sequence, whereas they are conceptually nested: Each second-order effect involves a first-order effect that has to be set off, and each third-order effect includes first- and second-order effects viewed from a macro perspective. For simplicity, every field is assigned to the type of effect that is dominating the CO_2 effects of measures in this field. We will briefly explain the fields mentioned in Table 1:

- Data Centers: The power consumption of data centers has doubled since 2002 and reached the order of magnitude of some kW/m^2, a fact that has triggered many initiatives to improve the energy efficiency of servers, cooling systems, power supplies, etc. (Mitchell, 2007)
- Mobile phone networks: According to LCA studies by Scharnhorst (2006), the power consumption of cellular networks dominates the life cycle of mobile comunication. The consumption of the Base Transceiver Stations (BTS) contributes roughly 60% to the total first-order climate change effect of mobile communication, making the energy efficiency of BTS and related equipment an important candidate for improvement.
- Electronic waste: Hischier et al. (2005) have shown that the recovery of raw materials from electronic waste clearly pays off in terms of climate change potential. In particular, the avoided burden of the primary production of metals surmounts the burden caused by the recycling activities. Since electronic waste streams containing scarce metals are increasing world-wide (Widmer et al., 2005), improving the the recyling processes can make a relevant contribution to CO_2 reduction.
- Space heating: A simulation study commissioned by the Institute for Prospective Technological Studies (IPTS) found that ICT has a high potential impact on the rational use of heating energy. Heating accounts for roughly 30% of total energy consumption in the EU, and conservation measures using physical materials tend only to be applied to the small annual share of buildings that is renovated or newly built. 'Soft measures' using ICT (such as intelligent metering and control) have the advantage of being applicable in all buildings, creating a significant potential (Erdmann et al., 2004; Hilty et al, 2006c).
- Travel to meetings and conferences: An Internet-based virtual conference can avoid 97-98% of the CO_2 emissions of an (international) physical meeting, even under pessimistic assumptions about the energy consumption of the Internet (Hischier/Hilty, 2002). ETNO and WWF estimate that ICT could reduce CO_2 emission in the EU by 50 Megatonnes until 2010, the largest part of which by substituting video- and audioconferences for business travel (ETNO/WWF, 2006).
- Services vs. ownership: The final goal of consumption is in most cases the use of a service, not the ownership of a material product (e.g. people want to wear clean clothes, not to own washing machines). Providing services always involves the use of material products, but the allocation of ownership (consumer, service provider or third party) has consequences for the life cycle of the products. There is no general solution to this issue, because the incentive structure of the resulting system depends on many factors that must be analyzed in particular cases. However, since ICT has the general potential to reduce transaction cost, ICT supports a structural change towards a highly resource-efficient economy (Hilty et al, 2006c; Hilty, 2007).

Table 1 also lists some fields in which – despite some hypes and hopes – ICT has only a low CO_2 reduction potential. The reasons are given below:

- Electronic media: Even if electronic media would fully replace print media, the effect in terms of CO_2 emissions and other environmental indicators would not be clearly positive. This is because the life-cycle-wide energy consumption per service unit of electronic media (such as a TV or a PC connected to the Internet) is roughly in the same order of magnitude as that of print media (such as a newspaper or book). Only under very restrictive assumptions (concerning the electricity mix and

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user behaviour) there is a clear advantage of the electronic media (Hischier/Reichart, 2003). The media substitution case is therefore very different from the travel substitution case, a fact that is not always embraced in literature.

- Intelligent transport: Empirical evidence from the history of transport shows that all technologies that make passenger transport more time efficient create a rebound effect leading to more traffic and related energy consumption. The same ist true for the optimization of freight transport, if the efficiency gains lead to lower prices. For this reason, transport optimization is not a field where ICT should be expected to contribute to CO_2 reduction.
- ICT miniaturization: The time, space, material and energy needed to provide a unit of ICT service have roughly decreased by a factor of 1000 since the first PC was sold. Paradoxically, it is the progress in ICT hardware efficiency that has made ICT a part of the problem, too. The global mass and energy flows caused throughout the hardware life cycle are increasing due to the wide-spread use of ICT products and their ever decreasing useful lives. Because of this rebound effect, we have no reason to expect that the continued miniaturization of electronics will contribute to CO_2 reduction. It could even create new problems for recycling (Wäger et al., 2005; Kräuchi et al., 2005; Hilty et al., 2006b).

Table 1 gives a basic impression of how ICT applications or ICT research support instruments can be assessed from a life-cycle perspective while taking all three levels of effects (from first to third order) into account. This type broad of assessment could be a part of integrated impact assessment (Ruddy/Hilty, 2007). The following section discusses some barriers that prevent from the realization of the existing large CO_2 reduction potentials.

4. Barriers

Table 2 shows some of the barriers we would have to overcome in order to unleash the ICT-related CO_2 reduction potential. The Table shows that is that there is a great variety of problems that have to be solved in order to make progress in reducing CO_2 with ICT. A detailed discussion of the particular barriers would go beyond the scope of this paper.

Table 2:
Fields of potential CO_2 reduction and some barriers preventing the exploitation of the existing potentials

Field of CO_2 reduction	**Current Barriers**
Data centers	No barriers, awareness is rising
Mobile phone infrastructure	Lack of awareness by most providers
Electronic Waste	Almost no incentives for producers to design for recyclability
Space heating	Misdirecting incentive structure in rented space (if owner would invest, tenant would benefit)
Travel to meetings, conferences	Simplistic technological solutions (e.g. leading to virtual squint in videoconferences), misdirecting incentives (e.g. frequent flyer programs)
Services vs. ownership	Cultural role of ownership (e.g. regarding social status), unsolved privacy issues (e.g. regarding billing data)

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5. Conclusion and outlook

ICT can be an important factor in combating climate change, if the effects of ICT applications are systematically assessed from a life-cycle perspective. Moreover, it is necessary to take all three levels of effects (from first to third order) into account to get a realistic picture of CO_2 reduction potentials.

The existence of reduction potentials alone does not imply that they will be exploited. The degree of exploitation depends rather of the incentive structures of the systems in which the ICT applications are socio-economically embedded.

It follows that, besides technological challenges, the change of incentive structures by organizational or policy instruments is the most important challenge that has to be faced if ICT is to serve climate mitigation.

Beyond that, we should be aware that future ICT will not be today's ICT. Precautionary strategies should take the pervasiveness of ICT into account (Som et al., 2004): What new opportunities and risks for the climate will be introduced by pervasive/ubiquitous computing? How can we systematically use ICT developments and their change potential to approach a sustainable information society?

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