Lorenz M. Hilty

Information Technology and Sustainability

Essays on the Relationship between ICT and Sustainable Development

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Preface

The idea to do this book came about only a few months ago when I noticed new public interest in the relationship between IT or ICT\(^1\) and sustainability. A lot of conferences are concerned with the energy consumed by ICT, and buzzwords like ‘Green IT’ and ‘Green Computing’ are proliferating. ICT is increasingly being put into relation with issues of energy, climate change and sustainability by the media and by decision makers in business and politics.

At long last ICT and sustainable development are being seen together, whereas until recently they had been considered separate domains.

Environmental and social aspects of ICT have been the topic of many projects of my research group at Empa since the year 2000. These activities have produced many reports, articles and lecture manuscripts about ICT and environment or – more generally – ICT and sustainability that until now have only been available as ‘grey literature’ or not in English. In order to make those reports available in a consistent and citable form I have decided to compile them into this book. All texts have been edited and refer to each

\(^{1}\) Information and Communication Technologies. It is not relevant for the purposes of this book to make a semantic differentiation between Information Technology (IT) and ICT.
other along topical lines. Nonetheless I cannot guarantee complete coherence in either terminology or content because the texts reflect a learning process. While editing the pre-existing papers, I have often added original material based on more recent lectures. This applies in particular to Chapters 5, 6, 7 and 8, which are largely new. All chapters can be read selectively according to topics of interest.

The basic ideas compiled in this book developed during the research programme “Sustainability in the Information Society”, which I led from 2000-2005 at Empa and which was funded by the ETH Council. Other important projects in this context have been commissioned by the Swiss Center for Technology Assessment (TA-Swiss) and by the Institute for Prospective Technological Studies (IPTS) of the European Commission.

Another source that has been very important for my work was the scientific community of Environmental Informatics, organized in the expert committee “Informatics for Environmental Protection” of the German Informatics Society (GI), and the Working Group 9.9 “ICT and Sustainable Development” of the International Federation for Information Processing (IFIP) I founded in 2005. I would like to thank all colleagues who have worked tirelessly to liberate the two topical areas ICT and sustainability from their respective disciplinary boundaries and to relate them to each other.

Does it still make sense to print books on paper today? Wouldn’t it be more sustainable to disseminate information
only over the Internet instead of sending printed paper around? There is a scientific method that can answer this question, at least as far as the ecological aspects are concerned: Life Cycle Assessment (LCA). One of the Empa’s LCA studies on various electronic and print media showed that there is not any clear ecological winner. Electronic media may impact the environment less or more than print media: it depends on how you use them. If you use your computer a few years longer, for instance, things look better because a smaller fraction of the material and energy needed to produce it is used to provide one unit of service; if you leave your computer on all the time things looks less favorable. Furthermore the result depends on the electricity supply mix used (namely the share of renewable energy used for generating electric power).

There is however one clear ecological loser when comparing media: to get information electronically and then print it out on your own printer. That is due to the fact that printing with a PC printer produces about 5 times more environmental impact per information unit than professional printing. That mainly has to do with paper formats and paper qualities.²

Therefore you can use this rule of thumb: If you intend to read at least 20 percent of this (or any other) book from paper, then it is worth ordering a printed copy.

This book is printed on demand. That means that a copy is not printed until an order for it comes in. That helps avoid remainders, which is a substantial advantage because remainder rates of 35 percent are common in the book business.

I would like to thank all my colleagues from Empa’s Technology and Society Lab who have supported me in compiling this book; first and foremost Thomas Ruddy who was involved as a co-author in some of the original papers underlying the first chapters of this book, and who corrected my English throughout the whole book. To Claudia Som I owe much of the insights on the Precautionary Principle, which is discussed in Chapter 5, and Roland Hischier contributed to an earlier version of Chapter 6. Last, but not least, I thank my former staff members Fabian von Schéele and Andreas Köhler who accomplished the psychological experiment reported in Section 4.8.

Lorenz M. Hilty

St. Gallen, May 2008
CHAPTER 1
Sustainability in the Information Society – an Introduction

Information and communication technologies (ICTs) are continuously making astounding progress in technical efficiency. The time, space, material and energy needed to provide a unit of ICT service have decreased by three orders of magnitude (a factor of 1000) since the first PC was sold.

The well-known principle called Moore’s Law, according to which the number of transistors per microchip doubles every 18-24 months, has yet to be disproved (see Figure 1-1). As a side effect, processor performance per energy input grows exponentially too (Figure 1-2).

However, it seems to be difficult for society to translate this efficiency progress into progress in terms of sustainable development.

Basically, the idea of an information society has a huge potential to solve the dilemma of sustainable development, which is: Providing quality of life to all people without overusing the ecosystem. This dilemma can only be solved

\[ \text{\textsuperscript{1}} \text{ This chapter is an expanded version of an invited lecture given by the author at the “International Symposium for the Establishment of the EcoTopia Science Institute”, University of Nagoya, Japan, June 13, 2006} \]
if society manages to create value with much less material and energy input. As has been discussed for decades now, a ‘dematerialization’ of the economic system by a factor of 4-10 is a precondition for sustainability. Creating an information society which makes use of ICTs to provide immaterial services where previously material goods were produced, transported and disposed of, could be a key to economic dematerialization.

The European Commission recently defined the role of ICTs in a similar way, although focusing slightly more on energy, by stating that “… the continued growth of the European economy […] needs to be decoupled from energy consumption […] Indeed, if nothing were to change, final energy consumption in the EU is predicted to increase up to 25% by 2012, with a substantial rise in greenhouse gas emissions. Information and Communication Technologies (ICTs) have an important role to play in reducing the energy intensity and increasing the energy efficiency of the economy“ (European Commission, 2008, p. 2).

The Global Information Infrastructure Commission (GIIC) recently stated in their Tokyo Declaration: “ICT has historically been viewed as a tool to advance productivity. We found and confirmed that the use of ICT can change the behavior of business and consumers, and through these changes, ICT can help the environment without sacrificing economic output“ (GIIC, 2008, p. 2).
Figure 1-1: Following Moore’s Law, ICT hardware demonstrates the type of technical progress called dematerialization (Source: Intel and Mattern, 2005, p. 41)

Figure 1-2: Development of the energy efficiency of microprocessors in Million Instructions Per Second (MIPS) per Watt (Source: Mattern, 2005, p. 42)
1.1 A Basic Classification of the Environmental Effects of ICT

However, in the ways ICTs are used under today’s economic conditions, they do not always contribute to dematerialization and may even have negative environmental impacts. In general, there are three levels of ICT effects on the environment that must be taken into account:

- ‘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, transport or consumption processes), resulting in a decrease or increase of the environmental impacts of these processes.
- ‘Third-order’ or ‘tertiary’ effects: environmental effects of the medium- or long-term adaptation of behavior (e.g. consumption patterns) and economic structures to the availability of ICT and the services it provides.

1.2 The Challenge of Dynamics

Research on the impacts of ICT faces the problem that both the technology and the way it is shaped and used by society are changing fast. It is therefore important to identify the basic principles and mechanisms that drive this process and to look for constant factors. On an experimental basis, my
research group tried in 2004 to systematically analyse the mesh of indicators for (at least) environmental sustainability. As part of an international project consortium\(^2\) we had undertaken to build a simulation model that would calculate the impact of ICT on some indicators of environmental sustainability up to the Year 2020 for EU-15. That is of course an almost impossible undertaking, because the development of environmental indicators depends on many other factors besides ICT applications, such as economic growth and the prices of fossil fuels. We tried to solve this problem by developing a number of scenarios with experts to represent the possible development paths of these external factors. We then simulated these scenarios with a system dynamics model and then only had the problem of isolating the influence of ICT from the other factors.

For this we ran each scenario in two different versions. Variation A was based on a continuing expansion of ICT applications (such as process optimization in industry, traffic management, heating controls, virtual meetings, etc.). Variation B froze the application of ICT at the level of the Year 2000 in each case. (In each case the period from 2000 to 2020 was simulated). Then we were able to isolate

\(^2\) Forum for the Future, London; Institute for Futures Studies and Technology Assessment (IZT), Berlin; International Institute for Industrial Environmental Economics (IIEEE), University of Lund; Swiss Federal Laboratories for Materials Testing and Research (Empa), St.Gallen.
the influence of ICT by comparing the two variations in all possible scenarios which result from the complex interaction of the many mutual influences among the model variables (Arnfalk et al., 2004; Erdmann et al., 2004; Hilty et al., 2004, 2006).

The most important result was: the influence of ICT applications turned out to be very different depending on the framework conditions. Under conditions generally conducive to environmental protection ICT reduced the overall environmental impact by around 20%, whereas under the least favorable conditions ICT was responsible for 30% of the additional environmental impact. Therefore it is the framework conditions that decide whether the ecologically positive or negative sides of ICT will prevail. That should suffice to disprove extreme positions such as “ICT will save the environment by itself” and “ICT can only hurt the environment”.

One other result of the simulation study was interesting: the environmental effects cited above are aggregations of numerous ICT effects in various sectors. If one takes these individually, some of them are more than +30% or -20% for certain environmental indicators. However some of them counterbalanced each other when taken together – in much the same way that the achievements of the best pupils

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3 We intentionally use units that are rounded off to 10% because the results are qualified by a high degree of uncertainty. If we gave more precise figures, it would only pretend there were a precision which does not exist.
and the worst pupils counterbalance each other in the average grade achieved by a school class. We can deduce from this that a well-designed policy that reinforces the ecologically favorable effects of ICT and counteracts the ecologically unfavorable ones could accomplish a lot more than the cited 20% reduction in environmental impact. Therefore what we are lacking is the same type of promotion that is sometimes given in schools for “accelerated learning” to be applied to those applications of ICT which are ecologically advantageous. A recent review of research on the environmental impact of ICT confirms that a model-based approach is needed to allow “that positive effects can be promoted and negative ones alleviated proactively” (Yi and Thomas, 2007, p. 1). In the same line, WWF recently introduced the idea of ICT applications with “high carbon feedback” or “low-carbon feedback” (Pamlin and Pahlman, 2008).

We may expect the above remarks to be true not only for the ecological effects of ICT but also for the role of ICT in all aspects of sustainable development.

It is apparent that the widespread use of ICT is changing our world, a development taking place even faster than political decision makers can react to the changes. The Internet (with e-mail, the Web, VOIP and unlimited future applications), the mobile networks, Radio Frequency Identification (RFID) systems and embedded ICT systems, to which a whopping 98% of all microprocessors belong, have massive economic, social and ecological effects on a global scale. As the simulation study mentioned above has
shown, when taken individually, these effects can be either positive or negative, making necessary a differentiated study. The remaining chapters of this book are intended to provide a contribution in this direction.

References


European Commission: Addressing the challenge of energy efficiency through Information and Communication Technologies. COM (2008) 241 final


CHAPTER 2
Environmental Informatics and the Vision of a Sustainable Information Society

This chapter discusses the relationship between the emerging information society and the goal of sustainability. How can information technology contribute to sustainable development? What are the opportunities and risks of the information society with regard to the goal of sustainability? Two major areas of interaction between Information and Communication Technology (ICT) and sustainability are discussed: environmental information processing (Environmental Informatics) and the impacts of Information Society Technologies.

2.1 Background

The emerging information society and the demand for sustainability are widely discussed issues. But what does the one have to do with the other? Before we give reasons

1 This Chapter is based on the article "Towards a Sustainable Information Society" by L. M. Hilty and T. F. Ruddy, which first appeared in Informatik/Informatique 4/2000, pp. 2-9. Reused and updated by courtesy of Thomas F. Ruddy and the Swiss Informatics Society (SI).
for our conviction that these two issues are in fact closely connected, we want to outline briefly our understanding of each of them. We take the term *information society* to mean the result of the societal change processes driven by the rapid spread of ever-cheaper Information and Communication Technologies (ICT), and taking us gradually forward into a post-industrial society. It is difficult for anyone to predict what exact form the future information society will take. However, one thing is for sure: The result will depend largely on how we ourselves influence this development.

A basic definition of *sustainable development* (or sustainability for short) was given by the World Commission on Environment and Development: In order to be considered sustainable, a pattern of development has to ensure “that it meets the needs of the present without compromising the ability of future generations to meet their own needs” (WCED, 1987). According to this notion of sustainability, the aim of economic development should be both *intragenerational* and *intergenerational* justice.

Since the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, the goal of attaining sustainable development has become the predominant issue in international environmental and development policy. It is widely accepted that sustainability has an environmental, a social and an economic dimension. A number of national and international research programmes and activities have been set up in order to refine the scientific basis for the sustainability concept.
During the 1990s two extreme interpretations of the sustainability concept emerged:

- **Strong sustainability**: The total natural capital must be preserved, i.e. industry, as a user of nature, may live only off the ‘interest’ of the natural capital. The use of non-renewable resources would therefore be ruled out and renewable resources could be used only within the scope of their regeneration rate.\(^2\)

- **Weak sustainability**: The total anthropogenic and natural capital must be preserved.\(^3\) This means that natural capital can be reduced at will if, in return, the stock of human-created capital is increased.

In political discussions it has become apparent time and time again that a viable consensus lies *between* the two extremes and has to be found continually. Sustainability is therefore a future-oriented social process of learning, searching and structuring, characterized by considerable ignorance, uncertainty and a variety of conflicts, a ‘regulative idea’ (Minsch et al., 1998).

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\(^2\) The strong principle of sustainability would rule out a scenario where, through the consumption of finite resources, “an economic upturn is created, associated with such great technical advances that economies can subsequently be made once again with renewable resources” (Meyer-Abich, 2001, p. 297).

\(^3\) “Extensive substitutions of the former for the latter are therefore compatible, e.g. seashores by swimming pools, historic regions by leisure parks, cross-country runs and walks by fitness centres” (Meyer-Abich, 2001, p. 296).
But while the most brilliant researchers are brooding over their second and third research proposals, discovering many small and large changes intended to bring society closer to the objective of sustainability, the world is rapidly changing under the growing influence of ICT. This change process, which is transforming us into an information society, has the potential to substitute information and knowledge for material products to some extent. But besides this so-called dematerialization, the change process also entails a progressive globalization of the economy that has thus far caused increasing transportation of material products and people. Finally, the information society also means acceleration of innovation processes, and thus an ever faster devaluation of the existing by the new, whether hardware or software, technical products or human skills and knowledge.

The rate at which the information society is coming about is determined by Moore’s Law, which says that the performance of ICT doubles every 18-24 months. It has remained remarkably accurate thus far, not only with regard to processor speed, but also memory capacity and data transmission rates in networks.

The result is that people can take advantage of more and more computing power and data transfer without requiring more space, energy or cost, thus giving rise to new services based on this technical infrastructure almost daily, services which are penetrating more and more areas of our lives. In order to make relationship between the goal of attaining sustainability and the transition to an information society evident, we use the categories of applications and societal
impacts of ICT shown in Table 2-1. The main distinction is between Environmental Information Processing (EIP) and Information Society Technologies (IST). The categories will be explained further in the remainder of this chapter.

<table>
<thead>
<tr>
<th>Environmental information processing (EIP)</th>
<th>Public sector: Environmental Information Systems (EIS) operated by public authorities</th>
<th>Public awareness about condition of public goods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private sector: Environmental Management Information Systems (EMIS)</td>
<td>Legal compliance</td>
<td>Prerequisites for political decisions</td>
</tr>
<tr>
<td></td>
<td>Environmental reporting to stakeholders</td>
<td>Executing instruments of environmental policy</td>
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<td></td>
<td>Eco-efficiency and material flow management</td>
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<tr>
<th>Information Society Technologies (IST)</th>
<th>Direct impact on material intensity of economy</th>
<th>Material intensity of ISTs' product life cycles</th>
</tr>
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<tbody>
<tr>
<td>Indirect impact on material intensity of economy</td>
<td>Substitution potential</td>
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<td></td>
<td>Optimization potential</td>
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<td>Induction potential</td>
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</table>

Table 2-1: Categories of interaction between ICT and the environmental dimension of sustainability

2.2 Environmental Information Processing

Computer-based systems for processing environmental information have been in use since the 1970ies. A broad range of applications is covered by these systems, including monitoring and control, information management, data analysis, as well as planning and decision support. The generic name for this type of system is ‘Environmental
Information System (EIS)' (Günther, 1998; Rautenstrauch and Patig 2001; Hilty et al., 2005). Progress in informatics has made an invaluable contribution to our ability to analyse the biological, chemical and physical processes in the environment. Inversely, the complex nature of problems occurring in environmental contexts is a great challenge to informatics. From this process of mutual stimulation, a special discipline has emerged known as Environmental Informatics. It combines computer science topics such as database systems, geographic information systems, modelling and simulation, knowledge based systems and neural networks, with respect to their application to environmental problems (Avouris and Page, 1995; Page and Hilty, 1995; Hilty et al., 2006). The categories of applications described in the following show the type of work being done in environmental informatics. Examples can be found in the proceedings of the three conferences series:

- **EnviroInfo** (since 1986): International Symposium on Informatics for Environmental Protection (e.g. Geiger et al., 1997; Haasis and Ranze 1998; Rautenstrauch and Schenk 1999; Cremers and Greve, 2000; Hilty and Gilgen, 2001; Pillmann and Tochtermann 2002; Gnauck and Heinrich 2003; Susini and Minier, 2004; Hrebicek and Racek, 2005; Tochtermann and Scharl, 2006; Hryniewicz et al., 2007);

- **ISESS** (since 1995): International Symposium on Environmental Software Systems (e.g. Swayne et al., 1997; Schimak et al. 2003);
• iEMSs (since 2000): Summit on Environmental Modelling and Software of the International Environmental Modelling and Software Society (e.g. Voinov et al. 2006).

2.2.1 Applications in the Public Sector

Computer applications for processing information related to the natural environment have been under development in the public sector since the early days of computing. For instance, simulation models were in use in water supply as early as the 1950ies. Today, most developed countries operate sophisticated environmental monitoring systems that regularly provide up-to-date information about the state of the environment. One part of the data is gathered by fully-automated telemetry networks that are used to monitor air quality, water quality and radioactivity. Telemetry means that automated sensor systems are placed in the medium (e.g. air, water) and transmit data to a central control office, usually operated by a municipal, regional or national environmental agency. This field has recently made great progress due to large-scale sensor network technology (Swiss Experiment, 2008). Another part of environmental data is obtained by increasingly powerful remote sensing techniques based on processing aerial or satellite images in combination with geographical information.

EIS in the public sector fulfill at least the following three important functions (see Table 2-1, right column).
Public Awareness

Agencies in many countries are legally compelled to publish data from environmental monitoring. When such data is published, the public becomes more aware of the condition of public goods (such as the atmosphere or recreation areas), which would otherwise not be the case because public goods, having no price by definition, cannot create awareness by means of price signals. Furthermore publishing environmental data has other important effects such as enabling citizens to judge the success or failure of the government’s environmental policy themselves.

Decision Support

Environmental information is an indispensable basis for making political decisions that have effects on the natural environment or inversely are dependent on the condition of the environment. Decision support consists not only of providing information about the status quo, but also about making predictions (e.g. short-range forecasts on ozone-related summer smog) and in considering the effects of various available alternatives (scenarios, what-if questions). Environmental Informatics makes an important contribution to decision support by providing methods and tools for modeling and simulation. One area of decision support in which such systems play a central role is the modeling of climate change and differentiation of its anthropogenic portion.
Executing Environmental Policy

Environmental policy instruments can only be implemented effectively when accurate and up-to-date information is provided continuously. EIS aid in checking for violations of regulations (such as tracing illegal emissions back to their source), help to monitor the success of measures taken, and provide the information needed for immediate action in case of crises and catastrophes. As an example, we can cite once again the area of climate policy. The 1992 UNFCCC treaty was made more binding by the Kyoto Protocol added to it in 1997. This protocol is an example of how treaties become international law in practice, laying out in ever-greater detail how environmental policy is to be executed. The treaty calls for the establishment and maintenance of national databases to serve as inventories of greenhouse gas emissions, primarily carbon dioxide and methane in all countries that are parties signing and ratifying the protocol. These inventories are a necessary basis for tracking annual emission levels.

2.2.2 Applications in the Private Sector

EIS were used almost exclusively in the public sector until the early 1990ies. However, during the 1990ies a market emerged for software systems that support environmental management in companies; these are known as Environmental Management Information Systems (EMIS) (Hilty and Rautenstrauch, 1997). After a time in which the first EMIS were developed to support operative activities in
individual facilities, today the trend is to incorporate environmental information in strategic decision and applications involving more than one facility – effective environmental management increasingly requires thinking in strategic corporate networks (Hilty et al., 2000a). Most EMIS today fulfill the following functions (see Table 2-1, p. 25, right column).

**Legal Compliance**

For one thing, EMIS help to comply with laws and regulations by providing insight into complex legal frameworks, in particular environmental regulations (Riekert and Kadric, 1997). Secondly, the information systems aid top managers in discovering and understanding developments in their own company relevant to environmental regulations. Examples of the second type of application are systems for company-internal emissions monitoring and systems for modeling material flows.

**Environmental and Sustainability Reporting**

Environmental or sustainability reporting EMIS enable a company to fulfill its many reporting requirements to stakeholders (government agencies, banks, insurers, suppliers and customers, employees, neighbors, and the general public) as regards its environmental impact and risks. Software has been developed to support environmental or sustainability reporting within companies. There has been a trend in recent years to make environmental reporting software suitable for use on intranets to share data
among subsidiaries and employees, and to publish a subset of the data to wider circles of interested stakeholders such as suppliers. Such HTML- or XML-based solutions then can automatically sift out the subset of the data public enough for publishing on the Internet (Isenmann, 2005).

Eco-Efficiency

Environmental Management Information Systems help to improve ecological efficiency (or eco-efficiency for short). This term denotes the ratio of a defined output of a product or unit of service (such as a cup of coffee or having clean clothes to wear for one day) to the input of material and energy expended to produce that function. In order to determine at which stage of the value-added chain eco-efficiency can be improved, Life Cycle Assessments (LCAs) are done, which investigate the life of a product or service “from cradle to grave” – starting with extracting natural resources from the environment, running through all production and utilization phases and ending with disposal of the waste – and evaluate its ecological impacts. Product life cycles, companies or production processes can be viewed as material flow systems and optimized for eco-efficiency. Such material flow management can be done on different levels, from the most strategic to the most operative level, and may include, for example:

- building up strategic corporate networks (especially recycling networks),
- using LCAs to rank existing product or process alternatives when making or buying products or parts,
• “Design For the Environment” (DFE) with the goal of reducing the life-cycle-wide material flows and environmental hazards caused by the future product,

• real-time process control for minimizing emissions or increasing energy efficiency. Various software systems are available for the support of LCA and (more generally) material flow management. The most flexible approach is to support the user in modelling and evaluating his material flow systems. An example is the commercial software product Umberto, which is based on material flow networks, a representation formalism derived from Petri nets (Schmidt et al., 1997).

For the purpose of illustration, Figure 2-1 shows how material flow networks can be modeled graphically using the Umberto software. Proceedings of the regular EMIS workshops provide surveys of early EMIS methods and tools, e.g. (Scheer et al. 1996; Bullinger et al. 1998; Hilty et al. 2000a). EMIS can be viewed as the IT infrastructure of Environmental Management systems (EMS).

Sometimes, eco-efficiency is interpreted as an abbreviation for both ecological and economic efficiency. This is the case with the World Business Council for Sustainable Development, which has propagated the concept of eco-efficiency internationally.4

4 http://www.wbcsd.org
2.3 Information Society Technologies

By Information Society Technologies (IST) we mean the technologies that enable and bring about the changes that will serve as a basis for the transition to an information society. IST can be viewed as a subset of ICT having a specific potential for deep societal change.5

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5 The term IST was coined by the European Commission when the programme “Promoting a User-Friendly Information Society” was defined as one of four thematic programmes within the Fifth Framework Programme (FP5). The term was dropped with FP7. From today’s perspective, it seems more adequate to speak of more specific types of ICT with the potential for deep
With regard to sustainability, the most important aspect of IST is how they could help to reduce the material intensity of economic processes (including production, consumption, and disposal, as well as the connecting logistical processes such as transportation and storing). As is common in discussions on this topic, we use the term “material intensity” in a very broad sense. It refers to the transformations of mass or energy that are involved in providing a product or service (or at macro level in creating the GDP). Reducing material intensity while maintaining or even improving a product or service is in fact the same as increasing eco-efficiency (as introduced in Section 2.2).

A significant reduction of material intensity (an increase in eco-efficiency) is also called dematerialization. Dematerialization can be defined as the *achievement of a maintained or improved product or service, whilst also achieving reduced use of material and energy.*

The spread of information society technologies affects the material intensity of an economy directly and indirectly:

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societal change, such as *Ambient Intelligence, Ubiquitous Computing* or *The Internet of Things.* However, when the first version of this article was written in the year 2000, these terms were not yet in common use.

6 Some authors make a sharp distinction between dematerialization and so-called immaterialization; we will return to this issue in section 2-5. The Dematerialization issue as such will be discussed in greater detail in Chapter 3.
• *directly* through the production, use and disposal of the IST hardware itself,

• *indirectly* through substitution, optimization and induction effects.

Both kinds of IST impacts are discussed in the following subsections.

### 2.3.1 Direct Impacts on Material Intensity

Information society technologies themselves change rapidly, in ever-shorter innovation cycles. We may think of the PC as the basic IST technology today, but it may well be replaced by other technologies in a couple of years. In discussions about substituting telecommunications for traffic, or digital media for paper (to mention two examples), it is usually assumed that the “virtual” alternatives are less material-intensive than the conventional ones. However, this assumption has to be investigated seriously from case to case, which means – among other things – that the whole life cycles of the respective hardware products have to be assessed (LCAs of electronic devices).

We first assembled a collection of some of the data in this area in 2000 (Hilty et al., 2000b). Evaluating the sources revealed that TV sets and PCs with CRT monitors have been examined most thus far, whereas in the areas of flat panel displays, networks, mobile phones and satellite communication there are still many questions open. With
regard to the PC, the most significant finding was that most of the material and energy throughput of a PC’s life cycle occurs during production. Less than 2% – one study says 0.1% – of the material used in PC production ever becomes part of the product, the rest being manufacturing waste. The energy expended for producing a PC (5-12 GJ) is about a factor of 10 higher than the energy consumed during the average use phase.⁷ Producing a color TV sets requires 1/4 of the energy for producing a PC. Compared to PC production, networks seem to contribute a relatively small part to the ecological burden attributable to IST. The energy demand for operating one telephone line, e.g., lies roughly on the order of magnitude of 100 kWh per year (0.36 GJ/a).

On the whole, the results of the study showed that the material and energy requirements of the basic technologies for IST are not to be neglected, and have to be remembered as they affect the ecological compatibility of the information society. This becomes all the more relevant when one considers that these technologies are spreading more rapidly all the time. On the other hand, we must take these figures with caution, recalling that they only represent a snapshot, whereas in principle, the development of technology and associated manufacturing processes is not predictable.

⁷ Newer studies found much lower factors for desktop PCs, which can be explained by the fact that the production has become more energy efficient and the typical use phase more energy demanding! See Chapter 6 for recent results.
2.3.2 Indirect Impacts on Material Intensity

According to a widely accepted scheme, the effects of IST on the realm of physical processes can be classified under the following three types. The scheme was originally introduced to classify the impacts of telecommunications on physical traffic and can be explained best using this special case as an example. Note, however, that we are generalizing this scheme to cover all kinds of IST and their respective impacts on all kinds of physical processes.

- **Substitution:** Telecommunications is substituted for physical traffic.
- **Optimization:** Telecommunications helps to optimize traffic systems.
- **Induction:** Telecommunications induces traffic (e.g. by enabling distributed forms of production).

Let us demonstrate how this scheme applies to other domains as well, using paper consumption as an example. The PC as the modern form of typewriter and especially the PC as a medium to access e-mail, the Web and other Internet services has in fact the potential to reduce paper consumption. Plenty of textual and graphical information can be received directly from the screen, which in fact is substituted for paper in many cases. There is also an optimization effect, since for instance many errors can now be corrected before a text or picture is printed for the first time.
However, as the reader may know from everyday experience, the *induction* effect offsets the other effects by far, because today’s PC and printer technology enables the user to print out hundreds of pages with just a few mouse clicks. Therefore, all in all, IST contributes to the same general trend for paper that has been observed for the past 60 years (Ehrenfeld, 1998). Moreover, per-capita paper consumption is now seriously considered an indicator of affluence. Newspapers recently celebrated the fact that an average Swiss person now consumes 240 kg of paper per year, and the trend is getting worse. Is this what we expected from the Information Society?

Still, the domain of traffic is probably the most important field in which the substitution and optimization effects of IST are presently being overcompensated by induction effects. While the substitution effect arising from telecommuting and various forms of tele-services (such as remote maintenance, e-banking, etc.) can reduce physical traffic, the induction effect arising from the globalization of markets and distributed forms of production due to telecommunications networks clearly leads away from the path to sustainability.

Figure 2-2 visualizes the conceptual structure of IST impacts as introduced in Sections 2.2 and 2.3.
2.4 The Rebound Effect

The counter-intuitive trends such as increasing paper consumption and increasing traffic are examples of a phenomenon known as the rebound effect. This concept, which will be discussed in greater detail in Chapter 4, refers to a potential created by efficiency gains that is balanced off or even overcompensated for by quantitative growth (Binswanger, 1999). Originally the rebound effect was discovered in the energy sector. Energy productivity (gross domestic product per total energy consumption) has been growing for a few decades now in highly developed countries by about 1% per annum. This ‘savings’, though, is
overcompensated by growth in the gross domestic product (GDP), so that in absolute figures more energy is consumed every year.

The situation will be hardly different in the information society: Every substitution or optimization effect achieved by IST creates new degrees of freedom which tend to be used for quantitative growth. Very often, it is the old technologies that continue to grow, while the new ones are used additionally, helping to extend the limits which the old technologies would have eventually hit. As F.-J. Radermacher puts it: “The ‘trap’ that we’ve fallen into again and again over the course of technical progress consists of our always using progress ‘on top’ of whatever went before (the rebound effect). This effect predicts that market forces and humanity’s apparently unlimited capacity for consumption will use new technology to convert more and more resources into more and more activities, functions, services and products.” (Radermacher, 1996) The most striking example of the rebound effect is ICT itself. According to Moore’s Law already mentioned, digital electronics dematerializes by a factor of 4 every 3-4 years. That raises the question as to why this continuing dramatic dematerialization has not caused a corresponding reduction of the total energy and material flows caused by ISTs. On the contrary: Electronics’ share of energy consumption continues to increase, and the amount of electronics waste indicates that material throughput is growing just as fast.

Under current economic framework conditions the most probable IST scenario predicts a continuing exponential
growth of the IST market until 2015, resulting in linear growth of the total physical mass contained in the IST devices that are in use (Hilty et al., 2000b).

We can conclude that technical progress in the direction of eco-efficiency or dematerialization is a necessary, but not a sufficient condition for approaching the goal of sustainability. At the same time, politics must create global framework conditions which lead to a worldwide optimal allocation of scarce ecological resources through market mechanisms. The necessity of changing the framework conditions is also emphasized by the Information Society Forum: “The rebound effect in a globalized economy can only be limited if appropriate social and ecological, guard-rails’ are installed world-wide by politicians as part of the world’s economic system. Such guard-rails have to be implemented locally in the form of national and regional framework conditions.” (ISF, 1998, p. 22).

2.5 From Eco-Efficiency to New Lifestyles

The idea behind eco-efficiency or dematerialization is that the intended output or ‘functional unit’ or ‘service unit’ for the end user is not changed (neither quantitatively nor qualitatively), while the physical input to the process of providing the output is changed, i.e. reduced. As it is called in Life Cycle Assessment (LCA), ‘functional equivalence’ is assumed. Functional equivalence, however, is a difficult concept. Even when such simple things as different beverage containers are being compared in an LCA study, it
is doubtful whether the containers can be considered really functionally equivalent. Furthermore, the concept of functional equivalence can be misleading in the case of IST, when virtual and real alternatives have to be compared with each other. This is typical of the case of substitution (as explained in Section 3.2), when an erstwhile physical function is replaced by a pure information service.8

Let us take telework as an example: Can working at home ever be functionally equivalent to working at the office? We think that people do telework not because telepresence is functionally equivalent to, but because it is different from, physical presence! We think that virtual substitutes for physical processes will never be functionally equivalent to the physical processes, but will always have some advantages and disadvantages as compared with physical processes. To ask for functional equivalence is misleading, because it denies the different quality of the virtual alternative. As they mature, Information Society Technologies will provide us with virtual alternatives that will enter our lives because they fulfill requirements different from their conventional counterparts. People may not change their lifestyles for environmental savings alone, but might be more strongly motivated by some functional advantage in a cyberworld.

8 This is the kind of change that is sometimes called ‘immaterialization’ in contrast to ‘dematerialization’.
2.6 Conclusion and Outlook

The transition to a global information society holds many opportunities for sustainable development. Environmental information processing leads to a better understanding of the complex natural environment on which our lives depend, and how it evolves under the influence of society. It also supports rational decision making with respect to environmental issues both in politics and corporate management. In many areas, Environmental Information Systems (EIS) are indispensable for the execution of the decisions taken. The information society offers great potentials to dematerialize products and services, i.e. to increase ecological efficiency, and enables society to make a transition to new and attractive lifestyles which take advantage of a variety of immaterial services. However, information technology contributes a necessary, but not sufficient condition for attaining the goal of sustainable development. As developments up to now have clearly shown, there is a risk that this technology may in fact induce more material and energy throughput through the economic system than it saves. In other words, it may keep us in the state of an industrial economy that measures its activity level in tonnes, instead of taking us across to a knowledge-based economy. The direct contribution of hardware to material flows and – more important – indirect induction effects and rebound effects, are the problems that have to be faced here. How society can counteract these risks on its way to an information society is clearly a political and cultural issue.
Sustainability will only be attainable through a change of lifestyles. Accepting more virtual, immaterialized goods and services is in fact a change in culture. This change can only be attained if the concept of an information society is not understood as doing the same things in a new way by using a different medium. Instead, the information society should be understood as a vision of a variety of new business models and services reshaping our lifestyle; services that let us do things virtually whenever that has clear advantages, and leave to the real what can be done better physically.

This idea has been further developed by the working group “Sustainable Information Society” of the German Informatics Society (GI). The working group has created a “Memorandum on a Sustainable Information Society” in 2004 (Dompke et al., 2004). We will cite the summary of the memorandum below.
Memorandum on a Sustainable Information Society


“…The rapid development of Information and Communication Technologies (ICT) is stimulating technical progress in all areas and increases the efficiency of everyday activities. New opportunities are available to get us closer to the goal of sustainable development, i.e. to reach a kind of economic activity that is compatible over the long run with human and social welfare, and with nature.

In writing this Memorandum, the Working Group «Sustainable Information Society» of the German Informatics Society (GI) calls out to politicians, business and the scientific community to seize this opportunity to make the sustainable information society a reality. There are clear signs that this opportunity is being missed. Only if the discourse on information society is combined with the discourse on sustainable development it will be possible to avoid negative effects of ICT on humans, society and nature […].

>>
1. We are concerned about the widely exhibited trend to interpret exponential growth in digitally stored and transmitted data as a growth of information or knowledge. The Internet, for example, may offer great opportunities to develop into a society that is more informed and more knowledgeable; but such a development should not be attributed to the existence of technical conditions alone.

2. Although ICT offers great opportunities for education, participating in markets and politics, the efficiency of markets, the creation of communities, open discourse and intercultural understanding, a trend is ascertainable today that these opportunities are being distributed very unevenly. ICT is threatening to exacerbate the divide between rich and poor, especially between the Global North and South, unless political will is brought to bear so that ICT applications are oriented more towards the local needs of people and to create more educational opportunity for young people worldwide.

3. ICT is creating spaces for individuals to choose their own lifestyles, to take self-responsible action and to enjoy more personal independence. At the same time,
though, they are bringing with them new dependencies on infrastructure and companies who dominate the market. Furthermore the technology is becoming increasingly obtuse, and as a result it is practically impossible to assign responsibility and liability in the event of a claim. Therefore research and politics should take into account the social risks arising from this state of affairs, especially as regards the distribution of responsibility.

4. The substantial increases in efficiency that are being demonstrated in the ICT sector itself (as per Moore's Law) and through application of ICT to optimize processes, and to substitute information services for products or telecommunications for travel, do not automatically cause any resources to be saved. This is partially due to the so-called rebound effect, according to which a transition to more efficient technologies causes an expansion of activities given constant financial and time budgets. Because of this effect, technological measures alone do not cause a reduction in the use of natural resources by production and consumption. Instead politicians have to create framework conditions which give incentives for a more economical use of material and energy.

5. Too little attention is being paid to the fact that both the energy consumption of ICT and the expansion of
electronics waste are becoming new threats. Most of the electronics waste collected worldwide is being disposed of in poor countries with technology that is totally insufficient, and is causing great danger for humans and the environment. There is no doubt that ICT offer great potential for sustainable development that has hardly been tapped yet. However, unless the downsides and risks of ICT described above are assessed realistically and discussed openly, the opportunity to reorient our activities towards a sustainable Information Society may be lost.”

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CHAPTER 7
A Conceptual Framework for ICT Effects on Sustainability

Over the course of many years of work – as may have been apparent in the preceding chapters – I have tried to define a conceptual framework in which all the issues we have discussed should find their respective places. The result is shown in Figure 7-1.

This matrix is also an attempt to integrate the terminologies used in the field. That applies especially to the classification into first-, second- and third-order effects, the breakdown of the product life-cycle into phases, the trio of optimization, substitution and induction effects, as well as the concepts which originated in different contexts: structural change, dematerialization, the rebound effect, and critical information infrastructure.

I have added in brackets the widely used classification into ‘direct/indirect/systemic effects’, although it is encumbered with various meanings and might cause misunderstandings (see table 6-1 on p. 137 for clarification).

1 This chapter is based on the lecture “Factors influencing the contribution of ICT to sustainability“ the author gave at a meeting of the ICT European Technology Platform (ETP) Leaders, European Commission DG Information Society and Media (INFSO), Brussels, February 2008.
The conceptual framework gives a broad perspective on ICT effects and thus offers space for finding one’s own idea in a new context, and for imagination. Any stakeholder may identify in it the points that apply to his/her potential contribution towards maximizing the positive and minimizing the negative effects of ICT.

I have tried to keep the framework normatively neutral; only the differentiation between “ICT as part of the solution” and “ICT as part of the problem” has obviously been based on values; it results from the normative decision to take sustainable development as a goal worthy of our striving, as has been discussed at some length in past chapters. However the framework does not predetermine in which cases and under what conditions the positive and negative effects identified in this way will prevail.

In Sections 7.1 to 7.3 I will explain the matrix from Figure 7-1 line by line. Recommendations for stakeholders will be derived from that in the next chapter.
7.1 First-order Effects (Primary Effects)

First-order effects are defined as effects that the physical existence of ICT hardware has, i.e. the fact that the hardware is developed, produced, used and disposed of.\textsuperscript{2}

At the negative side, first-order effects includes all relevant life-cycle impacts, including the effects of the so-called background system, such as the CO\textsubscript{2} emissions of a power plant providing electricity to a data center or the impacts of mining to provide precious metals for hardware production.

\textsuperscript{2} First-order effects are sometimes called 'direct effects', a term which, however, we would not recommend because it semantically overloaded. See p. 136 f. for clarification.
We must remember that ICT hardware is subject to rapid innovation cycles so that it is an inherent phenomenon of this sector for existing hardware to require frequent replace-ment by subsequent product generations, inducing mass and energy flows with relevant environmental impacts.

### 7.1.1 Making More from Less

One feature of the ICT sector like no other industry is that it can get an increasing amount of services from decreasing amounts of resources; the services come in the form of computing power, storage capacity and transmission performance (bandwidth). This doubling of resource productivity every 18-24 months is possible because in the ICT sector innovation is not in the material itself, but rather lies in its structures. Even if someday we no longer use silicon as basis material, innovation will still consist of manufacturing ever smaller structures in a controlled (or in future perhaps self-organizing) fashion. If this type of innovation could be spun off to other sectors, the effect would be huge.

Miniaturization has the positive effect that replacing a hardware product with a new one that performs equally well makes way for other things, in principle. In addition to the smaller space requirement, the specific material and energy requirements also become smaller. This self-dematerialization of ICT hardware would therefore be a trend in the direction of sustainability if it did not cause a rebound effect (see section 4.10)
The demand for ICT performance is growing faster than the resource productivity on the hardware level. If, for instance, a modern PC has one thousand times the power of the first PCs – while maintaining a resource requirement on the same order of magnitude – this means: if we had been satisfied with an increase in computing power by a factor of 10 instead of 1000 over the last 20 years, we should have been able to achieve an actual resource savings goal of a factor of 100, because we would have replaced each device with a small, lighter and energy-saving one every few years. In order to go far enough, we would have needed innovative interaction technologies (cybergoggles, virtual keyboards) to reduce the size of displays and housings.

This may come about one day; thus far, however, we have compensated for the efficiency progress mainly with the not very innovative demand for “more of the same”. However, as resources will become scarce, the rebound effect will recede, so that the high and presumably continually rising resource productivity of the ICT sector will make an important contribution to sustainable development.

7.1.2 The Life Cycle of ICT Hardware

As long as growing quantities of ICT hardware are being produced, used and disposed of, i.e. the mass flow in t/a is rising in absolute terms, the relevance of the environmental impact caused by it also increases. This may not be causing an overall environmental impact which would be comparable to that of the building and mobility sectors (instead it
lies an order of magnitude below the impacts of each of these two sectors). But the trend, which is still rising, makes it appear necessary to analyse and optimize the life cycle of ICT products continually under ecological aspects. We have described the current status of such investigations in Chapter 6. The user can primarily reduce the life-cycle impacts by extending the hardware use phase.

7.2 Second-order Effects (Secondary Effects)

Second-order effects are defined as the effects of using ICT on other processes.\(^3\) The ‘other processes’ generally belong to the life cycle of a product. An ICT service therefore has an effect on the life cycle of another product, which is optimized (optimization effect) or which is used less often (substitution effect) or more frequently (induction effect), as described in Section 6.2.

7.2.1 Optimization and Substitution Effects

Optimization and substitution effects are the real key to de-materializing the economy by a factor of 4-10 (as discussed in Chapter 3), and thus represent a necessary prerequisite for solving the sustainability dilemma.

\(^3\) Second-order effects are also called 'indirect effects', a term which is, however, semantically overloaded. The terminology of product LCA uses a differing direct/indirect dichotomy (see p. 136 f. for a clarification), as do the terminologies of sustainability reporting and some other related fields.
Optimization and substitution effects due to ICT applications, though, are not being exploited sufficiently today and are sometimes being compensated for by rebound effects. The greatest untapped optimization potentials can be found in the area of intelligent heating and cooling building spaces and in creating services substituting material ownership. Another type of substitution is the virtualization of office space, which is possible because the organization of the personal workspace is becoming more and more independent of physical space. The outcome is a much more efficient use of facilities with considerable indirect energy savings.4

The most obvious rebound effects can be found in the substitution of virtual for physical meetings: business travel has not decreased despite the increasing use of audio- and videoconferencing, telecollaboration, CSCW5 systems and other virtualization technologies.

However, this could change if the relative prices of natural resources continue to rise, especially if the price of fossil energy continues to rise after peak oil. Put simply: if heating and cooling become more expensive, people will be glad to reduce costs through ICT-based optimization. If travel becomes more expensive, people will be glad to find

4 This has been demonstrated, e.g., by the ‘e-place’ concept introduced by IBM Germany, which resulted in a reduction of energy consumption per housed headcount by almost a factor 2 in 4 years (Fichter, 2006).

5 Computer Supported Cooperative Work
virtual substitutes for the less interesting trips. The software tools for organizing discussions and project work over great distances and time zones will then experience a leap in quality and blend into everyday culture more and more, as was the case with the telephone only a few decades after its invention in the late 19th century.

### 7.2.2 Induction Effects

Induction effects are second-order effects that are problematical for reasons of sustainability and are not to be confused with the rebound effect. For example, inkjet and laser printers induce paper consumption: If I buy a PC with a printer, my paper consumption will increase. This is not a rebound effect because I am not buying the printer with the intention of saving paper, but rather for printing on paper.

As everyday experience shows, the Internet has induction effects as regards personal and freight transport. The possibility of communicating with remote locations and persons creates the need and the organizational means of undertaking trips and entering into trade relations which causes freight traffic. The Internet is only the last link in a chain of telecommunication media that are growing more powerful ranging from the telegraph to the telephone and fax.
7.3 Third-order Effects (Tertiary Effects)

Third-order effects are defined as adaptive reactions of a society to the stable availability of ICT services. Such adaptation may be either pro or contra sustainability. Third-order effects are also called ‘systemic effects’.

7.3.1 Structural Change toward a Dematerialized Economy

The long-term availability of ICT services may enable and foster a transition to a less material-intensive economy in two ways:

- Firstly, by helping us to monitor and understand the processes in the environment much better; this will hopefully lead to a higher level of awareness and more effective governance of our interaction with the environment, i.e. the mass and energy flows between society and ecosystems at the local, regional and global levels (environmental information processing);

- Secondly, by establishing business models and lifestyles in which production and consumption is dematerialized, i.e. value creation is based on creating structures and almost decoupled from mass and energy turnover, while consumption is focused on services and almost decoupled from traditional ownership of physical goods (structural dematerialization).
Environmental Information Processing

Our understanding of climate change, although limited, is based on numerical climate models and the computing power needed to run them. Without ICT, reducing the emission of greenhouse gases would not be on the political agenda.

Climate change is only one field of interaction between the economic system and Nature. Other fields too need deeper understanding and awareness, as we are approaching all kinds of limits due to the unchecked increase in our global activity level.

Processing environmental information has been supported by ICT applications for decades in the form of monitoring systems, databases and information systems, analytical and simulation models, spatial information processing and other kinds of ICT applications for environmental protection, research, planning, and disaster mitigation. This field may be called ‘Environmental Informatics’ (see Section 2.2) or ‘E-Environment’ (WSIS, 2003; ITU, 2008) and structured in many different ways; its welcome long-term effect is that a consensus on environmental strategies and policies may emerge, based on shared data and understanding.

Structural Dematerialization

What is needed from the standpoint of sustainability is a deep structural change which would make the above-mentioned substitution effects (Section 7.2.1) into an essential feature of the economy. In an economy that has
been dematerialized in this way, value-added would depend a lot more than it does today on the creation of structures and not on the churning of material and energy (see also Chapter 3).

Figure 7-2 sketches the basic idea of such an economy. In such an economic system, all scarce substances are carried in closed cycles which are maintained by renewable energy. All value creation takes place alongside these closed cycles, transforming the structure of material while keeping its physical properties within some limits that ensure that it can be re-cycled. The whole system consists of a network of such closed cycles.

Figure 7-2: The idea of a dematerialized closed-loop economy. The transformations of material resources at nodes denoted ‘S/H’ add value by creating structure without devaluing the material. Each value-creating node is driven by renewable energy (symbolized by a solar panel) and consists of a hardware part H (capital goods for transforming material and energy) and a software part S (the knowledge of how to control these transformations in a manner that adds value).
The hardware/software dichotomy of the ICT sector is generalized to the whole economy: Each node of the network consists of hardware (capital goods for transforming material and energy) and software (the knowledge of how to control these transformations in a manner that adds value). Today’s distinctions among raw materials, product and waste will become obsolete, since there is no beginning or end of the cycles. Innovation will mean the introduction of new nodes into the system.

7.3.2 Rebound Effects and the Emergence of Critical Information Infrastructures

Rebound effects occur if and when the efficiency of providing a service is increased but there is no factor limiting the demand for this service, such as the price to be paid or the time needed for consuming it. The economic system (as a functional system of society) adapts to the higher efficiency level at which the service is provided by increasing the demand for the service.⁶

But, even worse, the system does not only adapt to higher efficiency, it also adapts to stable availability of a service – by becoming dependent on it. The Internet and other ICT infrastructures such as mobile phone networks are therefore becoming critical infrastructures for society.

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⁶ This issue has been discussed in detail in Chapter 4.
Critical Information Infrastructure Protection (CIIP) has emerged as a new field of study and practice which aims to ensure that information infrastructures are less vulnerable to disruptions. ICT has pervaded other infrastructures (such as transport, energy, water, finance, national security), rendering them increasingly interconnected, complex, interdependent, and therefore more vulnerable (Hilty, 2008).

The actual security or vulnerability of an ICT system is almost impossible to describe due to the problem of unmastered complexity, as discussed in Chapter 5: Dijkstra’s spirit never found its way into commercial software products. It is because of this general and deeply rooted flaw that catastrophic attacks against ICT infrastructure can’t be ruled out. For the same reason, the risk of such attacks cannot be quantified in advance.

What we do know for sure is that software diversity mitigates the vulnerability of critical information infrastructures, whereas software monoculture makes them more fragile. Open standards make it possible to reconcile interoperability and diversity: They specify the ‘What’ based on a cooperative process and leave it to the market to find the best solution for the ‘How’. By contrast, so-called proprietary standards are used to create consumer lock-in effects and lead to monocultures.

From the perspective of complexity reduction, it is better to have a reliable specification (the definition of the ‘What’) and a variety of competing approaches to the implementation (the ‘How’) – which is then irrelevant and may be
hidden – than to have an unreliable specification with only one implementation, which is then replicated millions of times with all its errors and security holes.

Critical information infrastructures based on proprietary standards are therefore not sustainable. The fact that many commercial software products are peppered with errors and consequently depend on regular updates creates an additional problem because this leads to a concentration of power in the hands of any actor who is recognized as the legitimate provider of an update.

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