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The Role of ICT in Energy Consumption and Energy Efficiency

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Executive Summary

Despite the fact that Information and Communication Technologies (ICTs) are responsible for only a small part of worldwide greenhouse gas emissions – current estimations attribute around 2% of man-made emissions to ICT – this sector is one with the fastest growing emissions. As a result, there is an increasing concern about the environmental impact of ICT, especially the climate change potential induced by ICT-related energy consumption.

At the same time, there is a growing perception that ICT can also substantially reduce the environmental impacts of other sectors, in particular by increasing their energy efficiency. ICT can help all economic sectors to become more energy efficient – since ICT allows existing processes to be optimized or enables entirely new, more energy-efficient processes. The energy that could be saved by ICT-induced energy efficiency is estimated to be several times larger than the overall energy consumption of ICT itself. The European Commission recognizes this potential and hopes that Europe will go a long way toward achieving its target of 20% greenhouse gas reduction by 2020 by deploying ICT for energy efficiency.

The present study looks at the field spawned by these two main issues at the intersection between ICT and energy: ICT’s own energy consumption and ICT’s potential to induce energy efficiency across the economy. In its approach to these issues, the study looks both at today’s situation, as well as future opportunities and risks. The study discusses the following research questions:

a) estimates of the current energy consumption of ICT,
b) prospective future developments in this energy consumption, and
c) future energy efficiency potentials induced by ICT in various economic sectors.

ICT-related energy efficiency potentials already realized are not covered by this study, because it is virtually impossible to retrospectively allocate advances in energy efficiency to the various changes that created them.

Two methodologies have been used for the study: literature review and expert interviews. For the former, we have reviewed:

i) recent quantitative studies (since 2005) with a focus on “ICT energy consumption”, “ICT for energy efficiency”, “Green ICT”, “ICT and climate change” or “ICT and sustainability” in general;
ii) other documents describing projects, programs or initiatives aimed at reducing ICT-related energy consumption or increasing ICT-related energy efficiency;
iii) Life Cycle Assessment (LCA) studies on ICT products and services, and
iv) studies on the potential of smart power networks (smart grids).

We decided to include the more specific topics iii and iv because they are not sufficiently covered by items i and ii.

These sources were then evaluated and the relevant content structured according to relevance (Chapter 2), state of the art (Chapter 3), and research programmes (Chapter 5) in order to give the reader insight into the motivation driving this research area, current knowledge, and the focus of ongoing research, respectively.

Chapter 4 presents the results of expert interviews based on a questionnaire which we developed to fill the knowledge gaps identified in the literature review. The aim of the interviews was to collect ideas beyond the current state of quantitative knowledge and to identify research questions -- not to do a representative survey. The experts were only asked about future developments (research questions b and c). For ICT’s future energy consumption (b), the experts were asked to estimate for different categories of technologies (such as “data centres”, or “embedded ICT”) how their respective global energy consumption totals would evolve in both a business-as-usual scenario (alongside the foreseeable technological, political, and market developments) and in
an “energy-optimistic” scenario, in which energy-reducing measures would be rigorously applied. As for question c above (ICT’s potential for energy efficiency), the experts were presented with the possible application areas in which the deployment of ICT was expected to lead to better energy efficiency, and were asked to estimate their relative importance. Furthermore, the experts were asked to determine which ICT categories were relevant for inducing energy efficiency in other economic sectors.

In our analysis of the current situation and the future potential of both “ICT energy consumption” and “ICT for energy efficiency”, three main results become evident:

- A thorough overview of the state-of-the-art literature for all three questions considered, with emphasis on the LCA methodology and including a formal definition of ICT-related energy efficiency as well as a conceptual framework of the effects of ICT on energy efficiency.
- An overview of existing research programmes, project clusters, and institutions involved in them, both in the EU and beyond.
- The results of expert interviews regarding future ICT energy consumption and future applications of ICT for energy efficiency. In addition to comparing business-as-usual with energy optimistic scenarios, thus revealing where the largest energy-saving potentials for ICT lie, the experts have also – as a novelty – related the consumption of individual technologies to their respective potentials for inducing energy efficiency.

At a more detailed level, the results show that some application fields (such as “TVs and set-top boxes”) are expected to drastically increase their energy consumption without contributing to energy efficiency in any way, while others (such as “embedded ICT”), although increasing their collective energy consumption as well, are expected to play a crucial role in energy efficiency across the economy. We hope that this fresh thinking will help to introduce a more differentiated view of ICT into the public discourse and political decision making.
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1 Basic Definitions and Scope of the Study

1.1 Information and Communication Technologies (ICT)

1.1.1 Existing Definitions

Providing a formal definition for “Information and Communication Technologies (ICT)” is more difficult than it might seem at first glance. While everyone seems to have an intuitive understanding of the term’s meaning, definition attempts are surprisingly sparse. It is characteristic, in this context, that EU’s own Seventh Framework Programme, for example, does not formally define ICT, although it foresees 9.1 billion Euro for funding it. Moreover, both printed and online encyclopaedias have rather poor definitions of the term. For evaluating the role of ICT in energy consumption and energy efficiency, a definition of what constitutes ICT (and what not) is nevertheless needed – a need that has already been faced by national and international organizations when measuring the size of the ICT sector inside economies. 1 It thus comes to little surprise that the term’s few existing definitions come from these organisations.

ISIC

The “International Standard of Industrial Classification of All Economic Activities” (ISIC), developed by the United Nation’s Statistic Division, is a largely-used standard for classifying economic activities. While its latest revision (Rev. 4) 4 contains for the first time a top-level category “Information and communication” (cat. J), the ISIC classification, even on its most detailed level, consists of quite general subcategories. Furthermore, ICT is defined in a wide sense, including so-called “content industries” enabled by ICT. Whether categories such as “591 – Motion picture, video and television program activities”, or “602 – Television programming and broadcasting activities” belong to ICT or not is debatable – most experts do not see them as part of ICT (Pleypys 2004; OECD 2005). Other products though, such as digital cameras, digital music players, etc. – more likely belonging to ICT and continuously gaining importance, both in economic terms and with regard to energy consumption – do not appear in the ISIC classification.

OECD

Acknowledging the same need, the Organisation for Economic Co-Operation and Development (OECD) started in 1997 its efforts towards a definition of the ICT sector, under the guidance of the newly-formed “Working Party on Indicators for the Information Society” (WPIIS) (OECD 2005).


2 This is also true for the well-known online-encyclopaedia “wikipedia,” where the term “ICT” is, as of January 2009, still very poorly defined. See http://en.wikipedia.org/wiki/Information_communication_technology.

3 As put by http://www.oecd.org/dataoecd/5/61/22343094.pdf, “The main reason to have a classification of information and communication technology (ICT) goods is to facilitate the construction of internationally comparable indicators on ICT trade and ICT production. Such a classification would also provide a basis to develop internationally comparable indicators for ICT consumption and investment.”

In defining the ICT sector, the OECD started from the same ISIC categories of goods and services. It went, however, beyond a simple enumeration of categories. The OECD experts tried in numerous meetings to answer both the question about what represents the essence of an ICT product – i.e., of an ICT good or service – and of how the relevant parameters are best measured and expressed (OECD 2005), annex 1b. After years of discussions, compromises, and incremental modifications, nowadays’ OECD definition of the ICT sector is composed of three main pillars: ICT manufacturing, trade, and service industries (OECD 2005). Manufacturing industries include the production of goods such as circuit boards, computers, or magnetic and optic media; trade industries comprise the wholesale of computers and other electronic equipment; services include computer programming, web hosting, or ICT consultancy.

On a conceptual level, the OECD states that ICT goods “must either be intended to fulfil the function of information processing and communication by electronic means, including transmission and display, or use electronic processing to detect, measure and/or record physical phenomena, or to control a physical process” (OECD 2002). ICT services, on the other hand, “must be intended to enable the function of information processing and communication by electronic means” (OECD 2002).

The components of the three main categories (ICT manufacturing, trade, and services) are presented as ISIC sub-categories as well. For doing so, the OECD classification combines some (but not all) components of ISIC’s “Information and communication” section with subcategories from other ISIC sections (such as section C “manufacturing”). Furthermore, and for ICT goods only, a further taxonomy is used as well – the World Customs Organization’s “Harmonized System” (HS). The 6-digit Harmonized System is not only much more detailed than ISIC’s relatively general categorization, but also offers a unique advantage: while the ISIC system can be used for national statistics, international trade is measured (if at all) only through the HS: “The HS is the only commodity classification system used on a sufficiently wide basis to support international data comparison. A large number of countries use it to classify export and import of goods, and many countries use it (or a classification derived from it) to categorise domestic outputs” (OECD 2003).

As a last remark, and as might already have become clear from the summary above, very early in the OECD process the decision has been taken to exclude the so-called “content” industries from the definition of the ICT sector. Content industries offer services such as TV production or TV and radio broadcast. In the view of OECD, a broader “information economy” sector exists, which encompasses the ICT sector together with the content industry: “In the view of the members of the Panel, the ‘information economy’ consists of the economic activities of those industries that produce content, and of the ICT industries that move and display the content” (OECD 2005).

1.1.2 Reasons for Definitional Difficulties – Rapid ICT Development

The pace of progress for information and communication technologies – best represented by the so-called Moore’s Law (Moore 1965) – does not only imply exponential growth of storage and computing capacity as well as bandwidth per size and price. It also means that through these rapid advances, formerly non-computerized entities – from individual goods to entire economic processes – become increasingly ICT-based. This continuous shift towards the “digitalization” of life has three effects, which all hinder a precise definition of the ICT sector:

- Any enumeration or categorization of the sector will quickly become outdated. New (digital) technology appears at a quick pace. Roughly 15 years after their first appearance, for example, digital cameras are much more popular than their analogue counterparts. In even less time, roughly one decade, audio players (“mp3 players”) have almost entirely replaced portable analogue music devices. The fact that this unusual dynamicity of the ICT sector combined with slowly-changing classifications of goods and services makes an inventory of ICT components rather challenging, as has been noticed by OECD’s Working Party on Indicators for the Information Society: “The difficulties in establishing a list of ICT products have been recognised by WPIIS since 1998. These difficulties were related to the rapidly changing character of ICT goods and services, and the dated nature of current standard classifications” (OECD 2003).
• The general tendency of goods to be enhanced with (and of services to make use of) ICT technology. This trend, called “Ubiquitous Computing” (Mattern 2005b) or “Pervasive Computing” (Hilty, Behrendt et al. 2005), observes that due to the dramatically sinking costs and size, and the equally improving performance, ICT components start to be included in more and more objects and products: in cars, for example, they enable safety features such as ABS (anti-lock braking system), EPS (electronic stability control), and navigation systems; in printer cartridges they count the number of pages already printed and in coffee machines the number of coffees brewed; and included at the end nodes of power lines they allow Internet connectivity through the power grid. In a not so distant future, washing machines could exchange data with the shirts (receiving thus automatically washing instructions and freeing the user from programming them). More generally everyday objects could know their location and history of usage, as well as inspect their own status (allowing a sheer endless amount of possible applications). In this sense, ICT could be included in most objects and services, making a distinction between ICT and “non-ICT” ever more difficult.

• Several services that nowadays undoubtedly belong to ICT have always been related to “information” in the wide sense of the word. While, for example, digital photography (together with the enabling devices, digital cameras) is at the core of ICT consumer electronics, the aim of analogue photography has always been to preserve information. Does the digital camera industry thus represent a new member of the ICT family or has the (analogue) camera industry always been part of the ICT sector? Even more strikingly: analogue TV and printed newspapers have always had the purpose to inform the public. Do novel delivery technologies such as digital TV broadcast, TV over the Internet, or electronic newspapers make a semantic difference in terms of classifying the service within or outside the ICT sector? More generally: Does ICT implicitly relate exclusively to the “digital revolution”, i.e., to digitally stored or transmitted bits? Or does it, at the other end of the scale, cover any good or service related to information and communication in the wide sense?

1.1.3 Types of ICT Considered in this Study

Following the typical categories found in other studies (e.g., (Bio-Intelligence-Service 2008)), we consider three types of ICT: servers, end-user devices, and the network infrastructure typically used to communicate either between two or more end-user devices, or among end-user devices and servers. We have not followed the often-encountered (and increasingly artificial) separate clustering of communication devices (such as cellular phones) and computation devices, such as personal computers. For the same reason, we do not try to discriminate between “communication infrastructure” and “computing infrastructure.”

As can be seen from the expert answers presented in section 4.1, they all consider entertainment technologies such as TV sets and set-top boxes as belonging to ICT and significantly contributing to the overall energy consumption of the sector. They are thus definitely considered as part of ICT. There is less consensus whether other entertainment technologies such as digital music players or digital cameras belong to ICT or not.

Furthermore, embedded ICT components do definitely belong to the ICT sector, as can be seen from the same answers. For content industries, on the other hand, we follow the conventions mentioned above and do not consider them as part of ICT.

1.2 Energy Consumption

1.2.1 General Definition and Considerations

In general, energy consumption is the transformation of energy from a usable form into an unusable form. Final energy consumption refers to the amount of energy transformed at the point of use (e.g. in an electronic
device), whereas other indicators of energy consumption (such as Cumulated Energy Demand, CED) are in use to cover all necessary energy transformations in a system that provides energy (or any other type of service).

Energy consumption can refer to any energy carrier, such as electricity, natural gas, fuels, biomass, hydrogen, solar power, etc. However, in most of the studies on energy consumption by ICT the term “energy” implicitly focuses on (final) electricity (IBM 2006; EPA 2007; Koomey 2007; DEFRA 2008; Fichter, Clausen et al. 2008; Fraunhofer IZM-ISI 2008). The study by (Bio-Intelligence-Service 2008) explicitly focuses on electricity. Fewer studies include e.g. energy in the form of fossil fuels that are directly consumed by the ICT industry.

Furthermore, most of the studies assessing the energy consumption of ICT consider only the use phase of ICT products. The consumption of electricity or other forms of energy during other life cycle phases of ICT products (in particular hardware production and disposal) is considered only in few studies (Malmodin 2007; Mingay 2007b; Bio-Intelligence-Service 2008; GeSi 2008b).5

The types of ICT products under study are often defined with different scopes and investigated with different methodologies, which makes it difficult to compare results across studies. Furthermore, the inconsistent use of the term “cumulated energy” could lead to misunderstandings. The reason is that this term is similar to the term “Cumulated Energy Demand (CED)”, an environmental impact indicator commonly used in Life Cycle Assessment which includes all primary energy needed by a product-related system. Finally, when considering the influence of ICT on the energy efficiency in other sectors, it is inevitable to address not only electricity, but all relevant forms of energy.

### 1.2.2 ICT-Related Energy Consumption

For the purpose of this study, we define ICT-Related energy consumption as follows:

*ICT-Related energy consumption* (or *ICT energy consumption* for short) is the amount of energy consumed by a given ICT system in a given period of time.

This definition has several parameters which have to be set depending on the context. The most obvious parameter is the time period, which in statistical contexts is usually set to one year. Given that we use energy consumption as related to a time period as an indicator, this indicator could more directly be expressed in units of power (Watt) and not energy (Joule, Watt seconds, Kilowatt hours, etc.). However, it is common to explicitly write down “energy per time” such as kWh/a, although this fraction could in principle be reduced to kW/(365*24), yielding the average power.

A less obvious parameter of the definition is represented by the broad spectrum between final energy consumption (only the energy that is transformed within the ICT-System under study) and the cumulative energy demand (as defined in LCA methodology).

The third parameter is the “ICT system” itself. The borderlines of this system may be defined according to the type of ICT, geographic boundaries, ownership, the service the ICT system provides or a combination of these criteria. It is, for example, meaningful to ask for the total annual energy consumption of all PCs in the world, of all ICT in EU-27, of one specific data centre, or of a specific service Google provides to Internet users.

As soon as we focus on services to draw the borderline between the ICT system under study and the rest of the world, several methodological issues creep into the delineation task. The first issue is where to cut off the system. For example, is seems natural to include the energy used for cooling in the energy consumption of the data center, simply because cooling is a necessary part of producing the service. However, will lighting also

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5 (Bio-Intelligence-Service 2008) focus on the use phase but includes an analysis of the production and the end-of-life treatment; (Mingay 2007b) takes into account the design, manufacture and distribution and use; (Malmodin 2007) considers fuel chain, power plants, the grid, manufacture and use and (GeSi 2008a) considered in addition to the use phase the production and end-of-life treatment, when such data was available.
have to be included, then? What about the facility management service and their vehicles? The second issue is allocation. If the data center produces more than one type of output, i.e. we are interested in the energy consumption of Web hosting, but the data center also provides data backups, which part of the consumption has to be allocated to which output?

It is important to understand that these issues cannot be solved by providing a formal definition of ICT energy consumption, but only by understanding the objectives and context of each study. However, there is some methodological support from the LCA field. We will come back to these issues in section 3.3.3.

### 1.3 Energy Efficiency

#### 1.3.1 General Definition and Considerations

The energy efficiency of a system A is the ratio of the useful output of services from A to the energy consumption by A. Usually, both the output and the energy consumption are related to a period of time, which obviously leads to the elimination of time and yields the dimension "services per energy", such as km/kJ for a vehicle, kg/kWh for a recycling process, or kByte/Ws for an Internet service.

Let S be a measure of the service output of a system and P the energy consumption of the system (as defined in 1.2.1. above). Then the energy efficiency can simply be defined as

\[ \mu = \frac{S}{P} \]

Please note that according to this definition energy efficiency is different from energy conversion efficiency (sometimes also called "energy efficiency" for short), which physics defines as

\[ \eta = \frac{P_{\text{out}}}{P_{\text{in}}} \]

where \( P_{\text{out}} \) refers to the useful energy output of the system (which is an energy conversion machine in this case) and \( P_{\text{in}} \) to the energy input. Obviously, energy conversion efficiency \( \eta \) is a special case of energy efficiency \( \mu \): in this special case, the service consists in providing energy in a specific form and energy consumption is measured as direct energy input. For ICT systems we can generally assume \( \eta = 0 \), because all energy is finally converted to waste heat, while the purpose of an ICT system is not to provide heat. However, for some components of ICT systems such as power supplies or motors, there is of course a \( \eta > 0 \).

Very often, the expression "energy efficient" is used as a unary predicate, as in "A is energy efficient"; this presumes an implicit comparison of A with a system B, meaning in fact that the energy efficiency of A be higher than the energy efficiency of B. It is therefore preferable to explicitly state that "A is more energy efficient than B" in such a case, i.e. to use a binary predicate. In order to make quantitative comparisons, we define relative energy efficiency \( \rho \) as the ratio between the two energy efficiencies:

\[ \rho_{A,B} = \frac{\mu_A}{\mu_B} = \frac{S_A P_B}{P_A S_B} \]

This is the relative energy efficiency of A with regard to B. In many practical situations (and as common in LCA studies), we assume that the services A and B are functionally equivalent. In this case, relative energy efficiency of A with regard to B reduces to

\[ \rho_{A,B} = \frac{P_B}{P_A} \text{ (with } S_A = S_B) \]

i.e. it expresses by which factor energy consumption can be decreased by substituting A for B, all other things being equal. In many studies on energy efficiency, implicit reference to this type of relative energy efficiency is made, usually by stating energy savings potentials in percent \( (1 - \frac{1}{\rho_{A,B}}) \), often without explicitly addressing system B.

We have assumed so far that the system under study only produces one useful service output. If there are more useful outputs, measuring the energy efficiency with regard to one specific output requires defining an
allocation scheme which assigns a part of the total energy consumed \( (P) \) to the output of interest. The allocation problem is a general methodological issue in modelling multi-output processes (e.g. in LCA studies) and not a definitional problem of energy efficiency.

1.3.2 ICT-Related Energy Efficiency

Given two systems \( A \) and \( B \) producing a functionally equivalent output of services \( S_A = S_B \). Let us assume that \( A \) contains a subsystem \( C \) which is an ICT system and \( B \) does not contain that subsystem, all other things being equal.\(^6\) We can then define:

The *ICT-related energy efficiency of \( A \) with regard to \( C \)* is the relative energy efficiency of \( A \) with regard to \( B \) (with \( B = A \setminus C \)).

In other words, ICT-related energy efficiency is the factor by which the energy consumption of a system decreases if an ICT system is added to it and all other things are kept equal (in particular the service output). Very often, this is expressed in percent of energy saved instead of a reduction factor.

ICT-related energy efficiency is a special case of relative energy efficiency \( \rho_{A:B} \) (as defined above) with \( S_A = S_B \) and \( B = A \setminus C \), \( C \) being an ICT system.

![Figure 1. System model for the definition ICT-related energy efficiency](image)

1.4 Scope and Methodology of the Study

1.4.1 Selection of Literature

The literature search for this study was focused on four areas:

1. Recent quantitative studies (since 2005) with a focus on "ICT energy consumption", "ICT for energy efficiency", "Green ICT", "ICT and climate change" or "ICT and sustainability" in general;
2. Other documents describing projects, programs or initiatives aimed at reducing ICT-related energy consumption or increasing ICT-related energy efficiency;
3. Life Cycle Assessment (LCA) studies on ICT products and services.
4. Studies on the potential of smart power networks (smart grids).

\(^6\) In practice, \( B \) may often be a hypothetical system.
We decided to include the more specific topics (3) and (4) because these are not sufficiently covered by the general studies we found according to criteria (1) and (2).

These sources were then evaluated and the relevant content structured according to Chapters 2 (Relevance), 3 (State of the art), and 5 (Research programmes) in order to give the reader a survey on the motivation behind this research area, the current knowledge, and the focus of ongoing research, respectively.

In parallel, the literature survey was used to create a questionnaire for expert interviews (see next section) with the aim to enrich the established knowledge with estimates of future potentials and new ideas.

### 1.4.2 Expert Interviews

The aim of the expert interviews was to collect ideas beyond the current quantitative knowledge and to identify research questions, not to do a representative survey. We also wanted to give the authors or commissioners of the main studies we evaluated the opportunity to provide us with an update of their view, which may have changed since the study went to press.

We therefore primarily invited experts involved in the studies we used as literature sources for our study. Although this was an international and unbiased selection, we mainly got answers from German-speaking countries (Germany, Austria, Switzerland).

For the questionnaire see Annex 3: Interview Outline.
2 Relevance of ICT-Related Energy Consumption and Energy Efficiency

2.1 Importance of Sustainability Research in this Field

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. 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 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 (Hilty 2008).

The European Commission recently defined the role of ICTs in a similar way 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 2008c), 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 behaviour of business and consumers, and through these changes, ICT can help the environment without sacrificing economic output” (GIIC 2008), p. 2.

2.1.1 Outstanding Opportunities and Risks

The well-known principle called Moore’s Law (Moore 1965), according to which the number of transistors per microchip doubles every 18-24 months, has yet to be disproved. As a side effect, processor performance per energy input grows exponentially too (Figure 2).

![Figure 2. Moore's Law and the increase in computing power per unit electrical power (Source: (Mattern 2005a))](image-url)
However, this astounding progress does not reveal much about the influence of ICT on overall energy consumption for two reasons:

1. Despite the increasing energy efficiency of ICT hardware, the total energy demand of the installed hardware base is growing. This is because the demand for ICT services is increasing even faster than the energy efficiency of ICT devices. More and more powerful devices are used by more and more people.

2. ICT is an enabler of energy efficiency in sectors that use much more energy than the ICT sector. If these efficiency potentials are used systematically, ICT can make a substantial contribution to the reduction of energy demand and therefore to a low-carbon economy.

This implies that sustainability research on energetic aspects of ICT must look far beyond the efficiency of individual ICT devices. The complex dynamics of ICT impacts – in the positive or negative sense – on energy use must be understood by means of dynamic models.

A simulation study on the “Future impact of ICT on environmental sustainability” in EU-15 demonstrated that the impact of ICT on environmental indicators (including total energy demand) can be either positive or negative below the line, depending on the framework conditions assumed in the scenarios that were simulated. These framework conditions included energy prices, an external variable that had a strong influence on the realisation of efficiency potentials and on the occurrence of rebound effects. Another important result was that effects on the energy demand of specific sectors or areas of activity were usually much higher (in positive or negative directions) than the aggregated effects. In each scenario, some of the ICT effects counterbalanced each other when taken together (Erdmann, Hilty et al. 2004; Hilty, Wäger et al. 2004).

We can deduce from this that a well-designed policy that systematically reinforces the positive effects of ICT on energy efficiency and counteracts ICT-related risks is necessary.

The challenge for policymakers seems to be that there is no general strategy for unleashing the potentials of ICT to increase the energy efficiency of the economy. Instead, ICT effects must be analyzed and prospectively assessed at some detail. 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).

### 2.1.2 Relative Importance of ICT Regarding Energy Consumption

Compared to the total amounts of energy consumed by the industry, residential or transport sectors, ICT-related final energy consumption does not seem to be very relevant at a first glance. If we take the EU-27 energy baseline scenario by DG TREN (European Commission 2008e) and distribute the ICT-related energy consumption of the BAU scenario used in the European Commission’s recent Impact Assessment on ICT for energy efficiency (European Commission 2009b), the distribution shown in Figure 3 results.

In 2005, 4.5 % (120 TWh/a) of the electrical power in EU-27 were consumed by consumer electronics (mainly TVs and HiFis) and 3.5 % (97 TWh/a) for ICT in a narrower sense (PCs, telephones and the communication infrastructure including data centres) (European Commission 2009b). We allocated all consumer electronics to residential energy demand and split the rest (ICT in a narrower sense) equally between residential and industrial energy demand (Figure 3a).

The 2020 projection is based on the baseline scenario of DG TREN and the BAU scenario of the impact assessment. According to the latter, ICT-related energy consumption will rise to at least 400 TWh, mainly driven by the expected diffusion of larger-screen TVs, higher-speed broadband access or higher capacity data centres. Since these drivers are partly residential and partly industrial, we assumed the same distribution among sectors for 2020 as for 2005 (Figure 3b). The ICT-related energy demand in the transport sector is not known, because the electricity consumed by on-board ICT of vehicles is usually not measured.
The Role of ICT in Energy Consumption and Energy Efficiency

Final Energy Demand EU27 by Sector (2005)

- Industry, Services, Agriculture: 48.5 TWh
- Residential: 5745 TWh
- Transport: ?
- Total: 13'354 TWh

Final Energy Demand EU27 by Sector (2020)

- Industry, Services, Agriculture: 89.4 TWh
- Residential: 3'101 TWh
- Transport: ?
- Total: 15'275 TWh

Figure 3. Final energy demand in EU27 by sector and ICT-/non-ICT-related consumption, a) in 2005 and b) projected in 2020. No data on ICT in the transport sector, because the electricity consumed by on-board ICT of vehicles is usually not measured. (Source: Own Calculations based on DG TREN (European Commission 2008e) and (European Commission 2009b))
An interesting question is the ICT-related energy consumption of the traffic sector. Although vehicles are heavily equipped with ICT, this type of ICT is usually not included in the estimates. We therefore allocated all documented ICT consumption to the industrial and residential sectors. There may be a relevant, but statistically neglected ICT-related energy consumption in the traffic sector.

Overall, one could conclude that ICT-related energy consumption is less relevant than the energy demand of other types of technologies, such as industrial machines, non-ICT household appliances (heaters, ovens, fridges), and vehicles. After all, ICT will account for 2.55% of EU-27 final energy demand in 2020 according to these estimates.

However, there are several issues that deserve attention:

1. Final energy demand is different from primary energy demand (see also Sections 1.2.2 and 2.2.2). Depending on the energy supply chains used, the share of electricity-consuming devices (including ICT) in primary (or in cumulated) energy demand can be over-proportional as compared to final consumption. The same holds for the emissions of CO₂ or CO₂ equivalents.

2. The final energy demand of ICT alone is growing faster than the overall final energy demand. From 2005 to 2020 (Figure 3), the latter increases by 15.5%, but the former by 84.3%. For specific subsectors some authors predict much faster growth. For example, the BAU scenario for data centres in Germany calculated by Klaus Fichter for the German Environmental Agency (see Figure 4) extrapolated until 2020 would lead to an increase of 396% (Fichter, Beucker et al. 2009).

3. Finally, most of the innovative technologies needed in the industrial, residential and transport sectors to increase their energy efficiency are partly based on ICT; fostering the use of ICT for energy efficiency beyond baseline- or BAU scenarios will therefore lead to a faster increase of ICT-related energy consumption – although this will be over-compensated for by the resulting ICT-related energy efficiency.

![Graph](image)

**Figure 4.** Development of the energy consumption of server san data centres in Germany including three future scenarios starting from 2008: (1) Business as usual, (2) half of data centres adopt best practices in efficient energy use (3) 90% of data centres adopt best practices in efficient energy use (Source: (Fichter, Beucker et al. 2009))
2.2 Scientific Interest in this Field

As a field of investigation, ICT-related energy consumption and energy efficiency (or “ICT and Energy” for short) can be viewed as a part of the interdisciplinary research field “ICT and Sustainability” which analyses the opportunities and risks of ICT for sustainable development. Placing the “ICT and Energy” topic in the “ICT and Sustainability” context has the advantage that systemic interactions between energy efficiency and other environmental, economic and social phenomena come to the fore.

2.2.1 Emergence of “ICT and Sustainability” as an Interdisciplinary Research Field

This interdisciplinary research field has at least three roots:

1. Research done by economists interested in ICT-related innovation as a driver of structural change. One of the first studies was “Dematerialisation: The Potential of ICT and Services” commissioned by the Finnish Ministry of the Environment (Heiskanen, Halme et al. 2001).

2. Environmental Informatics, a field of Applied Computer Science in which principles and systems for the processing of environmental information and environmental modelling are developed. The 15th EnvirolInfo conference, held at ETH Zurich in 2001, has already been devoted to the topic “Sustainability in the Information Society” (Hilty and Gilgen 2001).

3. Technology assessment (TA) and Life-Cycle Assessment (LCA) studies on ICT hardware with a tendency to broaden the perspective beyond hardware issues. Early work was done at IZT Berlin (Behrendt, Pfizter et al. 1998) and by Eric Williams (Williams, Ayres et al. 2002).

“ICT and Sustainability” today is a field of research which systematically investigates the actual and potential consequences of ICT for sustainable development. This covers both the ICT-related potential to enable largely dematerialized or “de-energized” production and consumption, the role of ICT in emerging economies, rebound effects from efficiency increases, as well as the (minimization of) environmental impacts of ICT production, use and disposal (Hilty 2008; Streicher-Porte, Marthaler et al. 2009).

The topic of this study, “ICT and energy”, can be considered a special case of “ICT and sustainability”, since both reducing the energy consumption of ICT and realizing the energy efficiency potentials induced by ICT systems are essential parts of strategies towards sustainable development.

2.2.2 Issues of Scientific Methodology

Our literature study revealed two methodological issues in current research on “ICT and energy”, defining the boundaries of the energy-consuming system and defining the baseline or “Business as Usual (BAU)” scenario for measuring relative energy efficiency, which corresponds to “system B” in our definition of ICT-related energy efficiency (Section 1.3.2).

Defining the boundaries of the energy-consuming system

The most striking methodological issue is the problem of defining the boundaries of the energy-consuming system. In the case of ICT-related energy consumption, this is the ICT system itself. In the case of “ICT for energy efficiency”, it is the energy-consuming system that is intended to be improved (regarding its energy efficiency) by the use of ICT.

Boundaries of the energy-consuming system can be drawn as narrow as possible, which means considering only the final energy consumption (e.g. the electric energy taken from the power socket which enters a device). This narrow perspective is useful to compare several energy-consuming systems which use energy from the same source, e.g. to compare different PCs powered by the same grid. However, such comparisons are not meaningful across different energy sources, e.g. when the energy consumed by data centres is compared to...
the energy consumed by road traffic. In this case, the systems should be enlarged (in upstream direction with regard to the energy supply chain) until matching energy sources are reached, e.g. fossil fuels used to generate power and fossil fuels converted to gasoline. If this is done, all losses occurring in the two energy supply chains (viewed from their common starting point in downstream direction) are accounted for.

In LCA methodology, the system is always viewed from its useful output: the unit of service (called functional unit) it is intended to produce. All energy and material transformations that are caused by producing this functional unit have to be included in the system. Even if the objective of a study is only to measure energy consumption and not the depletion of material resources, emissions and other environmental impacts, the material flows are important because providing materials consumes energy, too (sometimes called “embodied energy”). Energy and material flows are thus closely intertwined. There is good practice in LCA studies concerning the definition of system boundaries based on the goal and scope definition of a study. Even purely energy-related studies that are not interested in a “full LCA” should learn from the LCA practice in defining system boundaries.

There is a trade-off between the accuracy of a study and the aim to limit complexity; the larger the system, the more accurate the statements about the energy consumption caused for producing one functional unit; however, this implies higher complexity and higher efforts for data collection.

There is some confusion in the “ICT and environment” discourse regarding the meaning of the terms “direct” and “indirect”, because these terms are used differently in the various contexts that merge in this discourse. See Table 1 for a clarification. (The list may not be exhaustive.)

Table 1. Different uses of the terms “direct” and “indirect” in the “ICT and environment” discourse.

<table>
<thead>
<tr>
<th>Context</th>
<th>Expression</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life Cycle Assessment (e.g. OECD 2008)</td>
<td>“direct impact”</td>
<td>Environmental impact of the so-called foreground system, e.g. emissions of a chip factory</td>
</tr>
<tr>
<td></td>
<td>“indirect impact”</td>
<td>Environmental impact of the so-called background system, e.g. emissions of the power plant generating electricity for the chip factory</td>
</tr>
<tr>
<td>Material Flow Analysis</td>
<td>“direct flow”</td>
<td>A material flow that enters the system of the domestic economy</td>
</tr>
<tr>
<td></td>
<td>“indirect flow”</td>
<td>A material flow that is caused abroad by the fact that a good is imported, whereas the material itself does not enter the domestic economy</td>
</tr>
<tr>
<td>Energy consuming products (incl. ICT hardware)</td>
<td>“direct energy consumption”</td>
<td>The amount of energy consumed in a device during the use phase (final energy consumption during use).</td>
</tr>
<tr>
<td></td>
<td>“indirect energy consumption”</td>
<td>The amount of energy consumed to provide the device (“grey energy”, “embodied energy”) and/or to provide the final energy as well.</td>
</tr>
<tr>
<td>ICT effects (OECD 2009)</td>
<td>“direct effects of ICT”</td>
<td>First-order impacts of ICT as defined in Section 3.1</td>
</tr>
<tr>
<td></td>
<td>“indirect effects of ICT” or “enabling effects of ICT”</td>
<td>Second- and/or third-order impacts of ICT as defined in section 3.1</td>
</tr>
</tbody>
</table>
Defining the baseline or “Business as Usual (BAU)” scenario

In order to assess ICT-related energy efficiency, it is necessary to compare two systems, which we called A and B in Section 1.3.2. Very often, A and B are just different hypothetical developments of one system, i.e. A and B are scenarios. A is the scenario “with ICT application for energy efficiency” and B can be called the “baseline scenario” or “Business as usual (BAU) scenario”.

Very often, relative efficiencies are postulated without defining the BAU scenario. For example, Nath and Haas pointed out that the Smart2020 study (GeSI 2008b) is not very explicit about the BAU scenario. According to Smart2020, ICT could enable approximately 7.8 Gt CO₂-equivalents of global emissions savings in 2020. This would amount to 15 % of emissions in 2020 based on a BAU estimation, economically it would translate into approximately € 600 billion of cost savings. However, the study does not define the BAU scenario (except for a few assumptions such as GDP growth). It would be essential to know what other components of efficiency (not related to ICT) are included in the BAU scenario and how they are quantified; in this regard the study refers to the Fourth Assessment Report of IPCC, which however explicitly negates to define a BAU scenario (Nath and Haas 2008).

2.3 Interest of the ICT Sector in the Field

As an indicator of the interest of the ICT sector in ICT-related energy issues, the considerable number of initiatives and studies from the private sector is documented in this section. A more comprehensive overview is provided by the OECD’s Working Party on the Information Economy (WPIE) in their latest report (OECD 2009).

2.3.1 Private-Sector Initiatives

The 80 plus Program

80 PLUS is a platform “that unites electric utilities, the computer industry and consumers in an effort to bring energy efficient technology solutions to the marketplace”.7 The main goal is to integrate more energy-efficient power supplies into desktop computers and servers. 80 PLUS certifies power supply products for high efficiency performance in server applications.

The Electronic Industry Code of Conduct (EICC)

EICC is a code of best practice adopted by nearly 30 major electronics brands and their suppliers.8 The goal is to improve conditions in the electronics supply chain. Co-operating with GeSI, EICC is creating and implementing a set of tools and methods with the aim of ensuring the standards in the Code are upheld throughout the electronics supply chain.

The “Green Grid”

The “Green Grid” is a global consortium of over 100 members – IT companies and professionals – dedicated to advancing energy efficiency in data centres and “business computing ecosystems”.9 A “Framework for Data Center Energy Productivity” is intended to make possible comparisons of data centres. It is described in one of three white papers published with support of the US Department of Energy (Green Grid Consortium 2008).

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7 See http://www.80plus.org/.
9 See http://www.thegreengrid.org.
IBM’s Big Green Project
According to IBM, this will be a $1 billion project with the aim of increasing the energy efficiency of IBM products: “New IBM products and services, announced as part of Project Big Green, include a five-step approach to energy efficiency in the data centre that, if followed, will sharply reduce data centre energy consumption and transform clients’ technology infrastructure into “green” data centres, with energy savings of approximately 42 percent for an average data centre.” See background document (Ebbers, Galea et al. 2008).

The Climate Savers Computing Initiative
Climate Savers Computing is a non-profit group of eco-conscious consumers, businesses and conservation organizations started by Google and Intel in 2007, which collaborates with the U.S. Environmental Protection Agency’s Energy Star program. The initiative was started in the spirit of WWF’s Climate Savers program which mobilized over a dozen companies in the early 2000’s to cut carbon dioxide emissions, with the aim of demonstrating that reducing emissions can be good business. The goal was to promote development, deployment and adoption of smart technologies that could both improve the efficiency of a computer’s power delivery and reduce the energy consumed when the computer is in an inactive state.

As participants in the Climate Savers Computing Initiative, computer and component manufacturers committed to producing products that met specified power-efficiency targets, and corporate participants committed to purchasing power-efficient computing products. The mission was to reduce global CO2 emissions from the operation of computers by 54 million tons per year by 2010.

2.3.2 Industry-Supported Studies

Saving the climate @ the Speed of Light
This study was produced in a joint project of WWF and ETNO, the European Telecommunications Network Operator Association (Pamlin and Szomolányi 2006). Started in 2004, the project provided a road map for reducing CO2 emissions in the EU and beyond. This road map aimed to close the gap between academic studies on the environmental impacts of ICT and policy making. The full road map is available for free download.

WWF has also been active in the developing world on ICT and sustainability. WWF-India and Wipro Limited, a company providing global IT and R&D services, have had an initiative to explore the use of IT to drive sustainable development. WWF-India and Wipro signed in 2008 a partnership agreement for sustainable development.

Smart 2020
This is a pivotal industry-supported study done by the McKinsey consultancy and organized by The Climate Group and the Global e-Sustainability Initiative (GeSI). The study’s main conclusion is that the consequent use of ICT towards energy efficiency throughout the entire economy could deliver by the year 2020 CO2 savings five times larger than ICT’s own impact (GeSI 2008b). Smart 2020 identified the greatest savings as follows: 2.03 Gt CO2e (CO2 equivalents) saved by smart grids, 1.68 Gt CO2e by smart buildings, 1.52 Gt CO2e by smart logistics and 0.97 Gt CO2e by smart motor systems.

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As for the “smart logistics”, the study predicts that new software could promote an inter-modal shift towards more efficient means of transport (mainly trains), eco-driving, route optimisation and inventory reduction. Furthermore the report notes that “although this figure is relatively modest compared to reductions offered by other ICT-driven solutions in this report, the opportunities to make the logistics industry more efficient have important economic considerations, since it operates such a high-value market” (GeSI 2008b).

2.4 Political Relevance of the Field

This section provides a survey of political initiatives that have created the political awareness for “ICT and energy” issues at the EU, OECD, and UN level. The focus is on the EU, however without investigating the level of member states. For a survey on national initiatives in OECD members (covering most of EU member states as well) we refer the reader to the latest report by the OECD’s Working Party on the Information Economy (OECD 2009).

2.4.1 EU Initiatives: Emergence of the Issue “ICT for Energy Efficiency”

Nowadays in the EC the main political driver is the new 20-20-20 commitment for the year 2020 described in greater detail below under the section heading “Top-level commitment to the future”. Although this development began in the EC in the mid-Nineties, it received further impetus in 2006 through the granting of the Nobel Prize to Al Gore and the Intergovernmental Panel on Climate Change (IPCC), and the publication of the report by the former World Bank Chief Economist Sir Nicholas Stern (Stern 2006).

As regards ICT for energy efficiency, a new trend is to be found in the improved collaboration between the DGs for Information Society and Media (INFOSO) and for Energy and Transport (TREN). In the words of the Commission itself, “bringing together sectors as diverse and distinct as ICTs and energy is rather challenging, as the approaches, and even timelines for investment, are quite contrasting (short-term for ICTs versus very long-term for energy)” (European Commission 2008c).

DG TREN adds to the mix its dual focuses on mobility (as one might expect under “transport”) and Intelligent Grids and Demand Side Management DSM (as one might expect under “energy”). Sometimes, however, in the EC mobility is treated as separate from Energy Efficiency, perhaps for expediency in the organization of calls.

This section looks next at historical background material behind this collaboration between DGs.

Formal Arrangements

One should bear in mind the different types of activities pursued by the European Commission in its work programme. The concept of “initiatives” as it is used here includes Commission terms such as “thematic strategies” and “action plans” (see (Pallemaerts, Wilkinson et al. 2006) for explanations), which are associated with a “white-paper” communication process. These intermediate steps help relate the “research projects” to policymaking. The normal sequence of these Commission activities thus proceeds from the research programme (see Figure 5) by means of an Impact Assessment process (Ruddy and Hilty 2007) and “white-paper” communication process in many cases to become a form of law.
The conceptualization of research priorities is in the hands of various Commission “services”, i.e. Directorates-General (DGs); but much awarding and funding of research is organized by a dedicated DG – the DG Research. In this way, the so-called framework programmes (FP) developed: “Various Community research activities, mainly in the energy sector, were combined in 1984 into a five-year framework programme (FP)” (Banchoff 2002). Banchoff deplores the lack of Commission power to harmonize the research funding by Member States: “the equation of research policy with the framework programme – a centrally administered distributive policy – impeded efforts to define it more broadly in regulatory terms as the co-ordination and integration of national [research] policies” (Banchoff 2002).

**Historical Background on EU Research on Energy Consumption and Energy Efficiency**

The historical starting point for energy efficiency in Europe was the founding of the European Coal and Steel Community (ECSC) in 1952. The ECSC predated the establishment of the European Economic Community proper six years later in 1958 through the Treaty of Rome. “Research policy is as old as the EU itself” claims (Banchoff 2002), p.7, looking back to 1958, recounting its original entanglement with nuclear power, a second important aspect of energy policy in the early days right after coal and steel.

From a common interest in coal, steel and nuclear power, European integration proceeded with a view to securing peace for future generations, but employed largely economic incentives to motivate member states to surrender sovereignty in carefully conceded increments. Rebuilding the Continent in the 1950’s after World War II entailed seeking economies of scale and efficiency. One example of this campaign can be cited from EU Member State Germany where there had been a government body to promote efficiency including energy efficiency, *Rationalisierungskuratorium der Deutschen Wirtschaft e.V.* since 1921, which after the war re-established its offices in Frankfurt/Main.

Energy efficiency in its core may be said to focus on the technical aspects of process management. In addition, though, there are organizational aspects such as infrastructure renewal and urban planning including building insulation that traditionally characterize the field. In the 1970’s the oil crisis sparked interest in energy efficiency, and EU Member States granted subsidies and tax breaks to promote it. Unlike them, the EU had no power to levy taxes, but identified other areas where it could expand its competencies by comparing and analysing Member States successes through research, and issue directives.

In the 1980 and 1990’s, traditional signal processing was gradually supplanted by the digital technology. This new technology wave swept through the economy based on an increase in the usage of digital signals, causing
it to be dubbed the Digital Revolution. As this trend spread, the potential became more evident and begged to be utilized along with the older, larger body of energy efficiency measures described above.

**Commission Measures on ICT for Energy Efficiency (ICT for EE)**

In 2006, an action plan for energy efficiency was issued (in general terms, EC 2006), which included a mobility chapter. Given this relatively early start on that subtopic, the Commission did an Impact Assessment on Intelligent Transport Systems (ITS) in 2008 (European Commission 2008b). and one on ICT for EE (European Commission 2009b). As documented, for the Intelligent Transport System (ITS) Action Plan, “an inter-service group composed of representatives of the Directorates-General concerned (SG, ECFIN, ENTR, EMPL, ENV, INFSO, RTD, TAXUD and JRC) was created to accompany the impact assessment. The group met four times between January and May 2008 and provided input to the impact assessment. In addition to this inter-service group, an ITS Steering Group was set up in April 2007 with Directors from five different Directorates-General: INFSO, RTD, ENTR, ENV and TREN. This Group provided guidance on the preparation of the ITS Action Plan” (European Commission 2008b). DG TREN has a Greening transport package containing its Intelligent Car Initiative from 2006 and its ITS programme from 2008.

In May 2008, a first official communication specifically dedicated to ICT for EE was issued stating that “It is initially proposed to focus on the power grid, energy-smart homes and buildings and smart lighting (due to their relative importance and potential for improvement). Other sectors with considerable energy-saving potential are the manufacturing industry and transport (estimated, by 2020, at around 25 % and 26 % of their total primary energy consumption). […] The need to improve the power grid is well documented in the Action Plan for Energy Efficiency” (European Commission 2008b), p. 6.

In November 2008, the “Second Strategic Energy Review – Securing our Energy Future” (European Commission 2008h) was published by DG TREN as a “wide-ranging energy package”. That package contained another package, “a new 2008 Energy Efficiency Package” (page 11) with an emphasis relevant here on reinforcing energy efficiency legislation on buildings and energy-using products. Impact assessments have been done both on the Energy Performance of Buildings (European Commission 2008g) and the Energy Efficiency of Products (European Commission 2008a). These products were originally covered by the Energy Labelling Directive for Household Appliances (ELD) now to be recast as one of the elements of the Action Plan on Sustainable Consumption and Production under the lead of DG ENV and on Sustainable Industrial Policy under the lead of DG ENTR recently reconciled as (SCP/SIP) (p. 3).

In January 2009, the second official Communication on ICT for EE was issued according to the Roadmap, (European Commission 2009a) Section 12, pp.41. ff.

Initiatives more directly related to ICT include the “EU Stand-by Initiative” (European Actions to Improve the Energy Efficiency of Electrical Equipment while either OFF or in Stand-by mode). Since then a draft “Code of Conduct on Energy Efficiency of Data Centres has been issued (version 0.8 of 8.04.2008) prepared by the Directorate-General JRC, Joint Research Centre, Institute for Environment and Sustainability, Renewable Energies Unit (JRC 2008).

The creation of “technology platforms”, such as the SmartGrids European Technology Platform (ETF), comprises a step towards organizing in the newer form “initiative”, such as the “European electricity grid initiative”. Such initiatives form parts of the Strategic Energy Technology Plan (SET Plan) (for FAQs see (IHS 2008)). The SET Plan is an attempt to improve collaboration between the EU and member states dating from November 2007.

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2.4.2 OECD
The OECD held a first workshop on “ICTs and Environmental Challenges” in Copenhagen in May 2008. Based on this Workshop and the OECD Ministerial Meeting on the Future of the Internet Economy in Seoul in June 2008, a high-level conference on “ICTs, the environment and climate change” was held by OECD and the Danish Ministry of Science, Technology and Innovation in Helsingor on 27-28 May 2009.16 Outcomes of this workshop will contribute to work towards the OECD Council at Ministerial Level in June 2009 and will be relevant in the context of the United Nations Climate Change Conference, 7-18 December 2009 in Copenhagen, Denmark (COP15).


2.4.3 UN Initiatives
The International Telecommunication Union (ITU), the oldest UN agency and organizer of the World Summit on the Information Society (WSIS, 2003-2005), has set up a Focus Group (FG) on ICTs and Climate Change.17

ITU has as constituent members most of the world’s leading telecommunication companies. They are involved in agreeing on future de-facto standards for measuring the effects of the use of ICT on the environment and second-order impacts as well. The current status of the FG’s work is that in April 2009 results will be presented to the ITU’s influential Telecommunication Standardization Advisory Group (TASG). One further proposal pending approval is to make ITU the world’s premier clearinghouse for ICT and climate change.

After the first year of this Focus Group’s work, the ITU has passed a resolution with the aims of

- “Creation of a framework for energy efficiency in the ICT field, taking account of WTSA Resolution 73” (ITU-T 2008), and
- Creation of a central “repository and knowledge base on the relationships between ICTs and climate change”; with the intention of receiving a “report on progress on the application of this resolution annually to the ITU Council and to the 2012 world telecommunication standardization assembly” (ITU-T 2008), p. 3.

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17 See http://www.itu.int/ITU-T/climatechange/.
3 State of the Art

3.1 Conceptual Framework

The conceptual framework used to structure the issue is based on a product life-cycle perspective, which is applied to two types of life cycles: (i) the life cycle of a given ICT product or service (such as a PC, a mobile phone, an operating system, a telecommunication service) and (ii) other life cycles that are modified through the availability of the information or communication service (IC service) provided by the first life cycle. We introduce the term “linked life cycles” to refer to this concept further on.

Figure 6 shows the generic life cycle model that will be used as a basic building block for the linked life-cycle framework. However, any other life cycle model could also be used, provided it views the life cycle as a system that has the purpose of providing a service at the cost of mass and energy that flow through it. On their way through the system, mass and energy are transformed. Roughly speaking, the production phase transforms input resources to a product and the use phase transforms the product to waste while providing the desired service. Both the physical inputs and outputs of the system, i.e. all flows crossing the system boundary, are evaluated with regard to their environmental impacts.

Energy consumed is related to the functional unit chosen, i.e. divided by the number of functional units that are generated during the use phase. This implies that the service life – the length of the use phase – of a durable product is an essential parameter in an LCA. Example: If the system under study is the PC life cycle and the functional unit is defined as “1 year of PC use”, the energy consumption of the non-use phases (production and end-of-life) is cut to half if the PC is used for 6 instead of 3 years.

![Diagram of the ecological product life cycle](image)

Figure 6. Generic model of the ecological product life cycle.

The effect of ICT as an enabling technology, namely as an enabler of change in production and consumption with the potential to mitigate environmental impacts, can be conceptualized with the approach of linked life cycles, i.e. by showing how the ICT life cycle can affect other life cycles. Figure 7 illustrates the concept. The environmental impacts of the ICT life cycle (shown at the bottom) are also called “first-order impacts” or “primary impacts” of ICT. The modification of the impacts occurring at the level of the second life cycle (shown at the top) are called “second-order effects” or “secondary effects” of ICT, because they are indirectly caused through the modification of the second life cycle by the availability of the IC service. The terminology traces back to EMPA (2005) and the sources cited there.

The potential modifications of an IC service to a product life cycle can be described generalizing a typology of relationships between telecommunications and transportation, which is based on the idea to differentiate among optimization, substitution and induction effects: An IC service can help to better organize traffic (optimization), replace traffic (substitution) or generate additional demand for traffic (induction). This typology is now generalized to all ICT applied in any field of application and interpreted form a life cycle perspective.
Optimization can refer to any phase of the life cycle in our framework, including the design phase, which usually is not regarded part of the life cycle in LCA methodology but included here as an important link between the two life cycles (see Figure 7). The red arrows refer to effects of the IC service which modify the efficiency of parts of the other life cycle, i.e. they represent optimization potentials.

Substitution and induction refer to the demand for the service which is affected by the availability of the IC service. If the original service is replaced by the IC service, the product becomes obsolete (at least in its function to provide the service), which is a substitution effect. However, the demand could also increase as a consequence of the IC service (such as the demand for paper increases due to the availability of inkjet printers), which is an induction effect.

Figure 7. Illustration of the “linked life cycles” concept. The information or communication service provided by the ICT life cycle at the bottom can modify the life cycle of another product (providing any service) in two ways: by modifying the design, production, use or end-of-life phase of that product (red arrows) or by influencing the demand for the service it provides (yellow arrow). Source: Empa

Table 2 shows how this typology can be interpreted in more detail in the linked life-cycle framework. This table can also serve as a checklist to screen a given IC service for potential second-order impacts.

An interesting special case occurs if both life cycles are ICT life cycles. In this case, ICT has second-order effects in the ICT sector. Example: The IC service is PC system software, the other life cycle PC hardware. If the software helps the hardware to come closer to the ideal of load-proportional power demand, it has an optimization effect on the use phase. If a new software version demands for more hardware capacity, it increases the demand for PC hardware by shortening the use phase. The latter effect has been called Software-Induced Hardware Obsolescence or SIHO (Hilty 2008).
Table 2. Explanation of the Linked Life Cycle Approach: How an information/communication service can influence the life cycle of another product (Source: Empa)

<table>
<thead>
<tr>
<th>Contact point</th>
<th>Effect of IC service</th>
<th>Second-order environmental impact</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design phase</td>
<td>Same design with less effort</td>
<td>Positive, small potential (no multiplication)</td>
<td>Conventional CAD 3D printing</td>
</tr>
<tr>
<td>(optimization)</td>
<td>New design enabling more efficient production</td>
<td>Positive, high potential</td>
<td>CIM Complexity reduction, designing multi-use parts</td>
</tr>
<tr>
<td></td>
<td>New design enabling more efficient use</td>
<td></td>
<td>Energy-efficient architecture</td>
</tr>
<tr>
<td></td>
<td>New design enabling longer use</td>
<td></td>
<td>Design for maintainability</td>
</tr>
<tr>
<td></td>
<td>New design enabling more efficient recycling</td>
<td></td>
<td>Design for recyclability</td>
</tr>
<tr>
<td>Production phase</td>
<td>More efficient production process</td>
<td>Positive, high potential (unless already used)</td>
<td>Process optimization Integrated process chain Optimized logistics</td>
</tr>
<tr>
<td>(optimization)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use phase</td>
<td>More efficient use</td>
<td>Positive, high potential</td>
<td>Energy management of user appliances</td>
</tr>
<tr>
<td>(optimization)</td>
<td></td>
<td></td>
<td>Intelligent heating, cooling and ventilation</td>
</tr>
<tr>
<td></td>
<td>Longer use</td>
<td>Positive, high potential</td>
<td>Smart grids</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>End-of-life phase</td>
<td>More efficient end-of-life treatment</td>
<td>Positive, high potential</td>
<td>Smart sorting techniques for recycling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand for the</td>
<td>Replaced by IC service (substitution)</td>
<td>Positive, high potential</td>
<td>Virtual meetings replace travel</td>
</tr>
<tr>
<td>service</td>
<td>Reduced demand (increased awareness)</td>
<td>Positive, high potential</td>
<td>Reduced energy consumption due to smart metering</td>
</tr>
<tr>
<td></td>
<td>Increased demand (induction)</td>
<td>Negative, high potential</td>
<td>Increased paper consumption due to PC printers Hardware obsolescence due to new, demanding software versions</td>
</tr>
</tbody>
</table>
3.2 EU-Funded Projects and Studies Contributing to the Field

Over the early decades of the EU’s existence, the Union’s influence over the field of energy gradually included more ICTs, as the technologies evolved and converged in new contexts. This was organized mainly under the Directorate-General for Transport and Energy (DG TREN). In the mid-1990s, a new Directorate-General was created for the emerging Information Society (DG INFSO). Henceforth, it shared with DG TREN the competence for energy and ICT.

The projects listed immediately below in approximate chronological order were carried out under DG INFSO, whereas DG TREN’s influence can be seen more distinctly in its lead role in the super-programme Intelligent Energy Europe (IEE) and in projects described at the end of this section under headings such as Buildings, metering and the grid and Intelligent Transport Systems. The relative importance of the sectors is dealt with under the “Studies” heading, leading into the next section with its discussion of how to measure the direct energy consumption of ICT.

3.2.1 EU-Funded Projects

Early Discourse-Oriented Projects

Global Society Dialogue: In September 2001, DG INFSO organised a workshop entitled “The Challenge of the Digital Divide”. The workshop was held in Vienna by the Global Society Dialogue (GSD) project supported by the European Commission and carried out by the Research Institute for Applied Knowledge Processing (FAW) based in Ulm, Germany. The workshop was documented in a brochure (Schauer and Radermacher 2001).

ASIS: Under the 5th Framework Programme, a series of projects involving Information Society Technologies (IST), entitled “Living and Working in the Information Society,” followed up on previous projects organized under Advanced Communications Technologies and Services (ACTS) and Esprit. In 1998, ACTS participants joined a new Alliance for a Sustainable Information Society (ASIS) assembled by Klaus Tochtermann at FAW in Germany. The Global Society Dialogue project was carried out in 2001 by DG INFSO under Robert Pestel and FAW’s Thomas Schauer. This was followed-up with the Terra 2000 project on the optimisation of ISTs’ contribution to sustainability, also with DG INFSO, Robert Pestel, the RAND Corporation and FAW Thomas Schauer, and Barry Hughes of International Futures (IFs).

Digital Europe: Following good experience in the U.K., the Forum for the Future conducted a project known as Digital Europe, which produced as series of studies on telework and dematerialization, such as “Digital Europe – Virtual Dematerialisation”, September 2003, as well as a book edited by James Wilsdon (Wilsdon 2001).

EPIC-ICT: Under the 6th Framework Programme a project called EPIC-ICT was conducted to measure ICT products’ environmental impacts.

IEE Projects

The Efficient Servers project was part of the super-programme Intelligent Energy Europe (IEE) described in section 5 below. The project aimed to demonstrate the large potential savings that could be achieved through efficient technology in the area of servers and to drive market development towards energy-efficient servers. The project consortium included the Austrian Energy Agency (as project coordinator), IBM, Sun, University of Karlsruhe, the French energy agency ADEME, and Robert Harrison Associates LTD. Compilation of IDG data

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from both the USA and the EU in various scenarios showed that 20 - 70 % savings could be achieved depending on the application. The Efficient Servers project lasted for two years culminating in the spring of 2009.

The SAVE programme was a further programme inside Intelligent Energy Europe. SAVE included many projects such as those chosen for their ICT content and listed below. SAVE did not include pilot actions for large smart buildings, which are covered under CIP-PSP 2008 Work Programme Theme 2: “ICT for Energy Efficiency and Sustainability in urban areas” (European Commission 2008d).

Odyssee was another well-known project within IEE, which produced two databases: one on energy efficiency data & indicators, and another on policy measures. The databases are still continually updated and access is free to registered users. Odyssee was included in a list of innovative projects by ECEEEE European Council for an Energy Efficient Economy.21

ARTEMIS Projects

The ARTEMIS Joint Undertaking (JU) was set up as an early major initiative to bring private-sector research actors together with the European Commission and a large number of contributing Member States. An association was formed in 2007 for R&D actors (such as DaimlerChrysler, Nokia, Philips Electronics, STMicroelectronics, and Thales) in Advanced Research & Technology for Embedded Intelligence and Systems22 to support the ARTEMIS JU programme. It issues its own calls.

- One major projects done in the context of the Artemisia Association was CESAR; it was intended to reduce development time, and had a total cost of Euros 58.5 million.
- Another major project is SOFIA on improving the interoperability among multi-vendor devices, which started in 2009 for three years with a budget of Euros 36.5 million.
- SCALOPES also started in 2009, for two years with Euros 36 million to be used for an “industrially sustainable path for the evolution of low-power multi-core computing platforms.”
- eDIANA is another such project running from Feb. 1/2009 to Jan.31/2012 called Embedded Systems for Energy Efficient Buildings (eDIANA) addresses the need of achieving energy efficiency in buildings through innovative solutions based on embedded systems. It is funded with Euros 17.3 million for 3 years from 1.1.09.

Electricity Supply and Demand Projects

CLEVERFARM was an FPS project for the advanced management and surveillance of wind farms.23 It began making wind farms more intelligent by providing remote measuring of the status of the wind farm, and sending warnings to the maintenance crew if something goes wrong. It will also predict its own output and schedule maintenance.

A similar project called ANEMOS dealt with Development of a Next Generation Wind Resource Forecasting System for the Large-Scale Integration of Onshore and Offshore Wind Farms.24

The POWERSAVER project conducted in 2006 aimed to improve household appliances with intelligence.

The Intelligent Metering project looked at energy and water savings which could be obtained in local and regional public sector buildings.25

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22 See http://artemisia-association.org/.


The SE-POWERFOIL project was devoted to the development of roll-to-roll manufacturing technology for the production of cost-effective, high-efficiency, flexible photovoltaic modules.

**Intelligent Transport Systems (ITS) Projects**

ITS projects seek to apply ICTs to transport. The main innovation is said to be the integration of existing technologies to create new services. ITSS can be applied in every transport mode (road, rail, air, water) and services can be used by both passenger (Intelligent mobility) and freight transport.

The FREIGHTWISE project developed theoretical models and Inter-modal Management Services, which are now being implemented as parts of the FREIGHTWISE Framework (FWF).

INTElligent inteGration of RAILway systems (INTEGRAIL),26 was an Integrated Project that ran for two years ending in December 2008. It had a budget of 20.66 million Euros, half of which came from the Commission. It was intended to test an all-pervasive, wide-band communication infrastructure providing digital data links between trains and ground installations, with the hope that it could to be used as the future reference standard in railways.

“Intelligent roads” (INTRO), a synergistic clustering action led by FEHRL (Forum of European National Highway Research Laboratories),27 strove to combine new and existing sensor technologies in pavements and bridges in order to prevent accidents, enhance traffic flows and significantly extend the lifetimes of existing infrastructure. It ran from 2005 until 2008 and had a budget of 3.5 million euros of which 2 million euros were from the Commission.

Modular urban guided rail systems (MODURBAN),28 was a coordination action to design, develop and test an open common core system architecture and its key interfaces to pave the way for the next generations of urban-guided public transport systems. It ran until 2008 and had a budget of 19.42 million euros, half of which came from the Commission.

**3.2.2 EU-Funded Studies**

**The Future Impact of ICTs on Environmental Sustainability**

The Institute for Prospective Technological Studies (IPTS) at the Commission’s Joint Research Centre in Sevilla, Spain, commissioned an early study – in fact, “the first quantitative projection” of the impact of ICTs on environmental sustainability (Erdmann, Hilty et al. 2004; Hilty, Arnfalk et al. 2006). Using a methodology combining qualitative scenario-building and quantitative modelling, the general conclusion reached was that ICTs could either improve the situation, reinforcing positive effects on the environment, or they could worsen the situation. This conclusion suggested that environmental policies have to be designed in such as way as to ensure that ICT applications make a beneficial contribution to environmental outcomes, and, at the same time, suppress rebound effects. The sectors “housing” and “passenger and freight transport” were identified as crucial with regard to ICT applications.

**Impacts of information and communication technologies on energy efficiency**

Looking at possible future developments in the area of ICTs and energy efficiency as well, this study (Bio-Intelligence-Service 2008) constructed “business as usual” (BAU), and Eco-scenarios. In the Eco scenario, ICTs

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26 See [http://www.integrail.info/structure.htm](http://www.integrail.info/structure.htm).


were shown to provide the largest energy efficiency gains in the area of building Heating, Ventilation and Air-Conditioning (HVAC). The total possible gains (for the Eco scenario) would outweigh seven times ICT’s own CO₂e footprint.

3.3 Measuring ICT-Related Energy Consumption

3.3.1 Approaches Based on Final Energy Consumption

A large number of studies focus on the final energy consumption of ICT in the use phase (IBM 2006; EPA 2007; Koomey 2007; Bio-Intelligence-Service 2008; DEFRA 2008; Fichter, Clausen et al. 2008; Fraunhofer IZM-ISI 2008). The studies we reviewed calculate the energy consumption by ICT end-user devices (such as PCs, telephones) and in some cases also by ICT infrastructure (such as data centers, servers, routers). This is done for a given geographic area with a bottom-up approach based on the stock of ICT devices and infrastructure and on their assumed average energy consumption.

The studies evaluated have similar but not the same scope with regard to the ICT considered. Thus, in some cases data centres and telecom networks are included and in some others not. Further, in the studies we evaluated, the authors consider different peripherals (see Table 3 and Table 5). In general, the ICT evaluated is rather poorly documented, particularly regarding the representative devices selected for calculations. Contrary to that, the procedure followed to estimate the stock of ICT units is mostly well explained. Usually, statistics from industry on shipments and stock turnover are applied. However, also assumptions on the lifespan of the devices and infrastructure have to be made, which introduces uncertainties in calculations. The procedure followed to determine the average energy consumption of the different ICT items considered is described with different levels of detail. Here also assumptions on usage patterns are made, which might contribute to uncertainty.

With regard to the last point, for example, important differences in energy consumption values can be expected for ICT or even for a category of ICT, such as data centres, depending on whether their related cooling and lighting services were considered or not (Cremer, Eichhammer et al. 2003; Bio-Intelligence-Service 2008; BITKOM 2008). Another issue that makes it difficult to compare results form different studies is the scarcity of standardized procedures for determining the typical use of ICT devices such as computers when assessing their electricity consumption (Jönbrink and Zackrisson 2007). In the so called EuP preparatory studies it has been carefully documented how the energy consumption was calculated for a wide range of ICT devices, using test standards when they were available. These EuP preparatory studies and their values on energy consumption are quoted in a large number of studies and they will certainly contribute to a harmonization of calculation procedures in European studies. An additional support can be found in the specifications for test procedures to be followed for computers within the ENERGY STAR Program and in the European Standard EN 62018 for methods of measurement of electrical power consumption by ICT devices in different use modes.

The differences in the scope definition and methodology followed in the studies evaluated makes it difficult to compare results.

Table 3 presents values of final energy consumption or CO₂ emissions caused by ICT worldwide. Interestingly, most of these studies only present CO₂ emission values and not the energy consumption values that must be behind. This does not only obscure the origins of the results, it also adds uncertainty to them because additional (implicit) assumptions about power generation and distribution are included.

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29 TheEuP preparatory studies were conducted in preparation for the Directive 2005/32/EC on the eco-design of Energy-using Products (EuP), such as electrical and electronic devices or heating equipment. This Directive provides coherent EU-wide rules for eco-design and ensure that disparities among national regulations do not become obstacles to intra-EU trade.

Table 3. Estimates of ICT-related energy consumption or CO₂-emissions worldwide

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>Energy consumption or CO₂ emissions</th>
<th>ICT types included</th>
<th>Life cycle phases considered</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Use phase</td>
<td>All phases considered</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Mingay 2007b) with additional information from (Gartner 2007)</td>
<td>2006</td>
<td>460 Mt CO₂ (^1)</td>
<td>600 Mt CO₂ (^1)</td>
<td>PCs (desktop and laptop), servers and cooling, fixed and mobile telecommunications, local area networks (LAN), office telecommunications and printers.</td>
</tr>
<tr>
<td>(Malmodin and Jonsson 2008)</td>
<td>2007</td>
<td>n.a.</td>
<td>650 Mt CO₂</td>
<td>Fixed and mobile telecommunications, other ICT commercial use, other ICT households use</td>
</tr>
<tr>
<td>(GeSI 2008b)</td>
<td>2007</td>
<td>640 Mt CO₂</td>
<td>830 Mt CO₂</td>
<td>PCs and peripherals (workstations, laptops, desktops, monitors, printers), IT services (data centres and their component servers, storage and cooling), and telecommunications networks and devices (network infrastructure components, mobile phones, chargers, broadband routers, IPTV boxes)</td>
</tr>
<tr>
<td>(Koomey 2007)</td>
<td>2005</td>
<td>123 billion kWh</td>
<td>123 billion kWh</td>
<td>Servers (high-end, mid-range and volume servers) and cooling and auxiliary equipment associated to server power</td>
</tr>
</tbody>
</table>

\(^1\) Mingay used an emission factor of 0.6 kg CO₂/kWh electricity

Table 4 presents the results of the Study by Bio Intelligence Service, which calculated the final energy consumption of ICT devices in the use phase only (Bio-Intelligence-Service 2008).

Table 5 presents server-related consumption values in the USA, also based on final energy consumption in the use phase. Energy consumption related to servers as reported by Koomey is comparable to the consumption by color TV sets in the US., the EPA value for data centers is much higher, corresponding to the electricity used by the entire US transportation manufacturing industry (which includes the manufacture of ships, trucks, automobiles and aircraft).
Table 4: ICT-related energy consumption (use phase only) in EU-25 (Bio-Intelligence-Service 2008).

<table>
<thead>
<tr>
<th>Year</th>
<th>Energy consumption</th>
<th>ICT types included</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Amount</td>
<td>Assumptions</td>
</tr>
<tr>
<td>2007</td>
<td>34 TWh/a</td>
<td>The installed base of servers was calculated based on (Fichter 2007; Koomey 2007)</td>
</tr>
<tr>
<td>2005</td>
<td>29.1 TWh/a</td>
<td>Servers and data centres: small to large centres and infrastructure including air conditions systems, ventilation systems, lighting systems, switches and uninterruptible power supplies (UPS).</td>
</tr>
<tr>
<td>2005</td>
<td>14.3 TWh/a</td>
<td>Core telecom networks and TV/radio broadcasting: this category contains copper or optical fibre telecommunications lines with respective terminal, router and switches. We also cover Radio/TV broadcast equipment including radio relays, directorial radio antennas, etc.</td>
</tr>
<tr>
<td>2005</td>
<td>13 TWh/a</td>
<td>Cellular phone networks: this category contains mobile phone telecommunications of the 2nd (GMS/GPRS) and 3rd generation (UMTS/WCDMA) with base transceiver stations (node B), main switch controls and other network components including their infrastructure (cooling, etc)</td>
</tr>
<tr>
<td>2005</td>
<td>56.4 TWh/a</td>
<td>Total ICT infrastructure, the sum of the previous 3.</td>
</tr>
<tr>
<td>2005</td>
<td>42 TWh/a</td>
<td>Computers: Desktop computers, laptops, and CRT/LCD Monitors.</td>
</tr>
<tr>
<td>2005</td>
<td>54 TWh/a</td>
<td>Television: CRT (cathode ray tube), LCD (liquid crystal diode), PDP (plasma display panel), RP (rear projection), TVs and TV component units.</td>
</tr>
<tr>
<td>2005</td>
<td>7.8 TWh/a</td>
<td>Imaging equipment: Inkjet- and electro photography based copiers, printers and multifunctional devices in monochrome and colour.</td>
</tr>
<tr>
<td>2005</td>
<td>0.5 TWh/a</td>
<td>Mobile devices: digital cameras, camcorder, etc</td>
</tr>
<tr>
<td>2005</td>
<td>27.8 TWh/a</td>
<td>Audio systems: compact systems, stereo systems and clock radios.</td>
</tr>
<tr>
<td>2005</td>
<td>4.5 TWh/a</td>
<td>VHS/DVD equipment</td>
</tr>
<tr>
<td>2005</td>
<td>9.1 TWh/a</td>
<td>Set-Top-Boxes: personal video recorders</td>
</tr>
<tr>
<td>2005</td>
<td>4.3 TWh/a</td>
<td>Telephones: DECT (cordless) telephones and smart phones (the latter includes phones with many additional functions)</td>
</tr>
<tr>
<td>2005</td>
<td>1 TWh/a</td>
<td>Fax machines</td>
</tr>
<tr>
<td>2005</td>
<td>4.1 TWh/a</td>
<td>Modems</td>
</tr>
<tr>
<td>2005</td>
<td>2.7 TWh/a</td>
<td>Mobile phones</td>
</tr>
<tr>
<td>2005</td>
<td>158.1 TWh/a</td>
<td>Total ICT end-use-devices</td>
</tr>
<tr>
<td>2005</td>
<td>214.5 TWh/a (8 %)</td>
<td>Total electricity consumption in EU-25 = 2691 TWh/a (Eurostat)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total ICT (end-use-devices + infrastructure)</td>
</tr>
</tbody>
</table>
The Role of ICT in Energy Consumption and Energy Efficiency

3.3.2 The Link between Energy Consumption and CO₂ Emissions

The consumption of energy by ICT -be it during the use phase or during the whole life cycle- has associated CO₂ emissions, which are released basically during the generation of the electricity. In some of the studies providing estimates of the energy consumption of ICT, the associated CO₂ emissions are estimated as well.

The CO₂ emissions are of general concern because of their impact of atmospheric phenomena such as global warming (IPCC 2006). However, even though CO₂ is the anthropogenic gas which plays the main role in the global warming, there are further “greenhouse gases” (GHGs) which also contribute to global warming (IPCC 2006). The contribution of an activity to the global warming, or its “Global Warming Potential (GWP)” through all GHGs generated can be measured as CO₂ equivalents, a coefficient which sums up the contribution of all GHGs. To this end, the amount of each of the GHGs gases is converted into the amount of CO₂ which would generate the same impact on the global warming. In some of the studies evaluated which present estimates of CO₂ emissions the values of emissions are expressed as CO₂ emissions (Malmödin 2007; Mingay 2007b; Pamlin and Pahlman 2008a) and in three studies, as CO₂ equivalent (Bio Intelligence Service et al. 2008; GeSI 2008b; Malmödin and Jonsson 2008).

The emissions of GHGs due to the generation of electricity strongly vary depending on the energy carriers used. The partial contribution of the energy carriers used to generate the electricity is referred to as electricity mix. Therefore, whenever estimations of CO₂ emissions are carried out it is necessary to carefully select the proper electricity mix for calculations. Further, it contributes to a better understanding and transparency of results if this is properly documented in the corresponding studies, as it is in (DEFRA 2008).

If not only the direct electricity consumption during the use phase of ICT is considered but during their whole life cycle, additional emissions of CO₂ and other GHGs would be addressed which are generated during the primary extraction of raw materials, the construction and maintenance of building and transport infrastructure and the disposal of wastes. Moreover, if not only electricity but also other energy carriers are considered, the associated additional GHGs emissions would be addressed. This would give a more comprehensive and adequate figure of the impact of ICT on climate change, as pointed out by (Malmödin and Jonsson 2008).

<table>
<thead>
<tr>
<th>Reference</th>
<th>Year</th>
<th>Energy consumption</th>
<th>ICT types included</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Koomey 2007)</td>
<td>2005</td>
<td>45 billion kWh/a</td>
<td>High-end servers (&gt; 500 000 USD per unit), mid-range servers (25 000 – 500 000 USD per unit), volume servers (&lt; 25 000 USD per unit) and cooling and auxiliary equipment associated to server power (classification according to IDC).</td>
</tr>
<tr>
<td>(EPA 2007)</td>
<td>2006</td>
<td>61 billion kWh/a (1.5 % of total US energy consumption) Stock data based on industry estimates of shipments and stock turnover. The authors based mainly on (Koomey 2007) to estimate annual energy consumption per server, disk drive or port, as well as the energy use of power and cooling infrastructure in data centres.</td>
<td>Energy consumption in data centres in USA, considering servers, external disk drives and network ports in the USA. Powering and cooling of the site infrastructure are considered.</td>
</tr>
</tbody>
</table>
3.3.3 LCA-Based Methods and Results

A study on ICT-related energy consumption in Danish households beyond final energy consumption provided the following rule of thumb: "When 1 kWh is consumed in the residence 1 kWh is consumed to manufacture, transport and dispose of the hardware and ½ kWh is consumed to run the Internet and the applied ICT infrastructure outside the residence." (Willum 2008), p. 14. The study looked at production, use and disposal of PCs and their peripherals as well as the hardware infrastructure needed at telecommunication providers (for the households’ ADSL access) and data centres. This result, even though a very rough estimate, shows that the entire life cycle of the whole system providing a given ICT service should be studied in order to correctly assess the environmental impact of producing one unit of this service.

A Life Cycle Assessment (LCA) is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product-related system through its life cycle (ISO 2006). It is a methodology that helps analyse the impacts on the environment caused by a good or service through the consumption of materials and energy and the generation of wastes, wastewater and emissions during its life cycle (Rebitzer, Ekvall et al. 2004). The boundaries of the study system can be defined taking into account all phases of the life cycle from the extraction of resources, generation of the energy in the required form, and manufacturing of raw materials up to the final disposal of wastes, what is called a "cradle-to-grave" approach. Instead, the boundaries can also be defined considering just the production process within the facility ("gate-to-gate"), or a combination (i.e. "cradle-to-gate", or less commonly, "gate-to-grave"). A cradle-to-grave approach is well-suited for evaluating ICT-related energy consumption because not only the use phase causes relevant energy consumption.

Nevertheless, the use phase plays a very important role along the life cycle of ICT. For mobile phone networks and other telecommunication networks some studies conclude that the use phase is the most relevant one with regard to energy consumption (Takahashi, Nakamura et al. 2003; Scharnhorst, Hilty et al. 2006). For semiconductors in general and for computers (Williams, Ayres et al. 2002; Williams 2004) report values indicating that the manufacturing phase has the largest energy consumption in the life cycle. According to calculations conducted by (Eugster, Hischier et al. 2007; Hischier and Lehmann 2008) for laptop and desktop PCs again the manufacturing phase has the largest impact along the life cycle. In the case of TV devices, the use phase is dominating and for printers, the paper is the component associated with the largest global warming potential. The difference between PCs (including screens) and TV sets makes obvious the fact that the average service life of the hardware (which is much longer for TV sets) is an essential parameter when production and use phases are compared. In a similar way, the dominance of paper consumption in the printer life cycle is obviously based on assumptions about the service life and usage of the device.

There is no general answer to the question whether the production or the use of ICT products dominates their impact on climate change, it depends on the devices under study, their service life and usage patterns. Therefore, it is advisable to address all phases of the life cycle when assessing energy consumption and the related greenhouse gas emissions of a specific ICT device or service.

Further, a more realistic view of the burdens generated by ICT on the environment would require considering other environmental impacts of ICT in addition to climate change. As a matter of fact, ICT has a broad spectrum of environmental impacts beyond global warming, such as human toxicity, eutrophication, depletion of resources, etc. These impact categories can be assessed with LCA as well. When considering the full spectrum of impacts it becomes even clearer that all phases of the life cycle have to be taken into account, since e.g. the disposal phase may not be dominated by energy consumption and the resulting global warming potential, but other types of impacts such as toxicity.

31 The assumptions of the study are: i) Laptop PC, desktop PC, keyboard, mouse, monitor (17-Inch LCD-screen), laser printer color: data from LCI database ecoinvent v2.01; CRT- LCD- and plasma television device (32 inch, 32 inch and 42 inch, respectively): own data, partially based on CRT resp. LCD-monitor-data in ecoinvent v2.01; ii) Duration of service life: TV: 8 Jahre [4 h/day] plus 4 weeks off, rest stand-by. All other devices: 5 years (250 days/year, 8 h/day, rest off). For printers and PCs: mix of active, stand-by and off phases; amount of LWC-paper (European supply-mix) and amount of toner were modeled according to the data in ecoinvent v2.01; iii) UCTE-electricity mix; iv) Final disposal: mix of manual and mechanical disposal: data from LCI database ecoinvent v2.01. The recycling of metals results in credits because the primary production of materials can be avoided by the use of secondary materials.
Indeed, the life-cycle phases contribute to the overall impact of ICT with different orders of relevance, depending on the environmental impact indicator considered (Williams 2004; Nokia Corporation 2005; Choi, Shin et al. 2006; Scharnhorst, Hilty et al. 2006; GeSI 2008b; Malmodin and Jonsson 2008).

From the analysis of the studies mentioned above it can be concluded that at least the production phase and the use phase should be covered when assessing the impact of ICT on the environment in general and on climate change in particular. We are aware that this is in disagreement with other studies such as (Bio-Intelligence-Service 2008) and (Jönbrink and Zackrisson 2007), who assume that the use phase has the largest impact due to the electricity consumption. This could be explained by differences in the methodological set-ups of the studies. For instance, the study by (Bio-Intelligence-Service 2008) has a gate-to-grave approach, which means that the life cycle phases previous to manufacturing (such as resource extraction) were not taken into account.32

Finally, both the end-user devices and the infrastructure play an important role in the environmental impacts of ICT (Matuono, Aoe et al. 2005). The high relevance of the infrastructure has been shown for the particular case of mobile communication systems by (Emmenegger, Frischknecht et al. 2006; Scharnhorst, Hilty et al. 2006).

The following decisions have a large influence on the results of LCA studies:

- the boundaries of the system under study, in particular the phases of the life cycle and the environmental flows that are taken into account (Hischier and Lehmann 2008; Scharnhorst 2008),
- the assumptions on the length of the service life of the devices (Emmenegger, Frischknecht et al. 2006),
- the assumptions on usage patterns and the definition of the functional unit, and of course the boundaries of the system under study (Pleypys 2004; Yi and Thomas 2007).

The relevance of a life-cycle approach when assessing the environmental impacts of ICT has been pointed out in many previous studies, such as in (Pamlin and Szomolányi 2006; Malmodin 2007). The ITU (ITU 2009) stated the need for considering the whole life cycle of ICT when assessing their contribution to climate change. In the same direction, the (European Commission 2008c) states in its communication on the challenge of energy efficiency through ICT that "to assess the energy efficiency of a product the energy consumed for its manufacturing, distribution, use and end-of-life treatment is to be considered". The consultant company Gartner, which has contributed substantially to the Green IT discussion, is aware that the life cycle of ICT has to be considered in environmental analysis and also in taking action for mitigating impacts (Mingay 2007c; Mingay 2007b; Mingay 2007a).

However, despite the advantages of LCA-based methods for the environmental assessment of ICT, (Mingay and Pamlin 2008) found in a recent study that significant LCA work in the ICT industry is very scarce. This can be at least partly explained by the difficulties for developing LCA of ICT, such as e.g. the complexity of the analysed systems (ICT industry has a complex supply chain) (Mingay and Pamlin 2008; Pleypys 2004; Scharnhorst et al. 2006). Due to the complexity of the systems it is difficult to obtain the necessary Life Cycle Inventory (LCI) data of the desired quality (Pleypys 2004; Choi, Shin et al. 2006; Scharnhorst, Hilty et al. 2006). For instance, one specific difficulty is to obtain data from sources with the same methodological background (Scharnhorst 2008). More LCA work is expected to be carried out during the next three years and beyond. However, (Mingay and Pamlin 2008) consider that the ICT industry urgently needs is a standard approach and methodology for LCA. (Williams 2004) points out also the need to overcome the lack of critical discussion of underlying data and assumptions.

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32 Further, the study focuses on energy consumption and therefore, its statement could be re-interpreted as following: the use phase has the largest impact on energy consumption over the life cycle of ICT.
3.3.4 From the Micro- to the Macro-Level

Measurements of energy consumption or environmental impacts of ICT as discussed so far refer to specific types of devices or infrastructures. Due to the explosive growth in the use of ICT it is also of great interest to aggregate this energy consumption to the total energy consumption of e.g. a national economy.

Existing studies base mostly on a bottom-up approach. Bottom-up approaches combine stock data and the unit energy consumption of considered devices to calculate the total energy used within a certain system boundary (Kawamoto, Koomey et al. 2001; EPA 2007; Koomey 2007; Bio-intelligence-Service 2008; DEFRA 2008; Fichter, Clausen et al. 2008; Fraunhofer IZM-ISI 2008). As already mentioned in Section 3.3.1, the existing studies consider similar but barely the same ICT equipment. Contrary to the definition of the devices used as representative sample, the procedure followed to estimate the stock of ICT units is mostly well explained. Usually, statistics from industry on shipments and stock turnover are applied in this step of the analysis.

In (Kawamoto, Koomey et al. 2001), the electricity used by office (e.g. computers, servers, printers) and network equipment (e.g. routers, switches) in the USA was evaluated. The total stock was estimated by using shipment data as well as device lifespans, the unit energy consumption by combining estimations of power requirement and usage patterns. Kawamoto found that that the total power use by office and network equipment amounts to about 74 TWh per year, which is around 2 % of total electricity use in the USA. In a subsequent study, (Koomey 2007) evaluates the total power consumption by servers in the USA and the world using the same methodology. He finds that the US aggregate electricity use for servers doubled over the period 2000 to 2005 and amounts to about 45 TWh in 2005. Worldwide, the total server electricity consumption is about 2.5 times bigger.

In Germany, a survey by the Fraunhofer Institute (Fraunhofer IZM-ISI 2008) estimates the energy demand of the present and future German information society, which amounts to ca. 50 TWh in 2007 (about 9 % of the total electricity consumption in Germany). They applied a similar approach, but in addition to office and network equipment they also included television, audio and telephone equipment. They argue that video and television will have the main share of IP-traffic in a medium term perspective, referring to so-called Triple Play Services, a combination of phone, internet and television services. If only the same sorts of equipment as in (Kawamoto, Koomey et al. 2001) are considered, the energy demand results in ca. 24 TWh or about 4 % of the total German electricity consumption in 2007.

A recent study of Danish households estimates that “in a few years on average ICT will make up half of household electricity consumption” (Jensen, Gram-Hanssen et al. 2009).

Not only a selected year but time series of electricity consumption of households were considered in an earlier Austrian study (Haas, Biermayr et al. 1998). It combined the development of ownership, unit energy consumption and total number of households from 1960 to 1995, which resulted in time series of total energy consumption by appliance. However, ICT equipment was not separately reported but included in the category ‘small appliances’.

The considerations of different ICT equipment and infrastructure in each survey and the different years of reference make it difficult to compare results, especially since consumption increases rapidly over time. Depending on the definition of ICT, the time of data collection and the applied method, ICT consumes between 2-9 % of the total electricity demand of a national economy, with a clear increasing tendency.

On the macro-level, so far it has not been possible to identify any study that considers ICT-related flows that could have environmental impacts beyond electricity consumption. The reason could be that for a life cycle inventory of a certain product or service all global contributions during its life cycle are identified and no geographic boundaries are taken into account. Therefore it is difficult to separate domestic from indirect flows. Furthermore, especially ICT infrastructure is often used beyond frontiers of a national economy for a service within the economy. This leads to allocation issues that are not yet solved and that add to the uncertainty of the results.

No information on data uncertainty is presented in the existing studies with the exception of (Kawamoto, Koomey et al. 2001).
3.4 Estimating ICT-Related Energy Efficiency

After having discussed the first-order effects of ICT with regard to energy, we will now focus on a specific second-order effect: the enabling effect of ICT regarding energy efficiency in other sectors (see Section 3.1 for the conceptual framework and Section 1.3 for a definition of energy efficiency).

Estimating ICT’s potentials for energy efficiency across the economy is a particularly challenging task, a difficulty that has its origins in several factors. Firstly, ICT cannot induce energy efficiency on its own. Regardless of whether we look at smart electricity grids, virtual presence, or any other domain, ICT can be an enabler for increased energy efficiency in these areas. In most cases, however, it can only work in conjunction with further technological solutions that lie outside ICT (e.g. a fundamental paradigm shift in the topology and concepts of electricity grids), with the political will for and economic conditions conducive to such changes, and/or with the individual and corporate willingness to accept and deploy novel concepts (such as telework or virtual meetings instead of travel). As one participant in our survey (presented in the next chapter) put it, while referring to increasing the quality of data available on ICT-related energy efficiency, “instead it is an allocation problem to explicitly identify ICT’s contribution to energy efficiency – it is mostly a mix of many measures, where ICT might be the enabler but efficiency gains are reaped only in conjunction with other measures.”

Secondly, for implementing such energy efficient solutions, more ICT components have to be produced, used, and finally disposed of – which induces more energy consumption in the ICT sector itself. An estimation about “ICT and energy efficiency” thus has to take a holistic view, estimating the gains on one side and the costs on the other side. Thirdly, and arguably more difficult, further second-order effects have to be taken into account, as presented in section 3.1. Second-order effects can be positive (such as optimization and substitution) or negative (such as induction), but can also provoke positive or negative systemic reactions (third-order effects) such as rebound effects. If, for example, widely-deployed smart vehicle navigation systems (which take into account the current traffic situation) shorten the average trip time, one possible consequence would be that more trips are undertaken by car, possibly increasing the overall energy used for private transportation.

Finally, the mere measurement of energy efficiency effects is rather challenging. Unlike for the relatively straightforward ICT consumption, direct measurements are impossible. An ex-ante analysis is inherently just an estimate, while an ex-post analysis necessarily compares the ICT solution with a non-existing hypothetical situation (“what if the ICT-induced solution did not exist?”), in which case this hypothetical alternative has to be estimated.

Despite these difficulties, the current section presents the state-of-the-art knowledge on ICT-related energy efficiency. After presenting the existing global estimations, it shows via three examples how imprecise such estimations already are on an individual level. When aggregating them on sector, national, or global level, the insecurities only add.

3.4.1 Macro-Level Estimates of the Impact of ICT on Energy Efficiency

The fact that the networking enabled by ICT seems to lead to a global decrease in energy consumption per unit of GDP has been discussed for several years. (Romme 2002) observed that in the US between 1992 and 1996, the GDP and the energy consumption grew by an almost identical 3.2 % and 2.4 % per year, respectively. Between 1996 and 2000, however, they grew by a yearly average of 4 % and 1 %, respectively, the energy demand being thus clearly decoupled from the GDP growth. In other words, the macro-economic energy demand per unit of GDP was decreasing more rapidly than before. (Romme 2002) explains this by two factors, both related to the diffusion of ICT. First, the ICT production sector (growing at a rapid pace in the years 1996-2000 and being partly responsible for the GDP growth) is less energy intensive than other production sectors. Second, the Internet seems to have increased the energy efficiency in different sectors of the economy in those years.

However, estimating the potentials for energy efficiency induced through ICT is a challenging task. The figures below represent rough estimations (not measurements), and potentials which can be realized or not depending
on the framework conditions. Whether and to which degree the potentials for energy efficiency will get tapped will depend on numerous non-technological factors, such as economic feasibility, societal acceptance, political will, or geopolitical context.

The best-known global figure has been put forward by the (GeSI 2008b) report. It estimates for 2020 a global, ICT-induced energy efficiency potential corresponding to emission savings of 7.8Gt CO₂e (as compared to a business-as-usual scenario). This corresponds to approximately five times more than the projected emissions of the entire ICT sector. The report also addresses the importance economic feasibility concluding that “the ICT-enabled energy efficiency translates into approximately Euro 600 billion of cost savings” (GeSI 2008b).

The most important sectors contributing to this global figure are:

- Smart Grids – 2.03 Gt CO₂e
  - Transport & Distribution (T&D) loss reduction – 0.90 Gt
  - Reduce consumption through user information – 0.28 Gt
  - Allow integration of renewables (microplants, etc) – 0.83 Gt
- Smart Buildings – 1.68 Gt CO₂e
- Smart Logistics – 1.52 Gt CO₂e
- Smart Motor Systems – 0.97 Gt CO₂e
- Dematerialization – 0.46 Gt CO₂

Complementing this data, the (European Commission 2008f) report adds a further area relevant for ICT and energy efficiency:

- Manufacturing Industry
  - Discrete Parts Manufacturing
    - Process optimization – 25-30 % energy reduction potential
    - Optimized logistics – 16 % energy reduction potential
    - Integrated process chains – 30 % energy reduction potential
    - Development of new products – 10-40 % energy reduction potential
    - Intelligent motor drives – 20-40 % energy reduction potential
  - Process Industry
    - Cement industry – 27.5 % energy reduction potential
    - Steel industry – 10-15 % energy reduction potential

The sub-categories of the manufacturing industry partly overlap with categories already comprised in the (GeSI 2008b) study (such as the “intelligent motor drives” or “improved logistics”). This makes it difficult to join the information from the two studies. We did not succeed in applying our definition of relative energy efficiency to the figures cited above, since the “business as usual” case (“system B” in Section 1.3.2) is not clearly defined.

### 3.4.2 Example: Direct Comparison of Virtual and Physical Meetings

A virtual meeting describes the encounter of two or more persons at the same time, but across at least two different physical locations. The multiple locations share communication channels through ICT—usually audio, video, and data channels (for presenting slides, for example).
Virtual meetings can (partly) replace physical meetings and the thus-needed travel. They can, for example, replace business meetings via teleconferencing, commuting to work through teleworking, and even one-site conferences with multiple-site conferences. Their energy efficiency potential comes mainly from the saved energy that otherwise would have been used by the participants for travelling to the single physical location of the meeting. Obviously, virtual meetings can only partly replace the physical get-together – there are losses such as personal travel and cultural experiences, lost aspects of networking, or even friendships. There are, however, more advantages to virtual meetings than energy reductions. They can reduce a company’s time and monetary costs involved in travelling, they can led people attend more meetings than if they were to travel, can increase overall society safety (due to the statistical risk of accidents when travelling), and can also increase the quality of life of the participants – by spending more time with their families and not on travel, for example.

Virtual Business Meetings

Analyzing the environmental effects of a business meeting versus a videoconference, (Takahashi, Tsuda et al. 2006) estimate that the physical meeting would lead to 2000kg of CO₂ emissions, while the videoconference only leads to 400kg, an 80 % reduction. This latter figure even includes an estimation of the CO₂ emissions due to the alternative activities that have been undergone by the traveller with the spared time and money. Without these activities (which account for 90 % of the 400kg), the emissions caused by the videoconference would be negligible.

Virtual Conferences

(Hischier and Hilty 2002), on the other hand, when organizing an environmental informatics conference, calculated what the environmental benefits of the conference would have been if they had organized it as a purely virtual conference.

Taking into account all conference-related environmental impact (such as print of booklets, proceedings, and CDs, production of the conference bag, the energy used for the conference website and secretariat, etc), the travel activities of the participants were responsible for the vast majority of the environmental impact – 96.3 %. As conference organizers, and thus knowing where the participants come from, they made following assumptions: the ones living less than 300km would come by train or car, between 300 and 1000 km they assumed a 50-50 distribution between train and airplane, and everyone further away was considered to have arrived by plane. Within the travel, the train and even the car travels were almost negligible, while the 6 % of participants taking long-distance flights were responsible for no less than 58 % of the environmental load of the travel activities (and thus more than the half of the whole conference).

The authors thus came to the conclusion that “minimizing air travel is, thus, the only way to reduce the environmental load of the conference” (Hischier and Hilty 2002). Assuming the conference was purely virtual, all presentations and discussions being offered via Internet, and no attendee would have travelled, the impact of the conference would have been reduced by more than 95 %, even considering the energy consumed by the ICT infrastructure and that every participant prints at home the entire proceedings. Since, however, an important function of a conference lies in the networking it makes possible, the authors also envisioned a three-site conference (Zurich, Dallas, Tokyo). The sites (which correspond to the continents where the vast majority of participants came from) would be connected via virtual meetings, and most intercontinental flights could be spared, albeit there would still be numerous flights greater than 1000km on the same continent. Nevertheless, even in this scenario, the conference’s CO₂ footprint would be reduced to roughly 50 %.

The R’09 Two-Site Conference

The idea presented above (one conference in two sites on different continents) is now going to be realized. In September 2009, the R’09 World Congress, a resource management conference, will be held simultaneously at
two venues – Davos, Switzerland, and Nagoya, Japan, connected by videoconferencing systems.\textsuperscript{33} We will briefly assess the environmental impacts.

Extrapolating from past experiences, if this year the “R” conference was organized again as a one-site conference (for example, in Europe), we assume that some 450 participants would have taken part. We further assume (similar to past experiences) that 150 participants would arrive by train or car, 150 by inner European flights (of an average length of 1000km) and 150 from via long-haul flights of 9000km average length (from Japan 10000km, Eastern USA 6000km, and Western USA 10000km).

For the two-site conference as it will be now, we assume that more participants will take part (since they have to travel lesser distances – which is in fact a rebound effect), approximately 300 in each Japan and Switzerland. We further assume that per site 150 participants will arrive by train or car (but mainly train since both in Europe and Japan the railway infrastructure is highly evolved), 100 with inner-continental flights, and 50 (North American participants) will still take intercontinental flights, however of a lesser average distance of 6000km, since Western USA will fly to Japan, and Eastern USA to Europe.

As shown by previous studies (such as (Hischier and Hilty 2002) mentioned above), train and (since it is typically used for short distances only) even car travel contribute with only a small percentage to the overall travel-related energy consumption. For measuring the CO\textsubscript{2} impact of flights, we use data from the “ecoinvent” database.\textsuperscript{34} According to this life-cycle inventory database, the average footprint of a long-haul flight is around 0.11kg CO\textsubscript{2}e per passenger and kilometer, while short-haul flights have a footprint of 0.17kg CO\textsubscript{2}e per passenger and kilometer.

Comparing the two alternatives (under the assumptions made), the travel to the one-site conference would be responsible for total emissions of

\[
(2 \text{ directions} \times 150 \text{ flights} \times 1000 \text{ km} \times 0.17\text{kg CO}_2) + (2 \times 150 \times 9000 \times 0.11) = 51t + 297t = 348t \text{ CO}_2e,
\]

while the two-site conference (as it will be organized) will account for

\[
((2 \times 100 \times 1000 \times 0.17) + (2 \times 50 \times 6000 \times 0.11)) \times 2 \text{ sites} = (34t + 66t) \times 2 = 200t \text{ CO}_2e.
\]

Under these assumptions, although 30 % more participants attend the conference than in the classic model, the emissions caused by air travel are reduced by more than 40 %, or, in absolute values, by 148t CO\textsubscript{2}e. Although we do not yet have estimations as of how much emissions the ICT infrastructure will be responsible for (mainly due to the energy needed for powering the videoconferencing infrastructure and for the high bandwidth connection), extrapolating from the two case studies presented above, they should amount to just a few percent of the travel emissions, since the estimates used by (Hischier and Hilty 2002) were based on very pessimistic assumptions regarding the environmental impact of IP-based videoconferencing.

\[3.4.3 \text{ Example: Direct Comparison of Electronic and Print Media}\]

An early study on various electronic and print media showed that there was not a clear ecological winner (Reichart and Hischier 2001). Electronic media may impact the environment less or more than print media: it depends on how they are used. Important parameters are the service life of the ICT equipment (because of the high energy investment for producing the devices) and the type of paper used by the print media (because of the energy used for paper production or recycling).

There was, however, one clear ecological loser when comparing media: to get information electronically and then print it out on a private 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 (Reichart and Hischier 2001).

\textsuperscript{33} See http://www.r2009.org.

\textsuperscript{34} See http://www.ecoinvent.org.
A recent Danish LCA study (Schmidt and Kløverpris 2009) compared “e-Boks” (different from e-books) with the use of traditional printed documents sent by post in an envelope. The e-Boks system is a safe electronic post box, where the users can receive important documents (annual statements from banks and insurance companies, bank accounts statements, payslips, etc.) electronically and free of charge. The system e-Boks has more than 1.5 million users in Denmark who each year receive 98.5 million documents via the Internet (Schmidt and Kløverpris 2009).

The study found that the energy consumed for transferring these documents via e-Boks, including viewing and some printing at home, amounts to roughly 13 MJ of energy. Using traditional letters instead would have needed more than 37 MJ, making the virtual solution clearly favourable. The same holds for the other environmental impact categories. Under the assumption that each e-Boks-document would be once printed at home, the ecological benefit would be reduced by (only) 40 %. This is explained by the fact the environmental impact of the traditional solution is dominated by the envelope life cycle. With other words, the most important environmental advantage of sending (small) documents electronically is that fact that no envelope is needed.

This study seems to contradict the results by (Reichart and Hischier 2001) cited above, who found that printing at home is worse than the traditional solution in any case. However, the contradiction is easy to explain:

- The function studied by (Reichart and Hischier 2001) was receiving news, not small documents. Envelopes were not involved.
- Moreover, the study from 2001 was based on equipment which nowadays would be considered outdated. The CRT monitors considered by (Reichart and Hischier 2001) have been replaced by more energy efficient flat screens. The energy efficiency of the distribution of electronic documents via the Internet has dramatically increased during the 8 years which lie between the two studies – by orders of magnitude.

Nevertheless, both studies conclude that viewing time (the time the end-user equipment is on to read the documents) is the most sensitive parameter in the system, since end-user energy consumption dominates the environmental impact of the electronic solution. This implies that, if the equipment is only kept running long enough before or after reading the documents, the LCA result will turn against the electronic solution. We can therefore conclude that the energy efficiency of end-user devices used for reading (e.g. low-power displays with excellent power management) is crucial for the future environmental success of substituting electronic data for paper.

### 3.4.4 Example: ICT-Related Energy Efficiency Potentials in Power Generation and Distribution Including Demand-Side Management

There is a need for an improvement of the power grid as has been highlighted by the (European Commission 2008c). The (European Commission 2008c) presents numbers on the potential for improvement in electricity generation (estimated at 30 % to 40 %) and on the losses in transport and distribution of electricity (about 2 % and 8 %, respectively). Given this situation, the (European Commission 2008c) considers it critically to “improve transformation efficiency, address loses and identify any potential problems before they compromise supply”. Further, the need for a smart grid in Europe was influenced by the liberalisation of the European market for energy, the multiplication of local energy networks, the integration of renewable energy sources, the spread of co- and micro-generation, and new user demands (European Commission 2008c). In one of its latest documents on the European energy network, the (European Commission 2008i) concludes that “the EU will be unable to deliver its climate and energy goals without new and improved networks.”

ICT has already been one of the principal drivers of increased energy productivity in the European Union during the past 15-20 years (Laitner and Erhard-Martinez 2007). ICT can continue playing an important role to enhance the energy efficiency in power generation and distribution. A term has been coined for this vision of an ICT-supported electricity network: “smart grid”. Although this term is defined in slightly different ways in literature, the understanding of it is common. For instance, it can be defined as “a set of software and
hardware tools that enable generators to route power more efficiently, reducing the need for excess capacities and allowing two-way, real time information exchange with their customers for real time demand side management. It improves efficiency, energy monitoring and data capture across the power generation and transmission and distribution network” (GeSi 2008b).

The concept of smart grids includes two-way-interactions between suppliers and consumers. This enables, for instance, consumers to produce their own electricity and sell the surplus. Indeed, one main benefit of smart grids is their ability to integrate the electricity supply from distributed energy sources (also called decentralized power generation) including fuel cells, photovoltaic, solar thermal, wind power, biomass, ground source heat pumps or micro combined heat and power (Laitner and Erhard-Martinez 2007; Schippl 2008). Here ICT is a helpful tool to forecast demand and supply (which in turn relies on satellites and weather-forecasting computing) (Karch, Winkler et al. 2008). Demand forecast is presently limited by several factors, such as a lack of real information on demand and supply, and is thus based on estimations. Furthermore, forecasting is particularly important on the supply side for sources such as wind power and solar power, which are an increasing challenge for the power grid because of their intermittency, difficulty of forecast and wide distribution.

Thus, a smart grid is required that balances an optimum share of renewable sources with a high reliability of supply and an adequate stability of the system (Karch, Winkler et al. 2008).

Two-way-interactions make the management of the grid also easier for grid operators, who then have a better overview of the power uploaded or downloaded (Schippl 2008). The two-way-interactions in the smart grid make a Demand-Side Management (DSM) possible. DSM groups those activities in which the energy consumer participate in the management of their energy supply. This can be achieved through a direct influence exercised by the energy supplier or the power system operator, or indirectly through price signals by flexible tariffs (Franz, Wissner et al. 2006). The goal of DSM is to influence the load curve in order to for instance, clip peaks and avoid the need for expensive balancing energy obtained from e.g. gas-fed power plants. See (Franz, Wissner et al. 2006) for a detailed description of this and other options for influencing the load curve.

DMS is supported by so-called smart meters. Smart metering refers to measuring and visualising energy consumption in order to detect saving potentials and corresponding options for action. Smart meters enable the customers to make smart decisions using real-time information with the aim to shift their consumption to low-load and low-rate times, or even to turn off applications (Laitner and Erhard-Martinez 2007; Schippl 2008). Important savings can be obtained from the use of smart meters, to a relevant part due to increased consumer awareness (Schippl 2008).

As presented by (GeSi 2008b) there is a wide range of ICT-applications needed in a smart grid, such as:

- sensors for remote measuring,
- chips and controllers for monitoring,
- smart meters (advanced metering infrastructure (AMI) or automatic meter reading (AMR)),
- energy accounting software,
- smart billing software,
- grid management systems (e.g. supervisory control and data acquisition (SCADA) and output management system (OMS)),
- asset inventory and network design systems (e.g. Geographic Information System (GIS) applications),
- load analysis and automated dispatch software,
- workflow management systems for the grid, performance contracting applications,
- demand response software that allows automated load maintenance,
- protocols for grid-wide system interoperability,
• operations and maintenance of grid communications systems,
• advanced telecommunications to allow distributed energy producers to pool resources and to handle spikes in supply and demand,
• new platforms (e.g. emissions trading scheme ETS)

According to [ELECTRA 2008; WEF 2008], most of these technologies required to create smarter grids are available at present. Current ongoing efforts (such as pilot projects) at different scales to implement these technologies composing smart grids are highlighted by (Bio Intelligence Service et al. 2008; BMWi 2008; DG INFSO 2008; WEF 2008). These authors also discuss the steps that government, ICT industry, researchers and other stakeholders should take in order to accelerate the smart grid development. Not only technical and policy aspects are considered relevant, but also the education and information of all stakeholders, including end-consumers.

Implementing a smart grid is a task with several difficulties, as discussed in (Bio Intelligence Service et al. 2008; Franz et al. 2006; GeSI 2008b; Pamlin and Pahlman 2008b). These studies present options for action to deal with the difficulties encountered and actions to support the implementation of smart grid. However, even beyond the challenge of implementation there are issues to be carefully addressed, such as security and privacy (Franz, Wissner et al. 2006; Bio-Intelligence-Service 2008). Further, (GeSI 2008b; Pamlin and Pahlman 2008b) discuss potential rebound effects of a smart grid with respect to energy consumption and their related emissions. (GeSI 2008b) points out that the prevention of rebound effects requires an emissions-containing framework to encourage the transition to a low carbon economy. Finally, (Pamlin and Pahlman 2008b) document a list of strategic solutions based on ICT that can help accelerate the reduction of CO2 emissions in the electricity network system and in other activity sectors. The particular contribution of these authors is that they evaluate whether these solutions could provide “low-carbon feedback”, i.e. not only reducing CO2 directly when they are used, but also strengthening structures that support further emission reductions.

(Karch, Winkler et al. 2008) consider that because of the huge scale of the generation and distribution of electricity, even a fractional improvement in efficiency will make a dramatic dent in European emissions. (Laitner and Erhard-Martinez 2007) calculated for the European situation that if smart grid technology facilitated just five percent increase in electric generation capacity from the more energy efficient combined heat and power systems, annual CO2 emissions could be reduced by as much as 20 Mt. At the global level (GeSI 2008b) estimated that ICT-enabled solutions for the energy sector could contribute globally to abatements of around 2 Gt CO2 equivalent by year 2020. In addition, (Schippl 2008) points out that ICT has an enabling role in the liberalization of European energy markets and as such, it contributes to a potential increase in energy efficiency. Finally, the improvement of efficiency and stability in the energy generation and supply system (associated with an increase in the share of renewable sources) has the additional benefit of mitigating the dependence on imported oil and thus, this issue has also national security implications (European Commission 2008c; GeSI 2008a).

In 2005, a major work summing up the progress made in Europe by that year was published by the work group on "Integration of Renewable Energy Sources and Distributed Generation into the European Electricity Grid". The cluster is still active, and the most recent of its three conferences was in December 2008 summarizing research trends in the US, Europe and Japan (European Commission 2005).

In the US, the novel Smart Grid plans comprise one of the more promising developments, and one headed for implementation after Congress has passed the Stimulus Package. The Smart Grid total of $ 11 billion breaks down into $ 10 billion for an upgrade enabling the grid to better link traditional and renewable power plants, and $ 1 billion for smart metering (Clayton 2009). The plan is documented in (Gross 2009).

35 See http://www.ired-cluster.org/.
4 Future Potential – Results of Expert Interviews

To better understand the opportunities and risks involved in the field of “ICT and energy efficiency,” we have also consulted recognized experts from industry, academia, and the civil society. The outline of the interviews is presented in Annex 3: Interview Outline. Fifteen experts have been asked to participate, as listed in Annex 2: List of Experts, eleven of them have taken part in our explorative survey.

The interview revolved around four main topics – three of which are directly related to the scope of this study, while the fourth resides on a meta-level and is concerned with the quality of available data for ICT and energy efficiency. This last subject could prove important for politically acting bodies (such as the European Commission), in order to decide where to foster methodologies and tools able to deliver verifiable and comparable measurements for “ICT and energy,” measurements which nowadays are often lacking.

The four topics are presented below.

4.1 Which Technologies Belong to the ICT Sector?

The first group of questions aimed at extracting the experts’ standing as of which technologies belong to the ICT sector and which not, as well as their opinion about which of these categories are relevant to either the overall energy consumption of the ICT sector, or to energy efficiency in other sectors, or both.

Following the categories typically found in other studies (e.g., (Bio-Intelligence-Service 2008)), we have clustered technologies into three classes: data servers, end-user devices, and the network infrastructure used to communicate either between two or more end-user devices, or among end-user devices and servers. We have not followed the often-encountered (and increasingly artificial) separation of communication devices (such as cellular phones) and computation devices (such as PCs). For the same reason, we did not discriminate between “communication infrastructure” and “computing infrastructure.” Furthermore, we have added – more as a reminder for the experts – a fourth and generally kept category called “embedded ICT,” which, as already argued in Section 1.1.2, is an area of growing importance where many ICT professionals see the true future potential of ICT. Finally, the experts were asked to add any new technologies that had been overlooked.

The categories specified by us are listed below, together with the total number of positive answers to the questions: “Does this technology belong to the ICT sector?”; “If yes, is it relevant to the overall energy consumption of ICT?”; “If yes, is it relevant to the energy consumption in other areas?”; respectively. The numbers represent positive answers out of 11 possible.

- A – Servers
  - A1 – servers outside data centres – 11 / 11 / 6
  - A2 – corporate data centres for in-house services – 11 / 10 / 7
  - A3 – data centres of ICT service providers – 11 / 10 / 7

- B – Network infrastructure (everything in between servers and end-user devices)
  - B2 – Wireless communication: GSM, WiFi, 3G antennas – 10 / 6 / 7
  - B3 – Wireless communication: telecom satellites – 8 / 3 / 7
  - B4 – Supporting Internet infrastructure: routers, DNS servers – 11 / 9 / 6
• C – End-user devices
  o C1 – Personal computing devices: desktops, laptops, netbooks – 11 / 10 / 5
  o C2 – Home telecommunication devices: landline phones – 9 / 6 / 3
  o C3 – Mobile telecommunication devices: cellular phones – 10 / 6 / 4
  o C4 – TV sets, set-top boxes – 10 / 10 / 3
  o C5 – portable media (i.e., music and/or video) players, e-books – 8 / 3 / 2
  o C6 – digital cameras – 5 / 3 / 2
  o C7 – Peripherals: scanners, printers, etc. – 10 / 6 / 3

• D – embedded ICT (e.g., a washing machine with digital control) – 11 / 8 / 9

From the numbers above, several interesting conclusions can be drawn. Firstly, the servers are undoubtedly seen by almost all experts as the big energy consumers. This observation refers not only to the three “data server” categories A1, A2, and A3, but also to the category B4, comprising “communication servers,” such as Internet nodes. 9 out of 11 interviewees view this last category as having a relevant own energy consumption.

There is not such a high consensus on whether servers are relevant for the energy efficiency in other sectors; however, 54-63 % of experts see them as relevant to this purpose as well.

Communication cables, antennas, and satellites, on the other hand, while considered ICT by a majority (by 10, 10, and 8 out of 11 experts, respectively), do not seem to be associated with a high own energy consumption – with the exception of antennas, where 6 out of 10 the participants who believe them to be part of ICT also think they do relevantly contribute to ICT’s overall energy consumption. Nevertheless, for all these categories the potential for energy efficiency is rated as more relevant than the own energy consumption – which might come to little surprise when thinking that the networking enabled by these technologies is a necessary basis for applications aimed at inducing more energy efficiency by automated control, metering, information gathering, etc.

Personal computing devices are – unsurprisingly – considered by everyone as part of ICT; and while contributing significantly to the overall ICT energy consumption, they are regarded as less relevant for inducing energy efficiency than servers, communication infrastructure, or embedded ICT. This observation actually applies to all “end-user devices” subcategories – where the ratio between own energy consumption and potential for energy reduction is the least favourable, as compared to the other three main categories.

This insight applies particularly to the category C4 “TV sets and set-top boxes.” From all the technologies that are not servers, it sticks out in a negative sense – all 10 interviewees who consider it as part of ICT, think that it is also responsible for a relevant part of the overall ICT energy consumption, while only 3 think it could contribute towards better energy efficiency.

Finally, the group D of “embedded ICT” is worth a look at. While all interviewees agree that it is part of ICT, and 8 think it has an important own energy consumption, 9 of them also think that it is relevant for inducing energy efficiency throughout the economy – the largest number of any category. And indeed – embedded ICT include, for example, sensors which are necessary in smart meters for providing fine-granular, real-time data about a building’s energy consumption, or for gathering the information needed in intelligent transport systems (ITSs). Embedded ICT further includes both the sensors and actuators needed for smart engines, along with numerous other categories, and is thus the technology expected to have the largest enabling potential for energy efficiency.
4.2 Reducing ICT-Related Energy Consumption

In the next group of questions, we asked about the development of ICT energy consumption over the next decade – setting 2020 as time horizon both because it is a conceivable future that will evolve mainly along foreseeable technological developments, and due to the “20-20 by 2020” aims of the European Union as well.

We asked about two possible developments in ICT-related energy consumption. The first, business-as-usual scenario, assumes a smooth continuation of the expected technological and market developments, but with no new policy incentives. In the second, energy-optimistic scenario, the full potentials to reduce the energy demand of ICT would be consequently tapped.

For both scenarios, we assumed as 100 % reference the corresponding energy consumption levels for the year 2008. Furthermore, we made clear that we were not interested in the per-device, but the overall consumption of all devices in the respective class. Thereby, we wanted to account for possible rebound effects – i.e., the case that for a given technology the consumption per device is expected to decrease, but (possibly as a consequence thereof) the application areas for such devices or the diffusion per application area expand, which might outweigh or trespass the individual savings.

The scale used encompassed 5 steps (as well as an “I don’t know” field):

- < - 15 % – Overall savings of more than 15 % (as compared to the overall in 2008) expected
- -15 % < - 5 % – Overall savings between 15 % and 5 % expected
- -5 % < 5 % – Roughly equal overall consumption expected
- 5 % < 15 % – Overall increase between 5 % and 15 % expected
- > 15 % – Overall increase of more than 15 % expected

4.2.1 Business as Usual

In the business-as-usual scenario, and especially for the categories identified as relevant to the overall ICT energy consumption (as presented above), all experts agreed that there will be a significant increase in the energy consumption.

Thus, for all “server” categories, the experts saw overall increases of either between 5 % and 15 %, or above 15 %. For category A3 (“service provider data centres”), for example, 1 expert expected a more or less constant energy consumption (i.e., a change between -5 % and 5 %), while 2 expected an increase between 5 % and 15 %, and 7 of them an increase of over 15 % (one having said “I don’t know”).

For the likewise highly relevant energy consumption domain C4 (“TV sets and set-top boxes”), only 1 opinion was that the consumption will decrease between -15 % and -5 %, 1 that it would remain on a level similar to today’s, while 3 considered it would increase between 5 % and 15 %, and 6 that it would increase by > 15 %.

A similar picture appeared for category D “embedded ICT” – while 1 expert considered that the consumption would decrease between -15 % and -5 %, and another one that it would remain unchanged (and one answered “don’t know”), 2 believed it would increase between 5 % and 15 %, and again 6 thought it would increase by more than 15 %.

4.2.2 Potential of Technical and Organisational Measures

Regarding the effect of technical and organizational measures (in the energy-optimistic scenario), the estimations were much more evenly distributed along the spectrum of possibilities.

Looking again at servers, for category A3 a majority of 6 experts thought the overall consumption would decrease (with 3 thinking it would decrease by more than -15 % and 3 between -15 % and -5 %), while 1
believed that the consumption would remain unchanged and only 4 think it would still increase (2 of them between 5% and 15%, and 2 by still more than 15%). Assuming that these estimates take into account the foreseeable growth in installed data centre capacity over the next decade, we think that the figures show the large potential of recent efforts towards “green data centres.” One of the two experts still believing in a large increase, however, wrote: “I think the growth in volumes will out any reasonable improvement in efficiency”.

Likewise, for TV sets and set-top boxes in the energy-optimistic scenario, the experts tended to expect an overall reduction – 1 a change of more than -15%, 3 of between -15% and -5%, 3 expect an unchanged overall consumption, and only 3 experts anticipated an overall growth (1 of between 5% and 15%, and 2 of more than 15%) – while one expert did not express an opinion for this scenario. When comparing these figures with the business-as-usual scenario (in which no less than 9 experts were expecting a substantial growth), this domain appears to be the one with the largest potential for the reduction of ICT’s overall energy consumption.

The difference between the business-as-usual and the energy-optimistic scenarios is not as great for the “embedded ICT” domain, although our survey shows some potential for savings here as well. Since, however, as argued above, embedded ICT is a technology crucial to all energy efficiency applications in other domains, these less favourable expectations stand to reason. The more energy efficiency is sought across the economy, the more embedded ICT will be needed, which will also consume energy – most likely a price worth paying.

### 4.3 Unleashing ICT-Related Energy Efficiency Potentials

In the third part of the interview the questions revolved around the potential of ICT to induce more energy efficiency across the economy. We took the currently widely discussed application areas and asked how their individual relevance for the reduction of the overall economic energy consumption was ranked by the experts on a scale comprising the following steps: “highly relevant,” “relevant,” “somehow relevant,” “almost irrelevant,” and “irrelevant.”

#### 4.3.1 Survey Results

The table below presents the results of this survey.

<table>
<thead>
<tr>
<th>Application area</th>
<th>Highly relevant</th>
<th>Relevant</th>
<th>Somehow relevant</th>
<th>Almost irrelevant</th>
<th>Irrelevant</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>smart electricity grids</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>consumer real-time energy</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>consumption feedback</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>buildings: intelligent heating/</td>
<td>9</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cooling/ventilation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>buildings and streets: intelligent</td>
<td>5</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lighting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>passenger transport and mobility</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>goods transport and logistics</td>
<td>9</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>discrete parts manufacturing</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>chemical process industries</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>virtual meetings and tele-work</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>virtual media</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analyzing these figures, three clusters seem evident:

- For the “buildings heating/cooling/ventilation” and the “goods transport and logistics” categories, a clear majority of experts (9 out of 11) think they are highly relevant domains in which ICT could lead to a substantial increase in energy efficiency.

- There is then a large “middle field,” of which several experts (between one and two thirds of them) also think they are highly relevant. However, there is less consensus here, and some experts also give them a subordinate value. This middle field is composed by the categories:
  - smart electricity grids,
  - buildings and streets: intelligent lighting,
  - passenger transport and mobility,
  - chemical process industries, and
  - virtual meetings and telework.

- Finally, the largest spread in the experts’ opinions (several of them regarding them as only “relevant,” “somehow relevant,” or even “almost irrelevant”) appears in following categories:
  - consumer real-time energy consumption feedback,
  - discrete parts manufacturing, and
  - virtual media.

This is a rather interesting observation, since the results only partly match the current priorities of the European Commission. The greatest surprise for the authors was the fact that smart electricity grids were not in the top cluster. For the future, it might be interesting to do a study or expert workshop with a Delphi-style analysis, in which experts have to justify their choices, to then in a second round, taking into account the motivations given by others, maybe revise their initial choice.

### 4.3.2 Future “Killer Application”

Finally, at the end this topic we asked the experts about the applications which would have the largest impact towards an energy efficient future society in their view. The question was phrased as follows: “Risking a more visionary look by widening the time horizon towards 2050, imagine a sustainable future largely enabled by ICT. Which has been the dominating application that has enabled this future? You may also mention more than one application.”

The experts who answered this question focused on buildings and (in seeming contradiction to the priorities expressed above) on smart grids and passenger transport and mobility. One expert thus answered: “From my point of view, the use of ICT as ‘intelligent’ systems to support human activities in being as energy-efficient as possible will be the most important / dominating application – e.g. intelligent heating/cooling, intelligent lightning, intelligent mobility, intelligent stand-by energy consumption.” Other two interviewees said “energy (especially power) control from production through grid to consumption (like in E-Energy),” and “ICT enables balancing the energy supply by (fluctuating) renewable resources,” respectively. As for persons’ transport and mobility, one participant answered “ICT based car management systems for electro-vehicles (load control, tour management, car sharing, etc.).” Another expert said: “electrification of transport system, metering, a further decentralized energy supply structure,” and finally “Logistics and public transport are optimized by minimizing energy consumption.”

Experts sporadically mentioned other fields as well (such as “People are always informed on their current energy consumption”), and partly also went past the confines of ICT by mentioning, for example, economic incentives (“Goods are priced by the overall energy consumption in their life cycle”), or looking at the energy sources: “There is no Green ICT without addressing renewable energy.”
4.4 Future Research Needs and the Relative Importance of Specific Research Fields

Both in this third part of the interview about ICT’s energy efficiency potentials, and in the fourth and last part (about the quality of available data), we asked the experts where future research priorities should lie. The results are presented in this section.

4.4.1 ICT and Energy Efficiency Research

For the energy efficiency part, we extended the purview towards a future (2050) sustainable society as follows: “Which research was necessary to come so far?”

The experts focused on smart grids and transport/mobility with answers such as: “Research needed in: smart energy grids, life cycle assessment, energy aware optimization in logistics, transport and production,” or “research will be necessary for the electrification of the transport system, also in general user-technology interface, socio-technical interface,” but again also looked beyond the borders of ICT by stating “serious governmental funding and support for science, technology and innovation to enhance R&D investment in renewable energy opportunities.”

One expert, who had been particularly pessimistic about ICT’s future energy consumption (expecting, even for the energy-optimistic scenario increases of over 15% in almost all ICT categories), focused in this answer on ICT’s own energy consumption as well, writing: “we need to find ways to adjust material and energy use, as well as the way ICT is manufactured and its end-of-life is managed, that is in line with a sustainable development. And, this needs to be made with public funding, it will never happen in a market-driven company.”

4.4.2 Quality of Data and Research Needed for Improvement

The fourth and last topic of the interview revolved about the quality of data available both for ICT’s energy consumption and the energy efficiency it can induce, as well as the research needed to improve this data.

The questions we asked about the quality of data and the respective answers are presented in the two tables below.

<table>
<thead>
<tr>
<th>Data</th>
<th>Very good</th>
<th>Good</th>
<th>Medium</th>
<th>Poor</th>
<th>Very poor</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT energy consumption – availability</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICT energy consumption – quality</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data</th>
<th>Very good</th>
<th>Good</th>
<th>Medium</th>
<th>Poor</th>
<th>Very poor</th>
<th>Don't know</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICT for energy efficiency – availability</td>
<td>3</td>
<td>6</td>
<td></td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICT for energy efficiency – quality</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from the figures above, both the quality and availability of data are generally considered to be unsatisfying. Furthermore, two trends can be observed: with one notable exception, the data on energy efficiency is regarded as substantially less mature than the data on ICTs energy consumption (both in terms of availability and of quality), and for both categories the quality of the data is worse than its availability.
As for the ways of improving this data, the experts gave quite a lot of impulses for improving data availability and quality for ICT’s energy consumption; however, they provided only a few ideas on how to improve the data on energy efficiency induced by ICT.

Among the ideas expressed for improving the data on the energy consumption were:

- “harmonized measurement and testing standards,”
- “Integration of this kind of information into the ‘general description’ of ICT devices,”
- “Integration of this kind of information into general databases dealing e.g. with Life Cycle Information (like e.g. Life Cycle Inventory databases),”
- “Joining forces of ICT and energy providers to measure and interpret consumption data,”
- “More visibility on device level and also service level, labeling concepts for energy efficiency of ICT products and services,”
- “Energy efficiency of ICT products and services (!) should be rated,”
- “Devices should inform on the typical energy consumption in their life cycle and in their use phase,”
- “Acquisition of more metering data, better modeling, improved data for life cycle analysis.”

The two repeating themes of these answers are evident: visibility of the energy consumption data through, for example, product labeling, and a focus on the life cycle of the products and not only on their electricity consumption during the use phase.

As for the energy efficiency, the typical answers on how to improve the data were: “no idea (sorry),” “???” (literally), or just empty space. One very interesting explanation for the inherent difficulty in improving the quality and availability of energy efficiency data was: “there is not much that can be done, it is instead an allocation problem to explicitly identify ICT’s contribution to energy efficiency – it is mostly a mix of many measures, where ICT might be the enabler but efficiency gains are reaped only in conjunction with other measures.”

The only practical solutions given here referred to case studies and best practices, such as “evaluate outcomes of model projects like E-Energy,” and “case-studies on every-day user scenarios and ICT-empowered alternatives to them.”
5 National and International Research Programmes

The recently released OECD report “Towards Green ICT Strategies – Assessing Policies and Programmes on ICT and the Environment” (OECD 2009) gives a comprehensive overview of existing programmes, analyzing not less than 50 governmental and intergovernmental research programmes (from 22 OECD member countries and the European Commission), along with another 40 industry association initiatives. The report not only presents the individual programmes, but, by having such a rich basis, can also identify OECD-wide trends. It is, for example, noticeable that more than two thirds of the programmes refer to improving the performance of the ICT industry itself – and here mainly during the use phase only – while the remaining third of the programmes focus either on ICT’s end-of-life phase, or on ICT-induced energy efficiency in other sectors (OECD 2009). This bias, though, is not surprising, since only recently the energy efficiency potential of ICT in other sectors has been fully recognized. Today, however, it has become one of the top priorities for EU research programmes. In a recent (9 July 2009) lecture, Viviane Reding, EU Commissioner for Telecoms and Media Digital Europe, listed “making better use of innovative ICT solutions to meet our objectives of a low-carbon economy” among the top four research priorities for the next five years (Reding 2009).

This chapter focuses mainly on programmes not considered by the OECD report. It gives an overview of ongoing research programmes that are directly or indirectly relevant for the “ICT and energy” field. We have intentionally included programmes in the energy or transport area that have a broader technological scope than ICT, but include ICT among other innovative technologies in an energy context.

5.1 EU-funded Programmes

i2010

i2010 is the EU policy framework for the information society and media put in place in 2005 by DG INFSO. Research funding involving ICT and energy efficiency must also be seen in the context of the DG for Transport and Energy (TREN) traditionally considered the main executor of all matters concerning energy. DG TREN plays the lead role in the Intelligent Energy – Europe Programme (IEE).

In the early 2000’s the newly acknowledged pressure for climate change mitigation accelerated the integration of digitalization into a range of activities intended to increase energy efficiency. The powerful European Council [of ministers] held a landmark summit in December 2008 and adopted a general “20-20-20 commitment” on carbon dioxide emission reductions. It comprised such a binding statement that additional DGs began contributing to its fulfilment besides DG TREN.

Intelligent Energy Europe (IEE)

IEE is a super-programme managed under the lead of DG TREN, which has encompassed over 400 projects between 2007 and 2013. Many of the projects have thus far focused on improving energy efficiency in buildings and transport applications. In this super-programme € 45 million are appropriated through DG TREN, which appears large in relation to the € 74 million funded through DG INFSO for its entire sustainable growth

The Role of ICT in Energy Consumption and Energy Efficiency

section77 (see Objectives 6.3 and 6.5 of the ICT Work Programme 2009-2010 below, with 6.4 constituting another €24 million).

The Intelligent Energy – Europe Programme (IEE)78 is part of the over-arching Competitiveness and Innovation Framework Programme (CIP). CIP is organised around three multi-year specific programmes:

- The Entrepreneurship and Innovation Programme (EIP)
- The Information and Communication Technologies Policy Support Programme (ICT PSP, see also Fig. 1)
- Intelligent Energy Europe (IEE)

The CIP has a budget of € 730 million for the years from 2007 to 2013, which is complementary to the 7th framework programme for research (FP7). ICT PSP comprises part of the € 1 billion the EC will invest between 2009 and 2013 for ICT and sustainability.

The SAVE predecessor programme to the current super-programme IEE ran from 1992 to 2002 and sought to improve energy efficiency and to encourage energy-saving behaviour in industry, commerce and the domestic sector through behaviour measures as well as research. Many SAVE projects had substantial ICT content such as those listed above in the section on “projects”. SAVE did not include pilot actions for large smart buildings, which are covered under CIP-PSP 2008 Work Programme Theme 2: ICT for Energy Efficiency and Sustainability in urban areas” (European Commission 2008d). Odyssee is a well-known project within Intelligent Energy, as evidenced by its inclusion in European Council for an Energy Efficient Economy.39

The IEE programme is run by the Executive Agency for Competitiveness and Innovation (EACI) on behalf of the European Commission, The EACI reports back to the following three Directorates-General of the European Commission: Energy and Transport (TREN), Enterprise and Industry (ENTR), and Environment (ENV) – a grouping from which DG INFSO is conspicuously absent. Inter-service consultations do however provide a degree of coherence.

The EACI also manages the Marco Polo programme promoting an inter-modal shift of transport capacity, which is running in its current, second phase from 2007-13 and has a programme budget of €450 million Euro.40

Intelligent navigation systems, road-pricing, and other ICT-supported enhancements of personal mobility, in conjunction with a better public transportation infrastructure have taken on a new, increased importance as means of reducing CO2 emissions to mitigate climate change. Intelligent mobility has thus become subject of research to two DGs. Traditionally, DG TREN had the mobility dossier, and did an Impact Assessment (IA) on intelligent mobility in 2008 (European Commission 2008b). DG INFSO has also recently published an IA on ICT for energy efficiency in several sectors including mobility (European Commission 2009b).

The two DGs cooperate in three ways at least:

- DG INFSO links its Information and Communication Technologies Policy Support Programme (ICT PSP) with DG TREN’s Intelligent Energy Europe Programme (IEE) in the common Competitiveness and Innovation framework Programme (CIP).

78 See http://ec.europa.eu/energy/intelligent/.
Objective 6.5 “Novel ICT solutions for Smart Electricity Distribution Networks” - The two DGs also have a joint call ICT & Energy No. 3 (based on Work Programme 2009) under FP7-ICT-ENERGY-2009-1 published on 19 November 2008 with a budget of € 20 million.

The division of labour between the two DGs seems to be roughly such that:

- DG TREN concentrates its research funding involving energy efficiency and ICT on areas such as deployment, road pricing, navigation systems, etc.
- DG INFSO concentrates on new applications and mobility services for people and goods such as those improving safety.\(^{41}\)
- Other DGs involved in ICT for Energy Efficiency are DG ENVT and DG ENTR, the former with reconciling energy issues with climate change mitigation goals, and the latter with Energy-using Products (EuPs). The role of DG Research should not be forgotten.
- One major new relevant focus of research in FP 7 is smart grids, for which a dedicated Technology Platform has been set up (European Commission 2006).

**ICT FET (Future and Emerging Technologies) Flagships**

In April 2009, the European Commission adopted a communication to the European Parliament (European Commission 2009c) that stressed the importance of greater investment in high-risk ICT research, as an important part of meeting the aims of the European Economic Recovery Plan. The traditional framework for such high-risk multidisciplinary research being the so-called “Future and Emerging Technologies (FET)” programmes, the Commission thus proposed the emergence of novel FET programmes, which should be ICT-based, but multidisciplinary in nature: “Europe requires a sustained scientific effort at the boundaries between ICT and other disciplines” (European Commission 2009c).

While the 2-3 envisioned “FET-Fs” (FET “Flagships”, as FET programmes are called) will not necessarily be in the field of ICT and energy, it seems however rather likely. The document lists three possible fields for the flagships, namely:

- “coping with the ‘data deluge’ and the increasing complexity of global systems”,
- “continuing miniaturisation of ICT components beyond the limitations of current technologies”, and
- “greening ICT”.

The Commission further recommends increasing the currently € 100 million spending for FET research by 20 %, to accommodate the new ICT FET Flagships (European Commission 2009c).

5.2 Selected National Programmes

5.2.1 EU Member States

**Austria**

7 million Euro were provided for Green ICT in the second call “Neue Energien 2020” that ran from 1.10.2008 to 15.1.2009. Most prominent among these, some 1 million Euro went to telematics, and 2 million to intelligent logistics.

\(^{41}\) Interview with Wolfgang Hoefs of the ICT for Transport section of DG INFSO on 20\(^{th}\) March 2009.
France
The main funders of research in the energy field are:

- L’Agence nationale de la Recherche (ANR),
- La Caisse des Dépôts et CDC Entreprises,
- OSEO, formerly known as “All” (Agence de l’innovation industrielle).  

In past years the funding of the Agency for Industrial Innovation (AII) has included the following research public/private co-funding programmes having at least a potential relationship to ICT in an energy context:

- a € 11 million programme Réseaux du Futur et Services (VERSO), (Agence de la recherche, 2009)
- a € 5.5 million programme Habitat intelligent et solaire photovoltaïque (HABISOL) (Agence de la recherche, 2009)
- a € 62 million initiative to develop new energy-efficient subway cars.
- a € 88 million programme to improve energy efficiency in buildings through improvements in insulation, heating, lighting and ventilation;


Germany
IKT2020. There is a public procurement project conducted jointly by different federal agencises, namely the “Beschaffungsamt des Bundesministeriums des Innern“, BITKOM, “Bundesamt für Informationsmanagement und Informationstechnik der Bundeswehr” and the “Umweltbundesamt”. It intends to provide public buyers on the federal, state, and municipal levels the possibility to formulate their calls for tender to procure ICT independently of brands, but in conformance with all applicable legal requirements and sustainable development.  

e-energy. “Under the umbrella of the E-Energy beacon project, the BMWi will provide some € 40 million in funding and the BMU will make approximately € 20 million available. The participating companies will raise another € 80 million so that a total of approx. € 140 million in research funds can be mobilized to give the new E-Energy area of innovation the impetus it needs” (BMWi 2008). E-energy is a support and funding priority flowing largely to model regions. The six price winners are:

- E-DeMa, Ruhr area model region,
- eTelligence, Cuxhaven model region,
- MEREGIO, Baden model region,
- Mannheim model city, Rhine-Neckar model region,
- RegModHarz, Harz model region, and
- SmartW@TTS, Aachen model region.

KMU-innovativ: Ressourcen- und Energieeffizienz. 300 million Euro subsidies are spent to support innovations towards resource end energy efficiency by SMEs. A strong ICT component is expected: “Over 80 per cent of the

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43 See http://www.itk-beschaffung.de.
innovations in the application areas typical for Germany's economic strength – automotive, medical technology and logistics – are ICT-driven” (BMWi 2007).

United Kingdom

UK research funding is based on seven research councils such as the Natural Environment Research Council (NERC) and the Science & Technology Facilities Council. The Research Councils have a joint Energy Programme and a joint programme entitled “Living with Environmental Change” (LWEC).

There is also a Science and Innovation Investment Framework and a new Capital Investment Fund for universities carrying out Research Council funded projects. The programme entitled Research into the Digital Economy most specifically targets Information and Communications Technology (ICT).

A second example of UK programmes is the decision to introduce smart metering in companies and eventually on the mass domestic level. An initial project is funded from 2007 to 2010 with £10m from the Government matched by equivalent funding from the companies (Ofgem 2009).

Denmark

Denmark’s Ministry of Science, Technology and Innovation has started in 2008 the “Action Plan for Green IT” (MSTI 2008). The plan focuses on ICT’s own energy consumption only, is however one of the few programmes taking into consideration the whole ICT life-cycle, by promoting “sustainable development of IT”, “sustainable production of IT”, “sustainable use of IT”, and “sustainable disposal of IT”. Starting with the Ministry’s own commitment of reducing its ICT-related energy usage by 10 %, the plan then aims at promoting green ICT to other public authorities, businesses, as well as children and young people as main private ICT users.

Risø DTU, Denmark’s National Laboratory for Sustainable Energy, will participate in the international Consortium on Digital Energy (CoDE). The Consortium on Digital Energy draws upon expertise and experience from the energy, information technology and communications sectors to create a converged perspective on the development of tomorrow’s digital energy infrastructure. Among the charter members are Duke Energy, Elster, eMeter Corporation, National Grid, GridPoint, Inc., Intel, Philips, Telecom Italia, Vodafone Group, Imperial College London, National Renewable Energy Laboratory and Risø DTU.

Finland

The VTT Technical Research Centre of Finland, the largest multi-technological applied research organisation in Northern Europe, participates in several national research programmes:

- CUBE – The Building Services Technology Programme, 2002 – 2006, was funded with € 27 million. Its objectives were to utilise innovations including ICT and energy technology.
- DENSY - Distributed Energy Systems Technology Programme 2003 - 2007, was funded with € 56.7 million.

Norway

Over the next 8 years, the Research Centre on “Zero Emission Buildings” (ZEB) of the Faculty of Architecture and Fine Art at the Norwegian University of Science and Technology, have been granted an annual budget of 4.5 million Euro. The activities have a strong focus on smart buildings.

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44 See [http://www.rcuk.ac.uk/default.htm](http://www.rcuk.ac.uk/default.htm).
47 See [http://www.ntnu.no/](http://www.ntnu.no/).
Sweden

MISTRA, the Swedish Foundation for Strategic Environmental Research, has funded between 1996 and 2002 a large programme for ICT-supported sustainable building, called “ByggMISTRA”. Presently, the foundation supports research programmes for sustainable transportation.

The MISTRA Centre for Urban Futures is supposed to start its work on a “more knowledge-based urban development agenda” in January 2010. The level of funding for an initial two-year implementation stage is expected to be up to SEK 15 million.

5.2.2 Outside the European Union

Japan

Japan’s “Green IT” initiative has been created by the Ministry of Economy, Trade and Industry (Myoken 2008). However, the Ministry of Internal Affairs and Communications (MIC 2008) is also involved in Japan’s efforts on improving the environmental impact of ICT. Both programmes are mainly concerned with ICT’s own energy consumption.

United States

The “Center for IT Research in the Interest of Society” (CITRIS) at the University of California at Berkeley has numerous relevant programmes. One example of them concerns intelligent infrastructure and is called “New Thermostat, New Temperature Node, and New Meter”. It is designed to meet the objectives of the California Energy Commission (CEC) to create inexpensive and “smart” thermostats and electricity meters that could be installed in all residences in California to help conserve energy via real-time, demand-response electricity pricing by an unspecified date.

48 See http://www.mistra.org/.
49 See http://www.mistra.org/mistra/finansiering/pagaendeutlysningar/urbanfutures.4.61632b5e117dec92f47800098011.html
50 See http://www.citris-uc.org/.
6 Conclusions

The energy used by ICT and the energy efficiency induced by ICT are two research areas of increasing importance. However, they have been studied almost independently so far. While many studies provide in-depth analyzes of numerous sectors, putting forward complex and detailed data, they fall short of conceptually contrasting ICT's own consumption and the energy efficiency it can induce across society.

Obviously however, pushing the second goal will compromise policies focusing on the first one. Fostering the use of ICT for energy efficiency beyond baseline- or business-as-usual (BAU) scenarios will necessarily lead to a faster increase of ICT-related energy consumption in certain application fields. This consumption, however, will have to be accepted since the very reason for its existence is that it is over-compensated for by the energy saved as a consequence of the energy efficiency induced by the ICT applications.

In short, we are proposing to distinguish "good" from "bad" ICT energy consumption. Without this difference, policies that effectively limit ICT energy consumption risk to undermine policies fostering ICT for energy efficiency. Viewed from the other side, policies boosting ICT diffusion based on the belief that this will advance energy efficiency in any case are at risk to create a net increase in energy consumption.

In order to do this distinction, it is necessary to decompose the "ICT monolith" and acknowledge the natural differences between specific Information or Communication Technologies, to then be able to analyze and then treat each of them separately. We have started this process with the present study, mainly based on a first round of expert interviews. The table below summarizes again – in a very condensed and qualitative form – the experts’ opinions about the level of energy consumption for the several technological categories, contrasted with their potential of inducing energy efficiency across society.

<table>
<thead>
<tr>
<th>Technology (A: servers, B: network, C: end-user devices; D: embedded)</th>
<th>Energy Consumption</th>
<th>Enabling Effect on Energy Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1: servers outside data centres</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>A2: corporate data centres for in-house services</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>A3: data centres of ICT service providers</td>
<td>high</td>
<td>high</td>
</tr>
<tr>
<td>B1: terrestrial and marine communication: optic fibre cables &amp; copper cables</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>B2: wireless communication: GSM, WiFi, 3G antennas</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>B3: wireless communication: telecom satellites</td>
<td>low</td>
<td>medium</td>
</tr>
<tr>
<td>B4: supporting Internet infrastructure: routers, DNS servers</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>C1: personal computing devices: desktops, laptops, netbooks</td>
<td>high</td>
<td>medium</td>
</tr>
<tr>
<td>C2: home telecommunication devices: landline phones</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>C3: mobile telecommunication devices: cellular phones</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>C4: TV sets, set-top boxes</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>C5: portable media (music and/or video) players, e-books</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>C6: digital cameras</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>C7: peripherals (scanners, printers, etc)</td>
<td>medium</td>
<td>low</td>
</tr>
<tr>
<td>D: embedded ICT</td>
<td>high</td>
<td>high</td>
</tr>
</tbody>
</table>
From the table above, several interesting conclusions can be drawn. Firstly, servers are seen by a clear majority as the big energy consumers. This observation refers not only to the three “data server” categories A1, A2, and A3, but also to the category B4, comprising “communication servers,” such as Internet nodes.

Communication cables, antennas, and satellites, on the other hand, are not associated with a high own energy consumption. Nevertheless, for all these categories the potential for energy efficiency is rated as more relevant than the own energy consumption – which might come to little surprise when thinking that the networking enabled by these technologies is a necessary basis for applications aimed at inducing more energy efficiency by automated control, metering, information gathering, etc., and has a potential to optimize and substitute physical transport.

Personal computing devices, while contributing significantly to the overall ICT energy consumption, are regarded as less relevant for inducing energy efficiency than servers, communication infrastructure, or embedded ICT. This observation actually applies to all “end-user devices” subcategories – where the ratio between own energy consumption and potential for energy reduction is the least favourable, as compared to the other three main categories.

This insight applies particularly to the category C4 “TV sets and set-top boxes.” From all the technologies that are not servers, it sticks out in a negative sense – without exception, all interviewees think that it is responsible for a relevant part of the overall ICT energy consumption, while almost no one thinks that it could contribute towards energy efficiency.

Finally, the group D of “embedded ICT” is worth a look at. While the majority of interviewees thinks it has an important own energy consumption, even more (91%) also thought that it is relevant for inducing energy efficiency throughout the economy – the largest number of any category or sub-category. And indeed – embedded ICT include, for example, sensors which are necessary in smart meters for providing fine-granular, real-time data about a building’s energy consumption, or for gathering the information needed in intelligent transport systems (ITSs). Embedded ICT further includes both the sensors and actuators needed for smart engines, along with numerous other categories, and is thus the technology expected to have the largest enabling potential for energy efficiency.

Comparing these last two categories C4 and D, underlines very well the point we are trying to make: Both categories “TV sets and set-top boxes” and “embedded ICT” are expected by experts to significantly contribute to the overall ICT energy consumption, but should not be lumped together. This is because the returns in terms of energy saved by efficiency-enabling effects are completely different.

We conclude that ICT energy consumption and ICT-induced energy efficiency are two areas of research that should be integrated. A conceptual and methodological integration is a necessary condition for assessing net energy impacts of ICT in specific application areas. This comes along with decomposing the “ICT monolith” into more specific technologies and their application fields. In each field, then, consumption can be related to efficiency potentials.

In a context of environmental or climate policies, it is crucial to focus on specific types of ICT, their application fields, their energy consumption and potential contribution to energy efficiency. Otherwise, if ICT is treated as a (however defined) monolithic block, but the energy consumption issue separated from the efficiency-enabling issue, it is hard to see how a coherent policy leading to true energy savings could ever emerge.

The work we presented forms only a beginning of the type of research we want to encourage. More can be done by systematically screening ICT application fields for hot spots of increasing energy consumption and unused ICT-induced energy efficiency potentials.
Annex 1: Involved Organisations and Research Institutes

European Commission, Directorate-General JRC Joint Research Centre, Institute for Prospective Technological Studies (IPTS), http://ipts.jrc.ec.europa.eu/
European Community ENERGY STAR Programme for energy efficient office equipment, http://www.eu-energystar.org/
European Environmental Bureau (EEB), http://www.eeb.org/
European Information & Communications Technology Industry Association (EICTA), http://www.eicta.org/
European Technology Assessment Group (ETAG), http://www.itas.fzk.de/etag/
Fraunhofer Institute for Reliability and Microintegration, http://www.izm.fraunhofer.de/
Institute for Technology Assessment and Futures Research (IZT), http://www.izt.de/en/
Institute for European Environmental Policy (IEEP), http://www.ieep.eu/
International Telecommunication Union, Focus Group on ICTs and Climate Change (ITU FG ICT&CC), http://www.itu.int/ITU-T/focusgroups/climate/
Joint initiative by the EU’s electrical and electronic engineering industry and the European Commission (ELECTRA), http://ec.europa.eu/enterprise/electr_equipment/electra.htm
The European Telecommunications Network Operators’ Association (ETNO), http://www.etno.be/
The Global e-Sustainability Initiative (GeSI), http://www.gesi.org/

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UK-Department for Environment, Food and Rural Affairs (DEFRA), http://www.defra.gov.uk/
Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste (WIK),
http://www.wik.org/index_e.htm
## Annex 2: List of Experts

<table>
<thead>
<tr>
<th>Name</th>
<th>Bernard Aebischer, Senior Researcher</th>
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<tr>
<td>Country</td>
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<td>Research focus</td>
<td>Energy Efficiency in the Service Sector and in ICT</td>
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<td>Research focus</td>
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<tr>
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<tr>
<th>Name</th>
<th>Roland Hischier, Project Manager</th>
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<td>Country</td>
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<tr>
<td>Organisation</td>
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<td>Research focus</td>
<td>Life-Cycle Assessment</td>
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<th>Frank Horn, Head of Department</th>
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<tr>
<th>Name</th>
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<tr>
<td>Name</td>
<td>Reiner Lemke, Corporate Responsibility</td>
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<th>Name</th>
<th>Jens Malmodin</th>
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<th>Name</th>
<th>Catalina McGregor, Deputy Champion</th>
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<tr>
<td>Country</td>
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<th>Name</th>
<th>Georg Meixner</th>
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<td>Country</td>
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<td>Research focus</td>
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<tr>
<th>Name</th>
<th>Simon Mingay</th>
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<td>Country</td>
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<tr>
<td>Organisation</td>
<td>Gartner Research</td>
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<tr>
<td>Research focus</td>
<td>ICT and Environmental Sustainability, Carbon Footprint of ICT, Green IT</td>
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<tr>
<th>Name</th>
<th>Luis Neves, Chairman of the board of GeSi</th>
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<tbody>
<tr>
<td>Country</td>
<td>Germany</td>
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<tr>
<td>Organisation</td>
<td>GeSi – Global e-Sustainability Initiative, Brussels</td>
</tr>
<tr>
<td>Research focus</td>
<td>GeSi coordinates efforts by ICT industry to use ICT to combat climate change and contribute to sustainable development.</td>
</tr>
<tr>
<td>Name</td>
<td>Jens Schippl</td>
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<tr>
<td>Country</td>
<td>Germany</td>
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<tr>
<td>Organisation</td>
<td>Institute for Technology Assessment and System Analysis</td>
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<tr>
<td>Research focus</td>
<td>Technology Assessment for Energy, Transport, and Mobility</td>
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<th>Name</th>
<th>Karsten Schischke, Environmental Engineering</th>
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<tr>
<td>Organisation</td>
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<td>Research focus</td>
<td>ICT and Energy</td>
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<tr>
<th>Name</th>
<th>Michael Sonnenschein, Professor</th>
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<td>Country</td>
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<td>Organisation</td>
<td>Oldenburg University</td>
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<td>Research focus</td>
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Annex 3: Interview Outline

Introduction

Within the EC-supported project ICT ENSURE (Information and Communication Technologies – ENVironmental SUSTainability REsearch),52 our Lab’s function is to investigate the role of ICT in energy consumption and energy efficiency.

The ICT ENSURE project relies on the rapidly spreading view (both in academia and within the European Commission) that ICT might be one of the most cost- and time-efficient ways to contribute towards a more energy-efficient society. Increased energy efficiency, in turn, could help reach concrete climate goals, such as EU’s “20 20 by 2020” goal. This goal has been announced by the president of the European Commission, José Manuel Barroso, on January 23rd, 2008. It consists of reducing European greenhouse-gas emissions by 20 % (as compared to 1990), and at the same time increase the share of renewable energy sources in Europe’s energy mix to 20 % – by 2020.53

Analysing how ICT can contribute to a more energy efficient society, two main aspects are significant: ICT’s own energy consumption (including the thus-related greenhouse-gases emissions), as well as the possibilities of using ICT components to achieve an increased level of energy efficiency in other sectors of the economy, such as transport or housing.

While highlighting these two facets, our study also follows a time-axis. Firstly, we will present a thorough overview of the state-of-the-art in both the “ICT energy consumption” and the “ICT for energy efficiency” research. Secondly, we want to offer an evaluation of future research directions in these areas, to answer questions such as: Which seem to be the best ways to keep ICT’s own energy consumption low? In which sectors (and how), will ICT most likely be able to contribute to a substantial increase in energy efficiency?

Especially for this peak into the future, we can greatly benefit from the opinions of recognized experts from both fields – ICT and energy efficiency. We are thus grateful for you accepting to participate in this study.

Please note: For the current study, we consider energy in general, and not exclusively electric power. Furthermore, for both energy consumption and energy efficiency, we do not look at the use phase of products only, but at the whole life cycle – i.e., including the production and the end-of-life phases. These distinctions, however, might not play any role for some or all of your answers, so feel free to consider them only where necessary.

Your answers will be analysed, aggregated with the other replies we receive, and ultimately become part of our study “The Role of ICT in Energy Consumption and Energy Efficiency”. We will list your name and affiliation in the list of experts that have answered to our questions, acknowledging thus your effort, and also informing the reader about the scientific value of our study. Your answers, however, will be treated confidentially – no one, but for the authors, will have access to them. Thank you again for your collaboration.

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52 See http://ict-ensure.tugraz.at/.
Topic 1: ICT Definition and Relevance of ICT for Energy Issues

There is no generally accepted enumeration of the technologies comprised within the ICT sector. This is partly due to the vagueness of the ICT concept, and partly due to the high dynamism of the sector, making existing enumerations quickly outdated. Against this background, which of the following technologies would you include within the ICT sector and which not?

These technologies, however, may differ largely in their energy consumption and in their potential to induce energy efficiency in other economic sectors. Our next questions thus refer to the relevance of the technologies for the two main questions of this study – the energy consumption of the ICT sector, and the usage of ICT to increase the energy efficiency across the economy.

- **A – Servers**
  - A1 – servers outside data centres
  - A2 – corporate data centres for in-house services
  - A3 – data centres of ICT service providers

- **B – Network infrastructure (everything in between servers and end-user devices)**
  - B1 – Terrestrial and marine communication: optic fibre cables & copper cables
  - B2 – Wireless communication: GSM, WiFi, 3G antennas
  - B3 – Wireless communication: telecom satellites
  - B4 – Supporting Internet infrastructure: routers, DNS servers

- **C – End-user devices**
  - C1 – Personal computing devices: desktops, laptops, netbooks
  - C2 – Home telecommunication devices: landline phones
  - C3 – Mobile telecommunication devices: cellular phones
  - C4 – TV sets, set-top boxes
  - C5 – portable media (i.e., music and/or video) players, e-books
  - C6 – digital cameras
  - C7 – Peripherals: scanners, printers, etc.

- **D – embedded ICT (e.g., a washing machine with digital control)**
Which technologies would you consider as belonging to the ICT sector? Which of them are relevant to the overall energy consumption of ICT, and which are relevant for the energy efficiency in other areas? Please feel free to add any further technologies that we might have forgotten.

<table>
<thead>
<tr>
<th>Technology</th>
<th>is ICT</th>
<th>Has a relevant own energy consumption</th>
<th>Is relevant for the energy efficiency of other processes</th>
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<tr>
<td>A1: servers outside data centres</td>
<td>☐</td>
<td>☐</td>
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<td>A2: corporate data centres</td>
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<td>A3: service provider data centres</td>
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<td>B1: terrestrial and marine cables</td>
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<td>B3: satellites</td>
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<td>B4: routers, DNS servers</td>
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<tr>
<td>C1: personal computing devices</td>
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<tr>
<td>C2: landline phones</td>
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<td>C3: cellular phones</td>
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<td>C4: TV sets, set-top boxes</td>
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<td>C5: portable media players</td>
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<td>C6: digital cameras</td>
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<td>C7: peripherals</td>
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<td>D: embedded ICT</td>
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**Topic 2: ICT Energy Consumption**

Looking at the next decade (until 2020), we are interested in your opinion as of how the cumulated energy consumption of the above-mentioned categories of products will evolve in a **business-as-usual scenario** – i.e., along the expected technological and market developments, but with no new policy incentives.

The 100% reference is the corresponding consumption for the year 2008. Furthermore, we do not aim at per-device consumption, but the overall consumption of all devices in the respective class. Under point C1, for example, we want to know how you think that the energy consumption (during production, use and end-of-life phase) of all existing personal computing devices in the year 2020 will compare to the year 2008.

If any of these categories you do not consider to be part of ICT, feel free to ignore the respective line. At the end of the table, we let some free lines for further technologies that you might want to add.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Savings</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Increase</th>
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<tbody>
<tr>
<td>A1: servers outside data centres</td>
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<td>A2: corporate data centres</td>
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<td>A3: service provider data centres</td>
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<td>B1: terrestrial and marine cables</td>
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<td>B2: land-based antennas</td>
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<td>B3: satellites</td>
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<td>B4: routers, DNS servers</td>
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<td>C1: personal computing devices</td>
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<td>C2: landline phones</td>
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<td>C3: cellular phones</td>
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<td>C4: TV sets, set-top boxes</td>
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<td>C5: portable media players</td>
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<td>C6: digital cameras</td>
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<td>C7: peripherals</td>
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<td>D: embedded ICT</td>
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</table>
For the same time period (until 2020), and the same categories of ICT products, how do you think the energy consumption will evolve in an **energy-optimistic scenario**, i.e., if the full potentials to reduce the energy demand of ICT would be consequently tapped.

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<td>5% - 15%</td>
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</tbody>
</table>

Which measures are the most important to achieve this second scenario?
Topic 3: ICT for Energy Efficiency

Looking at the currently widely discussed application areas in which the deployment of ICT could lead to better energy efficiency – how is their individual relevance for the reduction of the overall economic energy consumption?

At the end of the table, we let some free lines for complementary areas that you might want to add.

<table>
<thead>
<tr>
<th>Application area</th>
<th>Highly relevant</th>
<th>Relevant</th>
<th>Somehow relevant</th>
<th>Almost irrelevant</th>
<th>Irrelevant</th>
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<td>buildings and streets: intelligent lighting</td>
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<tr>
<td>virtual meetings and tele-work</td>
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</table>

Risking a more visionary look by widening the time horizon towards 2050, imagine a sustainable future largely enabled by ICT. Which has been the dominating application that has enabled this future? Which research was necessary to come so far? You may also mention more than one application.
**Topic 4: Availability and Quality of ICT and Energy Data**

How do you estimate both the availability and the quality of the data referring to ICT’s own energy consumption?

<table>
<thead>
<tr>
<th>Data</th>
<th>Very good</th>
<th>Good</th>
<th>Medium</th>
<th>Poor</th>
<th>Very poor</th>
<th>Don't know</th>
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</thead>
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<tr>
<td>ICT energy consumption – availability</td>
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Which measures should be taken to increase the availability and quality of data?

How do you estimate both the availability and the quality of the data referring to the deployment of ICT for energy efficiency?

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<th>Data</th>
<th>Very good</th>
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Which measures should be taken to increase the availability and quality of data?
Annex 4: References


European Commission (2009b). Impact Assessment. Accompanying document to the Commission proposal on Mobilising Information and Communication Technologies to facilitate the transition to an energy efficient, low carbon economy., European Commission, DG INFSO.

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