HELSINKI UNIVERSITY OF TECHNOLOGY
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POWER GUZZLER OR EFFICIENCY CATALYST?

THE ENERGY CONSUMPTION AND ENERGY SAVING POTENTIAL OF INFORMATION AND COMMUNICATION TECHNOLOGY

Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering

Espoo, 16 January 2007

Supervisor: Professor Tuula Pohjola
Instructor: D.Sc. (Tech.) Jyrki Louhi

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The target of this Master's thesis was to provide an up-to-date picture of the energy consumption of information and communication technology (ICT). In addition, ICT-enabled ways of reducing energy consumption were studied. The energy consumption of ICT was estimated based on an analysis of earlier research results and the relevant trends. It was found to be relatively small, at most 1.4 % of the global energy consumption. However, absolute energy consumption has grown in recent years due to the increasing stock of equipment and the trend towards more powerful devices. As a case in particular, the consumption of mobile phone networks in Finland was estimated. When the network, the mobile phone and the charger are all taken into account, the resulting annual energy consumption per user is between 40 and 48 kilowatthours.

The technological trend towards multifunctional devices could result in savings as regards the energy embedded in the production phase (including raw material extraction and processing, component manufacturing and assembly). Teleconferencing provides an opportunity to reduce travelling to meetings in firms. Its energy consumption is insignificant compared to that of travelling, which implies that it has considerable energy saving potential. Teleconferencing also offers firms the possibility to reduce travelling costs.

This Master's thesis contributes to the existing body of knowledge by providing an up-to-date picture of ICT's energy consumption balanced with examples of the energy saving potential of ICT. The results may be used to promote environmentally optimal use of ICT.

Keywords: information and communication technology, energy, energy consumption, energy saving, environmental impacts
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Tämän diplomityön tavoite oli tuottaa ajantasainen arvio tieto- ja viestintätekniikan (engl. information and communication technology, ICT) energiankulutuksesta ja muodostaa kuva ICT:n tuomista energiansäästömahdollisuuksista. ICT:n energiankulutus arvioitiin analysoimalla aikaisempia tutkimustuloksia ja tärkeimpiä trendejä. Sen todettiin olevan sangen pieni, korkeintaan 1,4 % koko maailman käyttämästä energiasta. Luku on kuitenkin kasvanut viime vuosina laitteiden määrän kasvun ja suorituskyvyn lisääntymisen myötä. Erityistapauksena tarkasteltiin matkapuhelinverkon kulutusta Suomessa. Kun huomioidaan matkapuhelinverkon, matkapuhelimen ja akkulaturin kulutus, matkapuhelimen käytöstä aiheutuva vuotuinen energiankulutus käyttäjää kohden on 40 – 48 kilowattituntia.

Tämän tutkimuksen perusteella matkapuhelimen, musiikkisoittimen ja digitaalikameran sisältävän multimediatietokoneen valmistukseen liittyvä energiankulutus vaikuttaa olevan pienempi kuin kolmen erillisen laitteen valmistamisen vaatima energia (valmistusvaiheen tulkittiin tutkimuksessa sisältävän raaka-aineiden tuotannon, komponenttien valmistuksen ja kokoonpanon). Esimerkkinä ICT:n energiaa säästävistä sovelluksista etäneuvottelu tarjoaa mahdollisuuden vähentää kokouksiin liittyvää työmatkustamista. Etäneuvottelun energiankulutus on mitätön verrattuna matkailun energiankulutukseen, joten sen säästöpotentiaali on merkittävä. Etäneuvottelutekniikoita käyttävä yritys myös säästää matkustuskuluissa.

Tämä tutkimus täydentää entuudestaan olemassa olevaa tietoa ICT:n ympäristövaikutuksista muodostamalla ajantasaisen arvion ICT:n energiankulutuksesta. Lisäksi se tarjoaa esimerkkejä ICT:n tuomista energiansäästömahdollisuuksista. Tuloksia voidaan hyödyntää ICT:n ympäristöystävällisen käytön suunnittelussa ja edistämisessä.

Avainsanat: tieto- ja viestintätekniikka, energia, energiankulutus, energian säästö, ympäristövaikutukset
Julkaisukieli: englanti

Preface

Writing one's Master's thesis is a solitary process—on the surface. In reality, most Master's thesis authors do have important figures acting behind the scenes. My case is not an exception.

Firstly, I'd like to thank my supervisor, professor Tuula Pohjola, for placing this interesting research problem in my hands. Tuula's encouraging feedback at the critical points of the process was perhaps more valuable than she may realise. My instructor, D. Sc. Jyrki Louhi from Nokia, deserves heartfelt thanks for his devoted guidance. The same applies to M. Sc. Salla Ahonen from Nokia, who initiated the research. Jyrki and Salla's sharp but friendly criticism was an endless source of improvement, and any quality in this work is as much thanks to them as it is to this author. I'd also like to thank Nokia Corporation for offering the chance to do this research, as well as all the professionals from Nokia and other companies who have sacrificed their time for this research.

A "thank you" is in order for my coworkers at the Environmental and Quality Management Unit. Even though I have worked on this research alone, the ladies and gentlemen at EMU have supported me by creating a pleasant working environment and setting an example of excellence.

Besides those who have somehow participated in my Master's thesis, there are others who have acted an important part on the way here. Studying would be dull indeed without my friends in TKK and outside it. Knowing them is a privilege which I'm increasingly proud of. My parents, Susanna and Kari, have taught their children the meaning of education and open-mindedness—the seemingly nonsensical family discussions at the dinner table have meaningful content as well! They have also shown unconditional faith in their daughter's talents. Finally, the gratitude I feel towards my boyfriend Teemu for having responded to my fretfulness, stressing and anxiety with care, tenderness and support is beyond expression.

Espoo, the 21st of December 2006

Marja Ollila

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List of abbreviations

BT	British Telecom
CAD	computer-aided design
CD	compact disc
CRT	cathode ray tube
ETNO	European Telecommunications Network Operators' Association
EU	European Union
GB	gigabyte
GSM	Global System for Mobile Communications
EDI	Electronic Data Interchange
EIA	Energy Information Administration (USA)
EIPRO	Environmental Impacts of Products research (EU)
FAO	Food and Agriculture Organisation (UN)
IEA	International Energy Agency
ICT	information and communication technology
IPCC	Intergovernmental Panel on Climate Change (UN)
IT	information technology
ITU	International Telecommunication Union
LBNL	Lawrence Berkeley National Laboratory (USA)
LCA	Life Cycle Assessment
LCD	liquid crystal display
LED	light-emitting diode
MP3	MPEG-1 Audio Layer 3 file format
NGO	non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
PC	personal computer
PVC	polyvinylcarbonate
PDA	personal digital assistant
SRES	Special Report on Emissions Scenarios (IPCC)
UN	United Nations
UNDP	United Nations Development Programme
UPS	Uninterruptable Power Supply
USA	United States of America
WBCSD	World Business Council on Sustainable Development
WCDMA	Wideband Code Division Multiple Access

List of symbols

° C	degrees Celsius
CO_2	carbon dioxide
g	gram
GJ	gigajoule
GWh	gigawatthour
h	hour
kg	kilogram
km	kilometre
kWh	kilowatthour
mAh	milliamperhour
MJ	megajoule
Mpx	megapixel
P	power
Q	capacity
U	voltage
t	time
TWh	terawatthour
V	volt
W	watt

1 Introduction

1.1 Background: ICT and the environment

Information and communication technology (ICT) has become an inherent part of the society in industrialised countries. The ICT sector contributed 15.3 % of the real gross domestic product (GDP) growth in the United States of America (USA) in 2005, fueling overall economic growth (BEA 2006). In the European Union (EU), ICT is likewise an engine of growth, corresponding to 5.6 % of GDP between 2003 and 2005 (IDABC 2006). The usage of ICT is also spreading: the percentage of people with access to communication networks is growing (ITU 2003, 2006). ICT has been compared to other revolutionary technologies that have changed the world permanently (Plepys 2002). It is predicted that ICT will continue to change the world in which we live (Pamlin 2002).

At the turn of the millennium, an interest in the environmental impacts of ICT emerged. The year 2000 issue of the prestigious *State of the World* report published by the Worldwatch Institute dedicated a complete chapter to a discussion of the links between ICT and the environment (O’Meara 2000). Afterwards, articles, papers and pamphlets concerning ICT’s environmental impacts have been published in abundance. Environmentalists and industrialists alike can be found among the authors, as well as scientists, politicians, and development workers. Still, the picture of ICT’s net environmental impact remains incomplete. The present literature is characterised by conflicting views: some see ICT as another cause of environmental deterioration, others think it can make human action more eco-efficient.

At the same time, there have been two interrelated developments that stress the importance of paying attention to ICT’s environmental impacts. Firstly, climate change and related environmental problems have become a public concern. Finding ways to reduce greenhouse gas emissions is now high on the global political agenda. Secondly, corporate sustainability—balancing financial matters against environmental and social ones—is increasingly being demanded from companies by their stakeholders (PricewaterhouseCoopers 2006). Although the ICT sector is not generally regarded as a major burden on the environment, the firms in this sector are also likely to face more environmental scrutiny in the future.

This Master's thesis describes ICT's positive and negative environmental impacts, focusing on energy consumption. Energy is intimately linked to climate change, and providing energy for the mankind in the future is a central question in combating climate change (WBSCD 2006). The goal of this thesis is to provide a clearer picture about ICT's own energy consumption and the ways in which it could reduce the overall energy consumption.

1.2 Research questions

The aim of this Master's thesis has been to answer the following research questions:

> *How much energy does the use of ICT consume?*
> *How much energy do mobile phones and networks consume, both individually and in comparison with other technologies?*
> *How could the use of ICT reduce energy consumption?*

The United Nations Development Programme (UNDP) has used the following definition for ICT: "ICTs include technologies and tools or instruments that can be used for storing, managing, communicating and sharing information" (UNDP 2003: 7). The Organisation for Economic Co-operation and Development (OECD), in turn, uses the following criteria for industrial activity: "For manufacturing sectors, the products of a candidate industry must fulfill the function of information processing and communication including transmission or display [and/or] must use electronic processing to detect, measure and/or record physical phenomena or to control a physical process." (OECD 2002: 81) In this study, ICT is viewed as including telecommunications and computer networks, and the equipment that can be considered as belonging to these networks, like printers and copiers in offices.

The term "information and communication technology" has come to replace an earlier one, namely "information technology" (IT). The latter is used in some of the research referred in this study. For the sake of consistency, IT has been replaced with ICT in the writing, unless there has been uncertainty about the definition of IT in the source.

1.3 Research objectives

The aim of this research is to provide a picture of the impact of ICT and its use on energy consumption. Generally, ICT is viewed as a non-energy-intensive technology. ICT is also considered to have great potential in making many activities in the economy more efficient. These views have become practical facts in the current discussion, to the extent that few inquire after empirical proof. This study will provides some empirical insight into the popular claims.

1.4 Research methodology

This study is descriptive in nature: it aims to describe the relationship between ICT use and energy consumption as accurately as possible (Järvenpää and Kosonen 2000). Time-wise, it focuses on the year 2006, when the research was carried out. Changes in ICT’s energy consumption between earlier studies and the present one are also observed. To construct a comprehensive picture of the studied phenomenon, the present research utilised both quantitative and qualitative data and means of analysis.

1.5 Structure of the Master's thesis

The research methods and the research process used in this study are described in Chapter 2. The actual research process consisted of two parts, a review of existing literature (Chapter 3) and empirical case studies (Chapter 4). The empirical findings are analysed in Chapter 5, which also contains validity and reliability considerations. The theoretical and the empirical findings are brought together in Chapter 6, which closes the research report by summing up the results and providing ideas for further research.

2 Research methodology and methods

2.1 Research methodology

This research adopted the descriptive research approach to illustrate the energy consumption of ICT and the energy saving possibilities that ICT may present. Descriptive research attempts to construct an accurate picture of the phenomenon under study (Järvenpää and Kosonen 2000). Scope-wise, the research focused on describing the situation at the execution time. In order to describe the relationship between ICT and energy consumption comprehensively, the research combined traits from positivistic and hermeneutic lines of research. The positivistic approach focuses on empirical reality and the objects and relationships that can be observed directly. It is typical in science. Hermeneutic research, in turn, usually relies on qualitative methods. Concepts like "understanding" and "meaning" are central in hermeneutic research. It is often associated with social sciences. (Olkkonen 1993) The present research combined the hermeneutic and the positivistic approaches by using both qualitative and quantitative data and methods of analysis.

This study is divided into two parts. The theoretical part of the study is a literature review. This existing theory was used as a conceptual tool to gain a more structured understanding of the environmental impact and potential of ICT. Such an approach is typical for social sciences (Pyörälä 2002), and also in line with the hermeneutic tradition. Based on the theoretical part, an initial understanding of the relationship between ICT and energy use was built.

The empirical part of the study consisted of two case studies that provided additional insights into the energy consumption of ICT and the efficiency effects that ICT may have. The first case focused on technological development, namely device convergence, which has been the trend in mobile phones. This means that one device incorporates the functions of several ones, such as a mobile phone that also contains a digital camera. The second case compared teleconferencing as an ICT-based solution with traditional meetings where the participants have to travel. The cases were analysed using essentially quantitative methods.

In addition, the energy consumption of mobile telephone networks in Finland was estimated based on primary data collected for this research. Besides this quantitative estimate, qualitative data about the mobile phone networks and their energy consumption was gathered.

The data collected in the theoretical part was also utilised in the empirical part in estimating the current energy consumption of ICT. The most recent of the existing studies was based on data from the year 2001. As carrying out a complete up-to-date estimation was beyond the scope of this study, the existing data from previous research was incorporated with information about recent changes to provide an estimate of the energy consumed by ICT today.

2.2 Data collection

2.2.1 Secondary data collection

Secondary data sources were utilised both in the theoretical part and the empirical part of this study. Most of the sources used in the literature review were either articles published in scholarly journals and in industry magazines or conference papers that were accessible through the databases of the library of Helsinki University of Technology. In addition, publicly available resources such as reports from research laboratories and environmental non-governmental organisations (NGOs) were used. The secondary data collected for the empirical part consisted of technical details from device manufacturers’ websites.

2.2.2 Primary data collection

The primary data for this research was collected used semi-structured interviews. These were used in the empirical part of the study. To estimate the energy consumption of the mobile telephone network in Finland, interviews were conducted with representatives of the three Finnish telecommunications network operators that build and manage their own network infrastructure. The interviews also contained questions related to the environmental management in the companies. The questions were e-mailed to the interviewees prior to the meeting. The interviews lasted from sixty to ninety minutes. They were recorded and later transcribed.

The teleconferencing case also involved a discussion with a representative of Nokia, which was chosen as the model company for the case. This discussion did not follow a specific structure, although the interviewer had prepared the discussion and decided upon some themes that should be covered. As with the interviews, the discussion was recorded and transcribed. For the device convergence case, complementary inquiries concerning the technical details of the devices were made over the telephone to the manufacturers' customer support services.

2.2.3 Problems related to data collection

The interviews with representatives of the network operators were the most problematic part of the data collection phase. The two first interviewees were unable to answer the questions about the energy consumption of the network. In part, this was due to the formulation of the questions, in which the interviewees were asked to estimate the energy used by the network per one call minute, and one gigabyte (GB) of transferred data or per customer. It turned out that the operators did not have such information because of the structure of the mobile telephone network. In Finland, a base station site owned by one operator can accommodate base station equipment from all the other operators, as well as other clients. The energy consumption is, however, recorded per site. Consequently, it is difficult for the companies to track the energy consumption in the units proposed in the questions. Even though the interview questions also gave the opportunity to estimate the energy consumption in some other terms, such an estimate was not obtained in two cases out of three. Hence, the interviews had to be completed afterwards. For the third interview, the questions concerning the network's energy consumption were modified. The interview questions can be found in Appendix 7.

In the device convergence case, the initial purpose was to compare devices in terms of their life cycle energy consumption. However, life cycle energy data was available for only a few products. Therefore, the comparison focused on the use phase electricity consumption and the weight of the products, which was used as a proxy for energy consumption in the production phase. Information on the weight of the products was readily available on the manufacturers' web sites. In turn, data from which energy consumption could be estimated had to be collected from various sources, including manufacturer technical support, product descriptions at Internet retailers' websites and external party sites. Even so, the data sometimes had to be completed with educated guesses.

2.3 Data analysis

In the quantitative part of the study, estimates of the current energy consumption of both ICT in general and the specific cases were analysed using mathematically simple methods. The energy consumption of ICT was estimated based on an analysis of previous research findings (see Chapter 4.1.1). In the device convergence case, different devices were compared in terms of their material intensity and electricity consumption. For this, the energy consumption of devices had to be derived from the technical details of the products. In some instances, the energy consumption figures were available directly. In the teleconferencing case, a fictitious company was used as an example to illustrate the energy saving potential of teleconferencing due to confidentiality reasons.

For the analysis of the qualitative data, straightforward and pre-defined methods of analysis do not exist. In the present research, the interview material was grouped in Excel tables by question and then analysed. A micro-narrative on the operators' perception of energy consumption was also constructed based on material from the three interviews and utilised in the analysis.

3 Literature review

3.1 Motivation: climate change and energy efficiency

3.1.1 Climate change

A considerable amount of evidence shows that the global climate is warming. Over the last century, the global average temperature rose by 0.6 degrees Celsius (°C). It is very likely that the 1990s were the warmest decade in the history of temperature measurement. (IPCC 2001a) Given that temperature records cover a relatively short period of our history, it is challenging to assess the magnitude of the warming that is currently taking place (IPCC 2001c: chapter 2.5). Some variability in temperature is inherent to the climate system. The climatic history of the Earth is a succession of glacial periods and interglacials, and at the local level there is even more variability. (IPCC 2001c: chapter 1.2.2) Nevertheless, paleoclimate proxy indicators and historical documents have led experts to believe that the 20th century warming of the surface climate has been the most rapid in the past millennium (IPCC 2001c: chapter 2.5). According to recent research by American climatologists, today's global average temperature is within 1°C of the peak temperature in the last million years (Hansen *et al.* 2006).

The current global warming, significant in both magnitude and pace, is referred to as climate change. It is powerful enough to impact the global ecosystem in many ways. Possible consequences of climate change include decreases in snow cover and sea ice extent, rise of average sea level, increase in rainfall and local increases in the frequency of extreme weather events. (IPCC 2001a) In fact, there are many indications that such developments are already taking place. They will also affect the life of animals and humans on the planet. Scarcity in the water supply, decreasing crops, vulnerability of human settlements and infrastructure on coastal zones and increases in water and air pollution are all examples of consequences of climate change on the life on the planet. (IPCC 2001b: chapter 7, Executive summary)

Another aspect of climate change is that it is accelerated by human. Most of the current global warming appears to be due to growing concentrations of greenhouse gases in the atmosphere. The atmospheric concentrations of carbon dioxide, methane and nitrous oxide have all increased significantly during the Industrial Era. There is evidence that these increases are anthropogenic; in other words, that they are caused by human activity. (IPCC 2001a) Humans disturb the natural cycle of matter in the Earth's ecosystem. Carbon, for example, is naturally stored in the atmosphere, in vegetation, in soil and in the oceans. Atmospheric carbon—in the form of carbon dioxide—is released and absorbed again in photosynthesis and in the oceanic cycle. Human activities, such as burning fossil fuels and cutting rainforests, increase the carbon load and, as a result, the atmospheric carbon concentration. Hansen *et al.* (2006) judge that the ongoing global warming meets the criteria of dangerous anthropogenic interference.

In 2000, a working group of the United Nations' (UN) Intergovernmental Panel on Climate Change (IPCC) produced a Special Report on Emissions Scenarios (SRES), which presented greenhouse gas emissions scenarios up to the year 2100. The SRES scenarios were based on a thorough assessment of the driving forces behind greenhouse gas emissions. Multiple modelling approaches were used in order to learn about the range of outcomes with different models using similar assumptions. (IPCC 2000: Summary for Policymakers) A total of forty scenarios were simulated. They fall under four different storylines, or scenario families, whose characteristics are summarised in Table 1 below.

Table 1. Summary of the SRES scenarios.

Scenario	Economy	Population	Technology	Trends
A1	Very rapid growth Reduced differences in per capita income	Low growth	Rapid introduction of new, efficient technologies	Convergence among regions Social and cultural exchange Capacity building
A2	Regionally oriented growth Fragmented income patterns	High growth	Geographically fragmented change	Self-reliance Preservation of local identities
B1	Structural change towards an information and service economy	Low growth	Introduction of clean, resource-efficient technologies	Global sustainability solutions No additional climate initiatives
B2	Intermediate development	Moderate growth	Less rapid and more diverse change than in B1	Local sustainability solutions

Interestingly, the scenario family associated with an “information and service economy” (B1) presents the lowest predicted amount of carbon dioxide emissions throughout the simulation period. In this family, energy-efficiency improvements and the dematerialisation of the economy will bring about a structural shift in energy production towards non-fossil energy sources. The energy intensity of the economy, or the energy consumed per dollar of GDP, will decline markedly. (IPCC 2000: chapters 4.4.5, 4.4.8.5 and 5.3) The B1 scenario family is characterised by strong environmental consciousness as the driving force for development. Both production and consumption patterns will change towards a more sustainable direction. Thus, the structural changes in activity patterns are not due to technological progress alone, but are also the product of a “sustainability orientation” at the individual and societal level. (IPCC 2000: chapters 4.4.10.3 and 5.3.1.3) As the IPCC scenarios are essentially based on earlier scenario analyses, it is difficult to say which exact assumptions lay behind the B1 scenario family and what their likelihood of becoming reality is.

IPCC’s analysis reflects the view of ICT as a general-purpose technology comparable to the steam engine: something that impacts both the economy and society profoundly (Plepys 2002). Put otherwise, ICT is an “enabling sector” of the economy that affects all other economic activity across sectors (Yeager and Stahlkopf 2000). As such, ICT is not a “clean” or “green” technology in the terms that we think of those. But should the term *environmental technology* be reconsidered, as Brad Allenby (2002) has suggested? Allenby pointed out that environmental technologies as we know them are usually mere add-ons (end-of-pipe technologies are a good example), while general-purpose technologies like ICT are inherent parts of the technological, social and economical system. According to Allenby (2002), true environmental benefit from technologies will only be created in such systems. The technologies with potential for this are too complex to be categorised in one class, be that “environmental” or something else. They are simply good technology. As the former EHS director of AT&T, Allenby has a stake in the discussion about ICT and the environment. Nevertheless, his point is worth considering.

3.1.2 Energy and climate

As awareness about climate change spreads, energy becomes the focus of discussion. Energy is “the fuel of growth” (WBCSD 2004) and the cornerstone of welfare in industrialised countries. However, prosperity has its price: the production and use of energy has significant environmental impacts, which are largely due to the use of fossil fuels. Burning fossil fuels releases carbon dioxide and methane which are both greenhouse gases and thus contribute to global warming. (Energia.fi 2006b) The majority, 80 %, of the world's greenhouse gas emissions are due to energy use (Birol 2006).

In the 1970's, electricity accounted for only a quarter of energy consumption in the industrialised countries. In 2000, the percentage had risen to almost 40 %. The near future will likely see the share grow to 50 % and even more. (Yeager and Stahlkopf 2000) In some respects, electricity seems environmentally friendly compared to fossil fuels—electric trains pollute less than gasoline-fuelled cars. Everyday discussion tends to disguise the fact that electricity can be generated in various ways, which largely determine its environmental impact. Matthews *et al.* (2002a: 191) make the remark that "electricity generation is one of the largest national sources of many pollutants, especially sulfur dioxide, nitrogen oxides, carbon dioxide, and particulates." While Matthews *et al.*'s statement describes the situation in the USA, it applies equally to all industrialised and industrialising countries. According to 2004 data, about 60 % of the world's electricity is produced using fossil fuels: coal, oil and gas. Of these, coal dominates with a share of roughly 40 %. In terms of primary energy, the share is still higher: fossil fuels account for 80 % of the global primary energy supply. Although the proportion of fossil fuels has declined slightly in energy and electricity generation, it remains considerable. (IEA 2006)

Globally, the consumption of energy is rising. This trend is intimately linked with the improvement of the global standard of living: if the UN targets for eliminating poverty are achieved, energy use could double or triple by 2050. (WBSCD 2004) The International Energy Agency (IEA) predicts that energy consumption will grow by 1.6 % annually, even without significant changes in the average standard of livings. This means that by 2030, the world will consume 50 % more energy than today. In the base scenario of the IEA, the majority, or 80 % of the increase in demand is met by burning fossil fuels. (Birol 2006) While Birol predicts that there will be enough energy resources to fulfill the world's growing needs, it is unclear whether the Earth's ecosystem can bear such a burden. The environmentalists of the world, like Greenpeace and the

WWF[1], are therefore promoting renewable energy and the improvement of energy efficiency as the true solution to climate change.

In the USA, the industrial sector is the biggest energy consumer with a 33 % share of the total delivered annual energy consumption. It is followed by the transportation sector, which corresponds to 28 % of the total. The residential sector accounts for 21 %, while the commercial sector's share is 18 %. (EIA 2006b) The EU-commissioned EIPRO (Environmental Impacts of Products) research, in turn, illustrates the situation in the twenty-five EU countries: based on earlier research, the three most energy-consuming sectors (in terms of primary energy) are food production (6—24 % of the total depending on the source), transportation (9—34 %) and heating (10—26 %). Sectors like office and household electrical appliances belonged into the mid-range sectors, of whose importance it was hard to conclude anything decisive. For example, the environmental impacts of office equipment were only considered in one of the EIPRO sources. An input-output analysis carried out by the EIPRO researchers showed that the "telephone, telegraph communications and communications services" sector was among the sectors accounting for more than 50 % of the aggregate environmental impact in four of the eight impact categories studied. Its contribution was nevertheless small, less than 2 % of the total in all impact categories. The use of household electrical equipment, which was also included in the model, contributes still less, about 1 % of the total in all impact categories. Other ICT-related sectors did not appear among the 35 most important sectors. (Eder and Delgado 2006)

3.2 Impacts of ICT on energy use

3.2.1 Classification of ICT's environmental impacts

The relationship between ICT and the environment is multifaceted, and different classifications of the points of interaction have been presented. One clear category is the so-called direct impacts, or impacts due to the life cycle phases of ICT products and ICT infrastructure. From the perspective of energy consumption, the manufacturing and use phases of ICT devices are the most significant. Manufacturing electronics, when viewed as containing not only the assembly of appliances but also the extraction and processing

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[1] See http://www.greenpeace.org/international/campaigns/climate-change/solutions [accessed 9.1.2007] and http://www.panda.org/about_wwf/what_we_do/climate_change/solutions/energy_solutions/energy_paradigm/index.cfm [accessed 9.1.2007].

of resources, is energy- and resource-intensive. (Plepys 2002) Energy use during the use phase may also be substantial, as will be shown further in this chapter. (O’Meara 2000, Fichter 2001, Berkhout and Hertin 2004)

Environmental NGOs have addressed the use of potentially dangerous substances in ICT device components. Some manufacturers are already making efforts to phase out materials such as polyvinylcarbonate (PVC) and certain chemicals. (Greenpeace 2006) The presence of these substances could cause environmental problems at the end-of-life phase, if the equipment is not disposed of appropriately. Certain authors have also expressed concern as to the mere amount of electronic waste from obsolete ICT devices, which is accentuated by the short life cycles of the equipment (Berkhout and Hertin 2004, O’Meara 2000). It is true that consumer electronics like mobile phones tend to become obsolete quickly—the average European buys a new mobile phone every two years (Telephia 2006), while a replacement interval of seven to twelve years has been suggested as environmentally optimal (Frey *et al.* 2006). On the other hand, ICT infrastructure tends to be more long-lived.

Compared to the direct environmental impacts of ICT, the indirect impacts are perhaps less straightforward. Romm (1999, 2000a, 2000b) classifies them as structural and efficiency gains. For example, a firm putting its products on sale on the Internet rather than in a retail building would represent a structural change, whereas the same firm using ICT to more efficiently manage its operations would exemplify an efficiency gain (Romm 2000). In turn, Berkhout and Hertin (2004) view the indirect effects of ICT as being mostly linked to our understanding about the environment or to the development, production and distribution of products and services.

The efficiency gains brought about by ICT may also result in a rebound effect. In general, rebound effects occur when an improved efficiency in resource use results in lower manufacturing costs, consequently lower prices and, ultimately, increased demand (Berkhout *et al.* 2000). Rebound effects may evolve around four axes: increased purchasing power, incentives for consumption due to lower prices, creation of new jobs that can increase consumption, and increased consumption due to time saved that can be used for shopping (Heiskanen *et al.* 2001).

Consequently, some researchers divide the indirect impacts into second-level and third-level effects. The third-level effects, then, are due to rebound effects and are manifested on a macroeconomic or societal level. (Fichter 2001, Plepys 2002) Berkhout and Hertin (2004) used a distinction between structural and behavioural effects of ICT. Fichter (2001) mentions life style changes as belonging to the third-order impacts. Allenby and Unger (2000), in turn, name three factors of importance in determining ICT's impact on energy demand: the power consumption of the equipment itself (the direct impacts), the need for a more reliable power supply, and ICT's impact on social changes and the consequent impact on energy use. The latter are ultimately decisive and also the most difficult to grasp (Allenby and Unger 2000). In the present study, the two-step classification into direct and indirect impacts is applied to avoid confusion.

3.2.2 Direct impacts of ICT

Energy consumption on a macroeconomic level

In the USA, the two fronts in the discussion about ICT's energy use are clearly visible. In 1999, Mark Mills argued that the Internet was already consuming 295 TWh of energy annually, or 8 % of the total US electricity consumption. He predicted that the share could easily go up to 30 % or 50 % in the next two decades. (Mills 1999) The writings of Mills and Peter Huber advanced the view of the Internet as a major energy consumer (see, for example, Huber & Mills 1999 and Huber 2000). Mills and Huber's statements were widely quoted both by representatives of media, corporations and financial analysts (Romm 2000b). Some citizen critiques have noted that Mills was affiliated to a pro-fossil fuels society questioning the negative environmental impacts of CO_2 emissions (Paperwight's Fair Shot 2005, Viridian 2006). This did not affect the reliability of his results in the public eye.

Such large figures provoked objections. At the request of the U.S. Environmental Protection Agency (EPA), a group of researchers at Lawrence Berkeley National Laboratory (LBNL) prepared a commentary of Mills' study, showing that several figures used in the estimate were unrealistically high. Their estimate of the energy consumption of the Internet was about 36 TWh instead of Mills' 295 TWh[2]. Koomey *et al.* (1999) however argued that it was questionable to assess the energy consumption of the Internet: in addition to browsing web pages, Internet-related office equipment is often used for other purposes as well, and it is difficult to allocate a "correct" proportion of the devices' energy consumption to the Internet. The total energy used by the equipment itself is more relevant. It is also easier to assess with reasonable certainty, as data concerning the stock of equipment and its energy use is readily available.

The approach recommended by Koomey *et al.* (1999) has since become best practice in estimates of ICT's energy consumption. In 2001, LBNL published its own estimate of energy use by office and network equipment. This report (Kawamoto *et al*. 2001) stated that the annual energy use for office and network equipment was approximately 74 TWh or 2 % of the total U.S. electricity consumption. The data used was from the year 1999. In a similar study commissioned by the U.S. Department of Energy and based on data from the year 2000, Roth *et al.* (2002) of the Arthur D. Little consulting company calculated the total energy consumption by non-residential office and telecommunications equipment. Their estimate of the aggregate energy use of the included equipment categories was 97 TWh. This corresponded to 3 % of national electricity use or to 1.1 % of the primary energy consumption.

On the other side of the Atlantic, a joint-forces research team from Fraunhofer Institute for Systems and Innovation Research and the Center for Energy Policy and Economics assessed the energy consumption of ICT in Germany. The scope of this study (Cremer *et al.* 2003) included, in addition to office equipment, entertainment, communication and intelligent home equipment, as well as the infrastructure associated with each equipment category. Based on data from 2001, their aggregate energy use was estimated to be 38 TWh. This corresponded to 1.4 % of the national energy demand or to 8 % of the overall electricity consumption in Germany. Table 2 on the next page gives a summary of the studies quoted above.

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[2] For more specific corrections presented by Koomey *et al.* (1999) to Mills' analysis, see page 18.

Table 2. Summary of earlier research on the annual energy consumption of ICT.

Researchers	Scope	Method	ICT equipment included	Result	% of national annual total
Mills (1999)	U.S. Internet equipment, including some energy embedded in manufacturing	Assessment based on stock of equipment and assumed consumption	Computers and peripherals; routers, switches, amplifiers, transmitters; servers	295 TWh	8 % of electricity consumption 3 % of primary energy (in 1999)
Kawamoto *et al.* (2001)	U.S. residential, commercial and industrial buildings	Assessment based on stock of equipment, average consumption and operating time in different modes; power management and extra energy use for printing etc. included	Computers, displays, servers, mainframes, minicomputers, terminals, printers, copiers, faxes; routers, switches, access devices and hubs	74 TWh	2 % of electricity consumption 0.8 % of energy consumption[3]
Roth *et al.* (2002)	U.S. commercial and industrial buildings	Assessment based on stock of equipment, average consumption and operating time in different modes	Computers, displays, servers, copiers, computer and telecom network equipment, printers, UPSs[4]	97 TWh	3 % of electricity consumption 1.1 % of energy consumption 9 % of the electricity consumption in commercial and industrial buildings
Cremer *et al.* (2003)	German households and offices	Assessment based on stock of equipment, average consumption and operating time in different modes	Entertainment, communications, data processing and "intelligent home" equipment and associated infrastructure	38 TWh	8 % of electricity consumption 1.4 % of energy consumption

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[3] In 1999, electricity corresponded to 39.4 % of all energy use in the USA (EIA 2005a).

[4] UPS: Uninterruptable Power Supply.

At a first glance, Mills' (1999) estimate of 295 TWh stands out: the figures provided in other studies are a third or less of this number. Cremer *et al.*'s result for Germany is the same in terms of proportion of national electricity consumption; however, this does not corroborate Mills' (1999) results, as the German study had a broader scope in terms of equipment included. To quote just a few observations from Koomey *et al.*'s (1999) critique, Mills had assumed the power consumption of a typical mainframe computer to be roughly equal to a 600-processor supercomputer worth tens of millions of dollars, he had estimated that four million servers are required to store the then five million pages of the Internet, and he also took the power consumption of a typical personal computer (PC) with undefined peripherals to equal 1 kW, while 200 W is according to Koomey *et al.* (1999) a more reasonable estimate for an office PC with shared peripherals. The approach used by Mills also differs fundamentally from the later studies. Therefore, comparing it with them or assessing its plausibility in the light of the other findings is difficult if not impossible.

The remaining three studies all use the approach recommended by Koomey *et al.* (1999). Each finds the energy consumption of ICT to be in the same order of magnitude, or one order of magnitude lower than Mills (1999). An interesting detail is that Cremer *et al.*'s (2003) estimate as a proportion of national electricity consumption is the same as Mills' (1999), even though their absolute figure is clearly smaller. This may point to a difference in the electricity consumption patterns between Germany and the USA. A closer look at the studies by Kawamoto *et al.* (2001), Roth *et al.* (2002) and Cremer *et al.* (2003) is taken in Chapter 4.1.1.

While ICT seems to account for a small part of total energy consumption, some authors claim that due to the continuing expansion of ICT this low percentage offers little comfort. Thelander (2004) expressed concern about the growth of energy use by IT, pointing out that Kawamoto *et al.*'s 2001 estimate of ICT's energy consumption in 1999 was already higher by 5 TWh than an earlier forecast from 1995. In addition, it is about twice as large as Koomey *et al.*'s (1999) tentative estimate in their comments on Mark Mills' study. In the U.S. residential sector, the category containing electronic devices is the fastest-growing component of energy consumption. It is estimated that by 2030, small appliances such as televisions and computers will account for 29 % of domestic consumption. In the commercial sector, the situation is similar. The energy consumption of computers and other equipment, although proportionally small, shows a rising trend. The component containing telecom equipment (and many other items, such as medical imagery) accounts for the major part of consumption and keeps growing. A part of the growth due to computers and associated equipment will be offset by efficiency gains, but the net effect is nevertheless an increase in consumption. (EIA 2006a) It has been observed that an increase in household revenue tends to result in the acquisition of additional electrical appliances.

Another worrisome aspect of energy consumption by ICT devices is that a considerable part of it is idle: the devices also consume energy when they are not actively used (see Fichter & Behrendt 2001, Berkhout & Hertin 2004, Thelander 2004). In the industrialised countries, standby consumption of electrical household equipment is estimated to account for 3 to 11 per cent of total residential electricity consumption. In the OECD countries as a whole, this standby consumption corresponds to approximately 1.5 % of total electricity consumption. The CO_2 emissions thus caused would be around 0.6 % of the OECD total. (IEA & OECD 2001) In Finland, the standby consumption of household devices amounts to 5–10 % of the annual electricity bill. The average standby power of a Finnish household is 33–39 W (Motiva 2006b). This leads to an energy consumption of 289–342 kWh annually, or 11 to 13 per cent of the energy consumption of an average household. Elsewhere, even more significant figures have been presented: in Canada, the idle power of households is estimated to be 49 W (Fung *et al.* 2003), while a study of ten Californian homes provided an estimate of 67 W (Ross and Meier 2000)!

Appropriate power management efforts could considerably reduce the power demand of ICT and other electrical appliances. Kawamoto *et al.* (2001) predicted that the annual total consumption of office equipment in the USA could be reduced to 50 TWh, or by a third, with power management and shutdown when possible. In a similar vein, Motiva (2006a) estimate that, with full-scale power management, the electricity consumption of office equipment in the Finnish public administration could be reduced to less than a half, by 0.120 TWh.

Unfortunately, power management efforts in computers often compromise functionality and usability (Thelander 2004, Motiva 2006a). PCs and associated peripherals may have different standby modes or lack off modes altogether. Besides, networked computers require standby power continuously. (IEA & OECD 2001) Sometimes a continuous power feed is a necessity and considerable backup installations must be built, which further increases the energy burden of ICT (Plepys 2002).

To conclude, while ICT's power consumption may currently be modest, it is certainly growing as the technologies spread. It seems that the energy efficiency of ICT use leaves room for improvement.

Direct impacts of mobile phones and networks

As a particular category of ICT, the environmental impacts of mobile phones and the associated infrastructure have been studied in various Life Cycle Assessments (LCAs). In general, researchers agree that most of the environmental impact is due to the network infrastructure. The calculation method may, however, influence the result. For example, Stutz *et al.*'s (2003) LCA found that the per GB environmental impact was higher for the mobile phone than for the base station. This is because the volume of data passing through during the equipment's lifetime is considerably higher for one base station than for one mobile phone (Faist Emmenegger 2006).

Hedblom's (nd) LCA of Ericsson's 3G (third generation) network suggests that most of the network's environmental impact is due to the base station. According to this study, most of the environmental impact was generated by the base station at its use phase, due to electrical energy consumed. The environmental impact of the base stations in terms of carbon dioxide ($CO_{2)}$ emissions was about three times that of mobile phones, for which the manufacturing phase contributed the most to the total environmental impact. The manufacturing phase included the raw materials, component assembly and equipment assembly subphases. Hedblom predicted that, if the network was assumed to have global coverage, it would consume 0.7 % of the aggregate Swedish energy consumption.

Schaefer *et al.*'s (2001) study of the use-phase energy consumption of the mobile phone network Germany is in accordance with Hedblom's (nd) results, as regards the distribution of energy consumption between the network and the mobile phone: the network consumes 678 GWh annually, or 15 kWh per subscriber; the handsets account for 47.4 GWh or 1.06 kWh per subscriber. The latter result is sensitive to the assumption about subscribers' use patterns: if all subscribers spent one hour talking on their phone every day, the gross result would be 90.6 GWh. Scharnhorst *et al.*'s (2006) comparison of the different GSM (Global System for Mobile Communications) and 3G network components by impact category and life cycle phase points to the same direction for WCDMA systems. In UMTS networks, the base station has the largest environmental impact in all categories and in all life cycle stages. The use phase contributes the most, in particular due to the energy consumption. The GSM system's environmental profile is different: while the use phase is the most important in the resource depletion category, the production phase generates the most impact on human health and climate change, and the end-of-life phase is the most burdensome upon ecosystem quality. Most of the production phase impact is due to the manufacturing of the GSM phone. The production phase in Scharnhorst *et al.*'s study included the extraction of raw materials, the processing of raw materials and the assembly of the network components.

Finally, the notion of the relatively small environmental impact of the mobile handset is again supported by an ecological footprint analysis by Frey *et al.* (2006), who note that the direct land use of a mobile phone—that is, the built-up land, forest, land for carbon sequestration and land requirements attributable to transport emissions—is small, corresponding to less than one per cent of the total available bioproductive area per capita in the world. Frey *et al.* (2006) limit their analysis to the mobile phone and do not estimate the footprint of base stations.

At the moment, a transition from GSM to UMTS technology is underway. This will influence the energy consumption, and the environmental impacts in general, of mobile phone networks. Scharnhorst *et al.* (2006) find that the absolute environmental performance of UMTS networks is worse than GSM networks'. The environmental impact of UMTS networks was higher in all of the impact categories, with most of the impact being due to the base station. According to Scharnhorst *et al.* (2006), the situation will however improve with new generations of the technology. Still, a UMTS network requires more equipment per area to achieve good coverage, thus increasing the environmental burden. This is because the high frequencies at which UMTS networks operate imply smaller cell sizes. (Miinalainen 2006, Scharnhorst *et al.* 2006) In their study of energy used by ICT in Germany, Cremer *et al.* (2003) similarly predicted a remarkable increase in the electricity consumption of mobile telephone networks, mostly due to the construction of UMTS coverage. Apart from the networks, Cremer *et al.* (2003) expected the energy consumption of mobile devices to decrease.

Nevertheless, changes in the amount of subscribers and data traffic will influence the environmental scores of the technologies. Currently, the UMTS system's per bit environmental impact is higher than that of the GSM system due to the low number of subscribers. The situation may nevertheless change as the amount of UMTS customer grows and the traffic volumes increase.[5] (Scharnhorst *et al.* 2006) All in all, UMTS networks can handle larger amounts of data than GSM networks (Toivanen 2006). Hence, with no decline in mobile communications in sight, the respective net environmental impacts of the technologies are not completely clear.

While it seems that mobile phones account for a small part of the total energy consumption of a mobile network system, the technological progress in handsets poses a challenge for their energy economics. The battery life of mobile phones has not increased as the phones' functionality has developed (Anonymous 2005), indicating that the power consumption of the phones has at best remained stable. In reality, the situation may be worse: according to a study by the Boston Consulting Group, the energy density of mobile phone batteries will grow by a modest 8 % a year, while the power consumption of mobile phones is expected to grow eight-fold by 2010 (Ankeny 2005, Voss 2005). Increases in power consumption are expected because of the widening spectrum of functionalities in mobile phones. The full-battery standby lifetime of a modern "all-in-one" phone with a wireless Internet connection may be considerably smaller than the lifetime of a less sophisticated device (Shih *et al.* 2002). The standby consumption of chargers could also be substantial, as Schaefer *et al.* (2001) point out. They estimate that it could amount to 578 GWh annually in Germany. In the light of Weidman and Lundberg (2000), who estimate that a charger that is kept plugged in all year long consumes 1 to 20 kWh of energy depending on the product generation, Schaefer *et al.*'s (2001) figure of German consumption falls within the limits of possibility, even though it seems high[6]. Currently, the standby consumption figures are lower (Louhi 2006).

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[5] Scharnhorst *et al.*(2006) assume in their scenarios that an increase in the amount of UMTS subscribers implies a decrease in the number of GSM customers.

[6] If assumed that a half of Germany's population of 82.5 millions keeps the mobile phone charger plugged on constantly, the annual energy consumption due to this is between 41 and 825 GWh. In 2001, there were 47 million mobile phone users in Germany (Cremer *et al.* 2003).

3.2.3 Indirect impacts of ICT

The digital economy and improved efficiency

The late 1990s saw a particularly rapid expansion of ICT. Enthusiasts declared that the industrialised world had entered into a new era, that of the digital economy. It was characterised by the growth in the relative importance of the ICT sector and the expanding use of ICT (Margherio *et al.* 1998, Fichter 2001). These two trends boosted the whole economy by improving productivity (Greenspan 1998).

The apparent efficiency due to ICT use led to environmental considerations: could the digital economy decouple economic growth from resource use? Indeed, some researchers noticed that the energy intensity of the U.S. economy had declined at more than 3 % per year in the late 1990s, while economic growth had been considerable at 9 % during the same period. The reduction in energy intensity could only partly be explained by warm weather (Davis *et al.* 2002, Takase and Murota 2004). Meanwhile, it seemed to correlate with the diffusion of ICT (Laitner 1999). Takase and Murota's (2004) simulation of the impacts of IT investment on national energy supply and demand in the USA and in Japan up to 2010 predicts that a higher level of IT investment would lead to lower energy intensities in both countries.

Romm (Romm *et al.* 1999, Romm 2000a, 2000b) proposed that the structural and efficiency gains brought about by the Internet lay beneath this apparent decoupling of energy use and economic growth. A sectoral analysis of U.S. energy use between 1988 and 1999 by Murtischaw and Schipper (2001) partly corroborates Romm's claims: they deduced that most of the decline in the energy to GDP ratio was due to structural changes. In turn, Collard *et al.* (2005) found proof of efficiency effects in the French service sector, in which the diffusion of communications equipment had contributed to a decline in the electricity intensity. It should be noted that Collard *et al.* (2005) separated computers and software from communications equipment; these would have an opposite effect. It is not entirely clear on what grounds the separation was made.

There were also critical voices who suggested that ICT would become an insatiable power guzzler (Huber and Mills 1999). Nevertheless, the increase in the U.S. stock of PCs was in fact accompanied by a reduction in retail electricity sales (Hakes 2000). In addition, ICT partisans advocated the view that the energy consumption of ICT was not purely incremental, but would substitute for other energy-consuming activities (Koomey *et al.* 1999). The rest of this chapter gives some examples.

Dematerialisation

Dematerialisation can have three forms: making products smaller and lighter, replacing material products with immaterial substitutes, and reducing the use of material- and infrastructure-intensive systems (National Research Council of Canada 2006). ICT-based solutions such as computer-aided design (CAD) are often instrumental in achieving the first form of dematerialisation. A more novel approach is “substituting bits for atoms”, where entire products are replaced with immaterial ICT solutions. In this respect, ICT is likened to services in some discussions.

According to 2005 statistics from the UN's Food and Agriculture Organisation (FAO), the global consumption for printing and writing paper has risen. The growth rate, however, differs between developing and / or newly industrialised countries and the industrialised countries. In the latter, the growth of printing and writing paper consumption has been about 2 % a year over the last decade, compared to rates of 4 % and more in developing areas. (Whiteman 2005) While it is impossible to say whether these changes are due to ICT penetration or other factors, it is true that the industrialised countries, where paper consumption growth is low, tend to be more advanced in terms of ICT use than the developing regions.

While the infamous paperless office has not become a reality, ICT may indeed replace some paper-processing chains in the economy (Allenby and Unger 2000). The European Telecommunications Network Operators’ association ETNO estimated that 45 % of the 156 million households in the then fifteen member countries of the EU could use electronic billing. Reductions in paper production and landfilled waste would then reduce CO_2 emissions by 1,902 million tonnes per year. (Szomolányi 2005) Another possibility for eliminating paper is in catalogues and dictionaries that are used only for short periods of time and not continuously. An online telephone directory’s life cycle environmental impact is about 17—20 % of that of a phone book or a compact disc (CD) catalogue with a use frequency of two searches a week (Zurkirch and Reichart 2002).

Other examples of ICT-enabled dematerialisation include the shift from analogue photography to taking pictures with digital cameras, which could reduce the yearly consumption of silver in the USA to 50 % of its 1999 level (Allenby 2002), the substitution of CDs for electronic files, like the MPEG-1 Audio Layer 3 file format (MP3) (Cohen 2000, Berkhout and Hertin 2004), and the replacement of answering machines with centralised voice messaging services. In Finland, the latter could save as much as 63,000 kWh of electricity and 18 tonnes of equipment annually (Mäki 1999)—however, this is a tiny fraction of the aggregate electricity consumption in Finland (Energia.fi 2006a). Deutsche Telekom has estimated the primary energy consumption and greenhouse gas emissions of an answering machine to be 27 times greater than those of its voice messaging service (Reichling and Otto 2002).

In some cases, the environmental benefits of replacing material products with data are not clear. For example, an LCA comparison of traditional and electronic mail suggested that the environmental burden from e-mail may actually be higher with files that require much disk space but are small when printed. This is because it was assumed that new servers would have to be installed to cope with increasing traffic. The use of office equipment (computers and printers) seemed to influence the result more than transportation or transmission of messages. (Zurkirch and Reichart 2002)

A relevant question is whether ICT-based dematerialisation can replace physical products or merely create products that are complementary to existing ones. The scope for dematerialisation may be limited, as Berkhout and Hertin (2004) point out: information is often just a part of the product-service package, rather than its whole content. Heiskanen and Jalas (2003) argue that ICT-based, non-material services are not alternatives to traditional products. Rather, their dematerialisation potential is the extent to which such economic activity will expand and consequently take space from more resource-intensive industries. New immaterial products could generate demand for new physical products (Berkhout and Hertin 2004), such as digital music players–not to mention their various trendy accessories like iPod socks. Finally, re-materialisation may occur: digital photos may be printed and MP3 files may be burned on CDs (Fichter and Behrendt 2001).

Shopping online

In electronic commerce, or e-commerce, the customer no longer drives to the local retailer to buy goods. Instead, the goods are delivered to the customers from a centralised warehouse. These changes in distribution and stocking, and the consequent changes in the amount of emissions and land use, determine the environmental impact of online retailing (Galea and Walton 2002). The elimination of customer-to-point of sales traffic is one of the main environmental arguments advanced by e-commerce partisans. This environmental gain is partially offset by the fact that e-commerce distribution often entails air freight, at least in large areas such as the USA (Matthews and Hendrickson 2001). Furthermore, consumers typically attend to several tasks during one shopping trip, which improves the efficiency of traditional shopping (Matthews *et al.* 2001). In addition, e-commerce may involve heavy packaging (Galea and Walton 2002, Matthews *et al.* 2001).

Matthews and Hendrickson's comparisons of traditional and online book retailing in the USA suggest that the major environmental benefit of e-commerce is the avoidance of excess production by matching supply to demand more closely—according to Matthews and Hendrickson (2001), about 35 % of the books in brick-and-mortar bookstores remain unsold. This makes e-commerce a more energy-efficient alternative (Matthews and Hendrickson 2001, Matthews *et al.* 2001). In a study of book retailing in Japan (Williams and Tagami 2003), where the avoided production was ignored, electronic book selling was found to consume more energy than traditional methods in urban, densely-populated areas.

In addition to travel between the consumer's home and the point of sales, e-commerce eliminates the retailer node of the supply chain. This could reduce the need for commercial floorspace: Romm *et al.* (1999) estimated that e-commerce requires sixteen times less energy for keeping up spaces than the traditional mode. Nevertheless, e-commerce may involve the construction of large central warehouses. This would offset some of the floorspace savings (Matthews *et al.* 2001). Moving warehouses away from cities may encourage sprawl in the community structure, which generally implies large environmental burdens due to traffic (Galea and Walton 2002).

Features of e-commerce that are contradictory to the sustainability goal include speed of delivery and elimination of distance (Galea and Walton 2002). These imply the use of faster transportation modes, whose fuel consumption is high (Sui and Rejeski 2002). It has been shown that the extent to which air freight is used influences the net environmental impact of e-commerce significantly (Matthews *et al.* 2001). Just-in-time delivery may also imply that the distribution vehicles are not always in full load, which further reduces the efficiency of transportation (Sui and Rejeski 2002). The population density, the distance between the production point and the consumer, and the personal transportation habits also matter when comparing e-commerce with traditional shopping (Williams and Tagami 2003). If the consumer travels to the retailer using public transport, traditional shopping may consume even less energy than online shopping (Reichling and Otto 2002). The significant factors also vary by country: for example, in the USA the modes of transport are critical, while in Japan the focus should be on reducing packaging, returns and energy use of buildings (Matthews *et al.* 2002b).

The benefits of real-time data transfer

A feature of ICT that is closely linked with e-commerce is its ability to store and distribute data rapidly and in considerable volumes. This aspect has some environmental interest. Cohen (2000) argues that e-commerce may introduce a paradigm shift in production towards so-called mass customisation. With electronic data interchange (EDI), firms can more easily gather information about their customers' preferences and match production to demand more accurately, both in terms of products and volumes. This results in smaller inventories and fewer obsolete products. (James 2001; quoted in James and Hills 2003) On the whole, ICT makes supply chain management more efficient, which contributes to increasing the stock turnover and reducing the amount of unwanted products (Berkhout and Hertin 2004).

The information transmitted by ICT could help change the consumption habits by bringing environmentally friendly products to the reach of buyers (Allenby and Unger 2000, Cohen 2000). Information about best practices in using products could be distributed to lengthen the useful life of products. Consumers could also be given the opportunity to order exactly the amount of a product or the parts of it they need in order to avoid waste. (Cohen 2000) On the other hand, the ease of online shopping and the vast selection of products available may also lead to careless consumption (Galea and Walton 2002, Plepys 2002, Sui and Rejeski 2002).

Besides more environmentally friendly shopping, ICT is instrumental in optimizing resource use. With real-time data, energy management becomes more efficient. (Laitner 2003) Responsive control systems for building energy use and electric metering that allows consumers to identify price peaks and adjust their use of electricity accordingly are examples of these (Allenby and Unger 2000). ICT applications can also be used to monitor and extract information on the environment itself, increasing the understanding of the state and structure of ecosystems (O'Meara 2000).

Telework

Arnfalk (1999: 7) defines telework as "regularly working remotely from an employer or from the traditional place of work, for a significant proportion of work time, at least partly with the use of telecommunications." Allenby (2002) cites the following types of telework: work at home or at clients' locations, work on the road, work at "satellite offices" (locations that are closer to the employees' homes than the main office. The portability of work is a prerequisite for teleworking: this means that the work is performed on information and can be carried out using ICT-based tools. Teleworking also requires technological and organisational support. (Heinonen 1998) This includes not only relevant data connections, software and hardware, but also good communication channels towards the organisation and the transfer of implicit knowledge (Allenby 2002).

Benefits of working from home for the employee include a better balance of professional and family life, saving time from commuting for other uses, and monetary savings in transport expenses. For the company, it offers cost-reduction possibilities from a reduced need for office and parking space. (Allenby 2002) The opportunity to work from home has also been found to improve employee productivity and employee retention, as well as to enhance the firm's recruitment opportunities (Allenby 2002, Arnfalk 1999). At the societal level, widespread teleworking has the potential to reduce the use of fossil fuels and emissions from traffic. It may have a positive impact on economy-wide productivity. (Allenby 2002) Working from home has also been suggested as a way to employ people that are otherwise excluded from the labour market, like the disabled (Allenby 2002) or residents of remote areas (Arnfalk 1999).

Working from home also has its costs. From the company, it requires investing in and maintaining an array of new technologies. At the societal level, large-scale teleworking may increase geographical dispersion, which implies more traffic. (Arnfalk 1999) The home worker experiences mostly social consequences: he or she no longer has the pleasure of leaving home for the office (Arnfalk & Kogg 2001), may experience social exclusion (Arnfalk 1999) and faces increased household heating and lighting costs (Allenby 2002, Arnfalk 1999). The heating and lighting energy consumption varies across regions but can be considerable, thus offsetting some of the energy savings from reduced transportation.

Notwithstanding these issues, it is clear that reducing the amount of transportation is one of the central questions of coping with climate change, and that avoided mileage has environmental benefits. For example, 110 million miles of avoided commuting at AT&T resulted in a reduction of 50,000 tonnes of CO_2 emissions (Allenby 2002). According to an estimate by Williams (2003), fully utilizing the Japanese telework potential would save 31.3 and 10.2 billion megajoules from reduced transportation and reduced need for office space, respectively. This corresponds to 2.1 % of Japanese energy use—more than is consumed by ICT (see 3.2.2 and 4.1.2). However, such savings would only be possible with four days of home working a week. According to ETNO, 22.2 million tonnes of CO_2 emissions could be avoided annually in the EU-25 countries by making 10 % of the workforce flexiworkers. ETNO assumed that every flexiworker avoided travelling 133 km by car and 60 km by train each week. This corresponds to 2.3 % of all transport-related CO_2 emissions in the EU-25 countries. (Szomolányi 2005)

Nevertheless, there may be rebound effects from home working. The increased residential energy consumption and a more scattered community structure are among them. Furthermore, commuting may be replaced with travelling for other purposes. Harvey and Taylor (2000) found that people who lack social content during the office hours, like home workers, are more likely to travel in their free time. In general, skepticism abounds as to the transport reduction potential of ICT. O’Meara points out that “No communications technology in history has ever been associated with a net reduction in travel.” (O’Meara 2000: 130) Research evidence suggests that telecommunications and travelling are complementary rather than substitutes (Mokhtarian 2003). Certainly, ICT enables a dispersion of activities in space and time, which could ultimately lead to a net increase in transportation—however, it is hard to say whether such fragmentation will inevitably lead to more travelling (Lenz and Nobis

2006). In addition, the societal implications of teleworking could be significant. They merit a study of their own and are therefore not discussed here in detail.

Besides working from home, telework may refer to the utilisation of particular technologies like teleconferencing. Teleconferencing means that a face-to-face meeting is replaced with an audio or video conference using ICT-based tools. It provides a more clear-cut case for assessing the environmental implications that telework may have.

The trend towards cross-border travelling is clearly observable in business travel (Arnfalk 2002). Travelling to and sitting in meetings can therefore consume a significant proportion of working time. With teleconferencing, some of the travelling can be avoided. The positive impacts of teleconferencing include improved work performance due to time freed from travelling, more efficient meetings and less preparation time required to reach group decisions. For the employees, teleconferencing is an easy way of including people in decision-making and it also allows more frequent contact with geographically distant team members. (Hopkinson *et al.* 2003, James *et al.* 2005) Time saved from travelling means more time for personal life (Arnfalk 1999), which increases employee satisfaction. For the company, this translates into increased employee productivity and direct savings in travel costs (Arnfalk 1999, Arnfalk & Kogg 2001). Like home working, telecommuting has the potential to cut fuel consumption and consequently emissions due to avoided travelling.

According to studies of teleconferencing at British Telecom (Hopkinson *et al.* 2003, James *et al.* 2005, James and Hopkinson 2006), well over a half of the company's employees use teleconferencing. While the percentage of the respondents who had used teleconferencing in the last four weeks declined from 92 % to 55 % between studies, the estimated amount of saved CO_2 emissions due to teleconferencing grew notably, from 20,100 tonnes in 2002 to 54,200 tonnes in 2006[7]. The monetary savings to British Telecom in 2006 reached 145 million pounds, which is ten to fifteen times the cost of teleconferencing (James and Hopkinson 2006). ETNO estimates that the replacement of one average business trip with an audio conference by 50 % of the EU-25 workforce would result in CO_2 emissions savings of 2.1 million tonnes a year, or two tenths of a

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[7] One reason for this difference is that the 2002 study used conservative estimates of the maximum length of a travel, whereas in the 2004 study actual mileages were used. On the other hand, the 2006 study applied conservative estimates. (James *et al.* 2005, James and Hopkinson 2006)

per cent of all transport-related CO_2 emissions in the EU-25 countries (Szomolányi 2005).

Surveys on teleconferencing at British Telecom also presented some downsides of teleconferencing. Some employees missed face-to-face contact. According to some, the ease of use of teleconferencing techniques resulted in excessive conferencing that was no longer efficient. (Hopkinson *et al.* 2003, James *et al.* 2005) Teleconferencing also enabled contacts with more people, which could eventually result in more travelling (Hopkinson *et al.* 2003). Not having the opportunity to get out of the office could also represent a loss for some people (Arnfalk and Kogg 2001).

3.2.4 Conclusion on the literature review

The chapters above have discussed both the energy consumed by ICT and the energy saving possibilities it entails. According to previous research, the energy consumption of ICT is low; only about 1 % of the national energy consumption in industrialised countries. The direct impact of ICT on the energy use thus seems minor. Nevertheless, technological development presents the potential for increased power consumption. In addition, "leakages" such as standby power consumption suggest that ICT itself is not as energy-efficient as it could be.

The expansion of ICT at the turn of the millennium coincided with a decline in the energy intensity of the economy in the USA. There is some evidence that the spread of ICT actually contributed to the increased energy efficiency, even if it is yet too early to draw conclusions on any permanent change (Laitner 1999, 2003). Thus, while the direct energy use of ICT has increased, its applications have offered several opportunities for energy savings. These include optimising production and distribution, replacing concrete products with data, and avoiding travelling by using real-time communication.

There is little research as to what the aggregate effect of utilizing these opportunities would be. NTT (2001) estimated that the potential energy savings due to ICT would be 3.6 % of the national energy consumption in Japan. This is more than three times the amount consumed by ICT, which NTT assumes to be 1.1 % of the national total consumption. In a similar vein, ETNO (Szomolányi 2005) calculated that the European-wide CO_2 emission reduction potential of ICT would amount to 48.37 million tonnes. The reduction potential is ten times greater than the estimated CO_2 emissions of the

ETNO companies according to the report. As NTT and ETNO are ICT businesses, these estimates should be viewed as coming from ICT partisans.

The net indirect effect of ICT on energy consumption depends on two fundamental issues. Firstly, as Romm puts it: If people spend more time in the Internet, *what are they spending less time doing?* (Romm 2000: 6) An eliminated activity will be replaced by a new one, but an important issue is whether the new activity is more or less energy-intensive compared to the old one (Heiskanen *et al.* 2001). Secondly, a vital question is the degree to which the manufacturing and the use of ICT actually substitute for existing activities—will the people buying MP3 music also maintain a comprehensive collection of CDs?

Table 3 below illustrates the set of possible outcomes of replacing a standard activity with an ICT-enabled one. In order to reduce energy consumption, ICT use must both substitute (to an adequate extent) for an existing activity and consume less energy than it did.

Table 3. Possible outcomes of replacing a standard activity with an ICT-based solution.

	The existing activity consumes more energy than using ICT	The existing activity consumes less or as much energy as using ICT
ICT use is complementary to the existing activity	Energy consumption increases	Energy consumption increases
ICT use substitutes for the existing activity	Energy consumption decreases	Energy consumption increases or stays the same

What factors will then determine the energy consumption and the degree of substitution? As regards energy consumption, technological development is certainly an important factor—whether additional processing power and increased functionality will imply higher power consumption. Usage habits also matter. In the substitution side, the central question is whether the ICT-based solution is convenient enough to replace old habits, or is perceived as beneficial compared to the traditional solution. Ultimately, there could be rebound effects, whose occurrence depends to a large extent on consumer preferences (Plepys 2002, Romm 1999): whether a euro saved will be spent on more energy-intensive products than would normally be bought, what people choose to do if they have more free time, and the like.

Figure 1 below illustrates the various factors affecting ICT’s net impact on energy consumption. At the centre are the two main variables, the energy consumption of ICT itself and the degree of substitution between ICT use and other activities. Around it are factors influencing these variables. The outer circle describes the possible rebound effects and their major determinants.

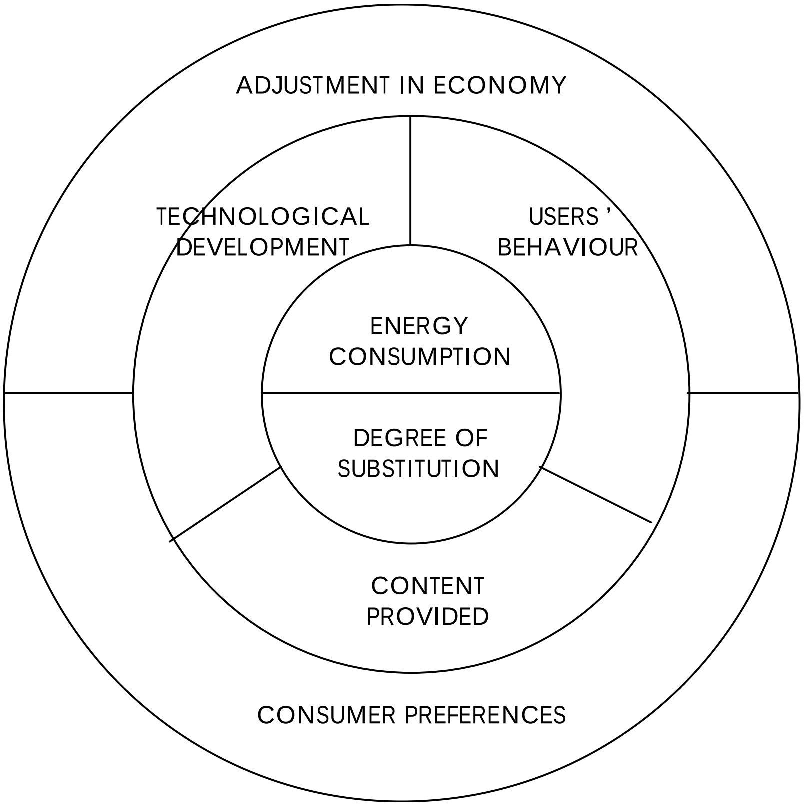

Figure 1. Factors influencing ICT's impact on energy consumption.

The empirical part of this research, presented on the following pages, will provide some insight as to the significance of the different factors presented here. The direct energy consumption of ICT is addressed in two ways: by estimating the energy consumption of ICT as a whole and of the Finnish mobile phone network. The impact of technological development is examined in a comparison of different ICT devices. As an example of replacing a traditional activity with an ICT-based solution, the energy consumption impact of teleconferencing is also illustrated.

4 Research results

4.1 Energy consumption of ICT on the aggregate

4.1.1 Comparison of earlier studies

This section compares the estimates of ICT's energy consumption presented by Kawamoto *et al.* (2001), Roth *et al.* (2002) and Cremer *et al.* (2003). They all use the same basic methodology: the energy consumption of ICT is defined by the equipment stock in the economy, the energy consumption of devices in different equipment categories and in different operating modes, and the operating time in different operating modes. Figure 2 below illustrates this approach.

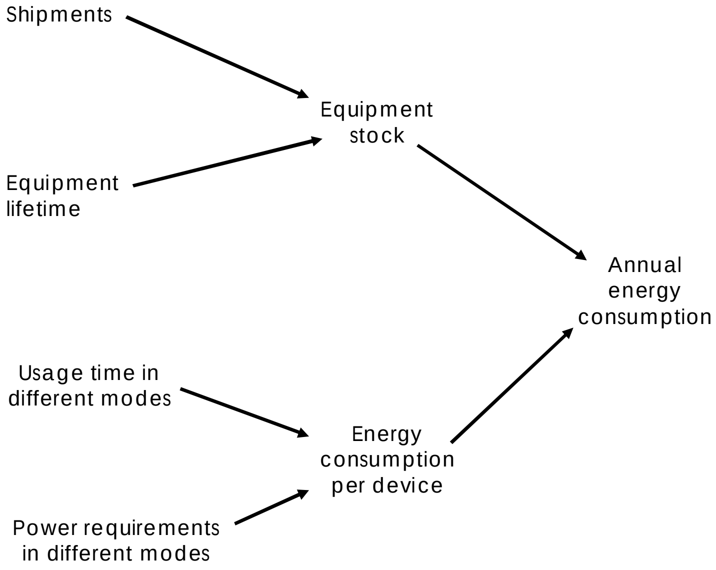

Figure 2. A bottom-up approach for estimating energy use by ICT.

The three studies differ in scope, as to both the sectors of the economy and the equipment categories included. Kawamoto *et al.* (2001) and Cremer *et al.* (2003) estimated the energy consumption of ICT in all sectors of the economy, whereas Roth *et al.* (2002) focus on the commercial and industrial (non-residential) sectors. The two others distinguish between the residential and non-residential sectors as well, but present aggregate figures as the final result. Kawamoto *et al.* (2001) and Roth *et al.* (2002) use roughly the same equipment categories. Roth *et al.* (2002) have added telephone networks, UPSs and some other categories, whose impact is however minor; in addition, they use a more sophisticated breakdown by equipment type. Cremer *et al.*

(2003), in turn, have also taken into account the energy consumption of televisions, audio devices and other entertainment electronics.

The four figures below depict the composition of ICT's energy consumption (in terms of electrical energy) by equipment categories. Cremer *et al.*'s (2003) results are presented in two pictures. The first contains all equipment included in the study, the second only those that were considered as ICTs in the other two studies as well. These equipment categories correspond to 52 % of the consumption of all devices included in the study, i.e. 0.7 % of German national energy consumption. This falls between Roth *et al.*'s 1.1 % (2002) and Kawamoto *et al.*'s 0.8 % (2001).

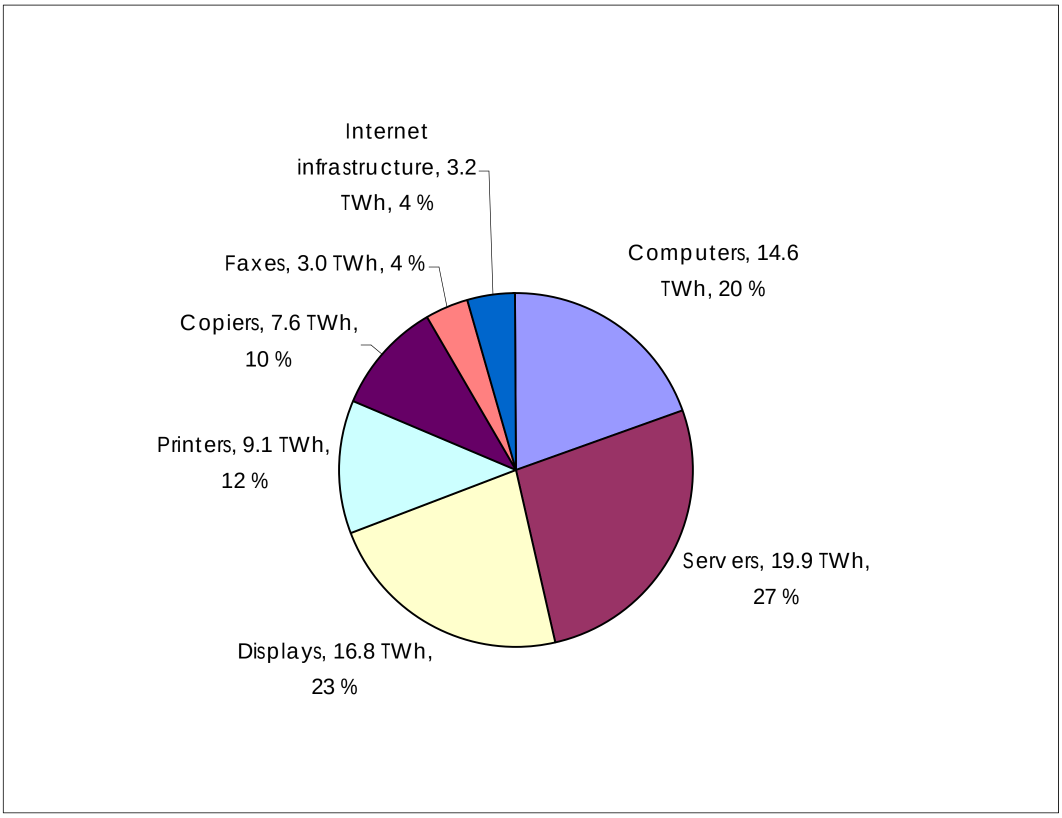

Figure 3. Electricity consumption of ICT in the USA according to Kawamoto *et al.* (2001).

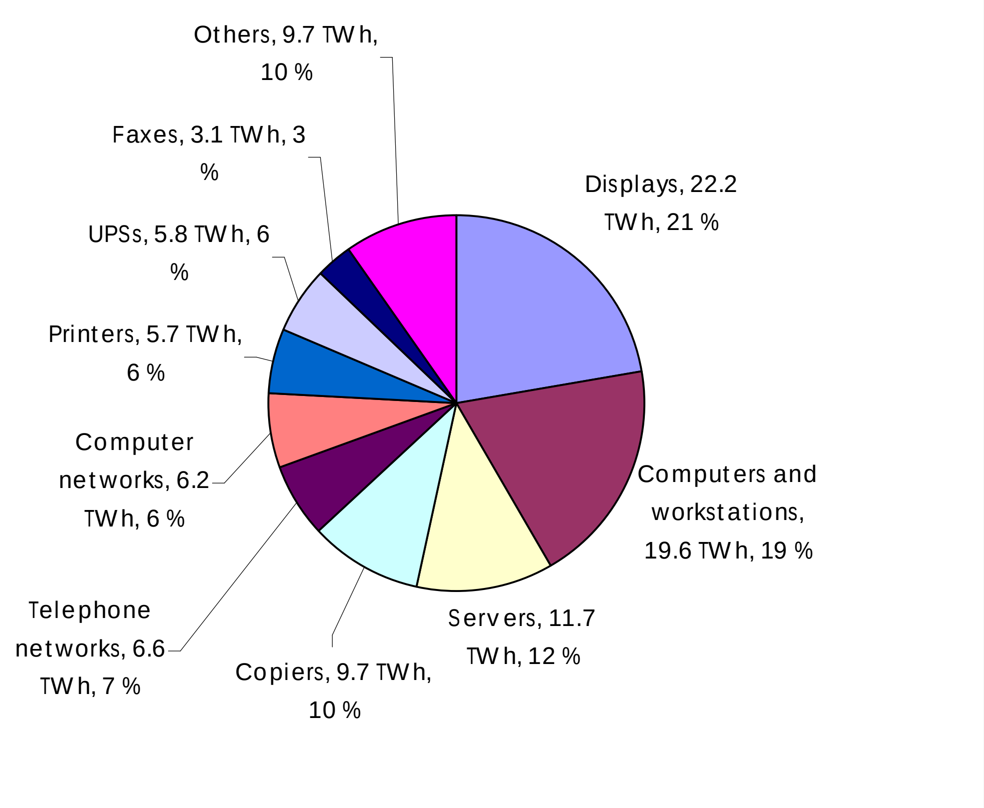

Figure 4. Electricity consumption of ICT in the USA according to Roth *et al.* (2002).

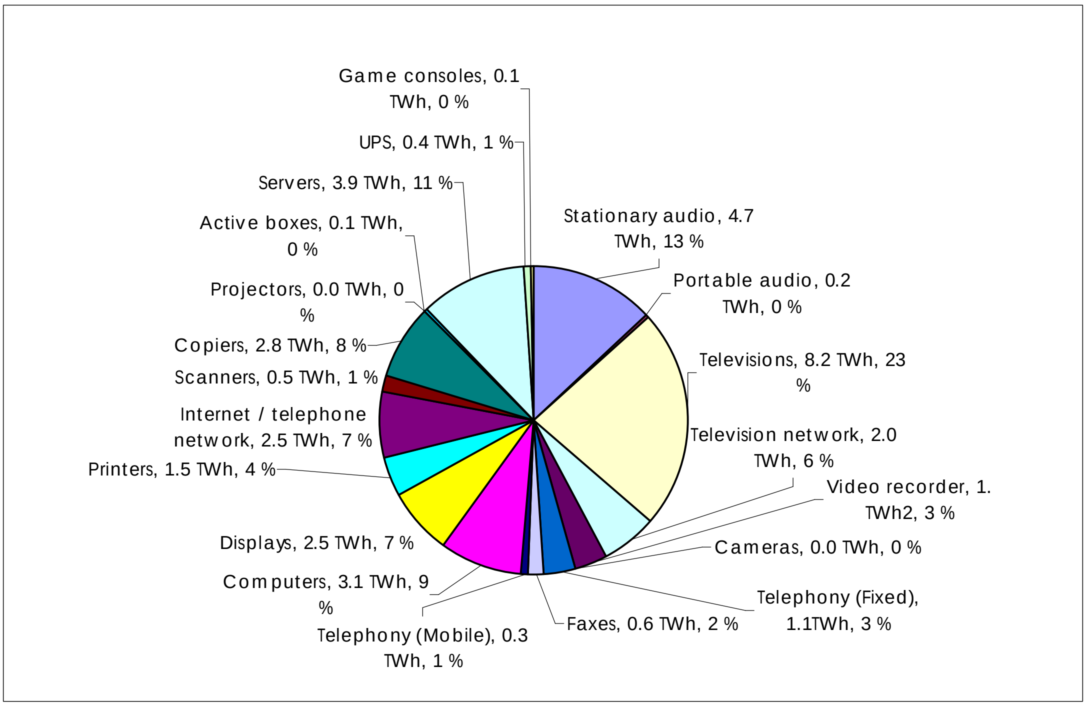

Figure 5. Electricity consumption of ICT in Germany according to Cremer *et al.* (2003).

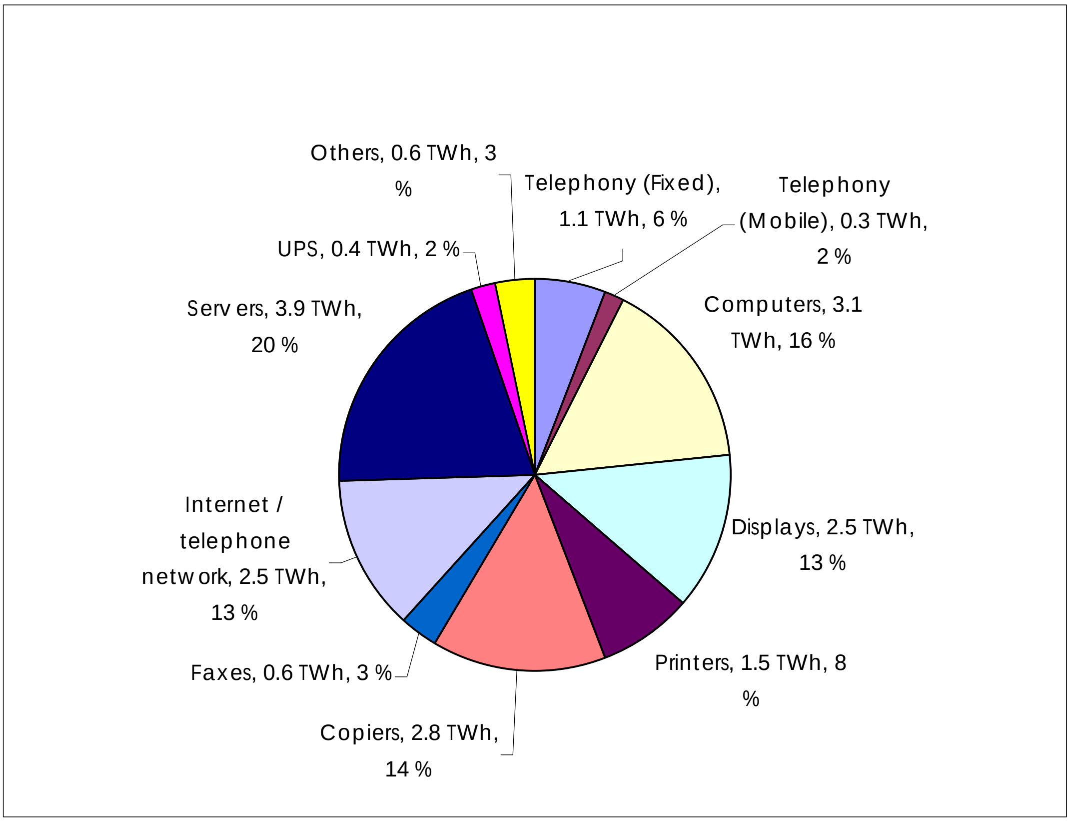

Figure 6. Electricity consumption of equipment regarded as ICT in earlier research (Cremer *et al.* 2003).

The assumptions and methods used in the studies merit some attention (see Figure 2 above). To estimate the stock of equipment, Kawamoto *et al.* (2001) used shipment data and average lifetime. Roth *et al.* (2002) point out that such an approach results in some uncertainty especially with short-lived equipment. They have utilised other sources, such as industry market reports, but in many cases had to settle with Kawamoto *et al.*'s (2001) method. Roth *et al.* (2002) estimate however that the error due to this approach is small, about 3 %.

All studies rely on actual measurements in estimating the power consumption in various operating modes, complemented with information published by manufacturers. The latter is problematic, as the rated power draw represents the maximum power that the device can take and therefore leads to overtly large estimates (Roth *et al.* 2002). In addition, there is a scarcity of data as regards power consumption in the non-active modes (Cremer *et al.* 2003). Where there are no measurements, the researchers have estimated the average power consumption in different modes of usage as a percentage of the nameplate value. Such estimates are educated guesses, even if well-informed, and therefore contain uncertainty. The measured values are not completely reliable either:

Kawamoto *et al.* (2001) state that few measurements were made for certain types of equipment, and the results are therefore uncertain. All researchers have chosen a single set of power consumption values to each category. This is a simplification, but justifiable due to the lack of more accurate data.

There is some variation between studies as regards the assumed average lifetimes of devices, which may in turn be reflected in the stock of equipment. Kawamoto *et al.*'s (2001) values tend to be larger than Roth *et al.*'s (2002): the difference is one year for computers and two years for servers and printers. The former study builds on an earlier (1995) report by LBNL, whereas the latter uses more recent sources to estimate lifetime. With the ever-shortening technology cycles, the smaller values are probably closer to reality.

Perhaps the most delicate component is the usage time of equipment in various modes. Kawamoto *et al.* (2001) rely on their own estimates, while Roth *et al.* (2002) cite Kawamoto *et al.* (2001) and other sources as their references. Cremer *et al.* (2003) have survey data concerning the operating time in active mode in households. Otherwise they use estimates based on literature. Consequently, there are considerable differences in the energy consumption of some equipment categories between the studies.

Bearing in mind the uncertainties and differences cited above, it seems that the majority of ICT's energy use is due to four categories:

1. personal computers,
2. displays and monitors,
3. servers, and
4. communications network infrastructure.

Together, these account for 62 to 74 per cent of the aggregate energy consumption of ICT in the three estimates presented here.

There are some differences between the studies in these key sectors which deserve to be examined and explained. For example, Roth *et al.* (2002) obtain a higher energy use value for displays than Kawamoto *et al.* (2001) do (22.2 TWh > 16.8 TWh), even though they only include the commercial sector and take into account the lower consumption of liquid crystal displays (LCD). Kawamoto *et al.* (2001) assumed that all displays represented cathode ray tube (CRT) technology. Most probably, this is due to the significant differences in presumed usage patterns: Roth *et al.*'s (2002) estimate of the weekly active-mode operation time of displays and PCs is notably higher than Kawamoto *et al.*'s (2001) (62.5 h/week and 98.6 h/week > 19 h/week). 98.6 hours of active use of computers in the office means 14 hours a day, seven days a week! If the computers were used actively for 10 hours a day, 7 days a week—which is still a long time—the annual operation time in the active mode would equal 3640 hours. Due to these differences, Roth *et al.* (2002) also obtain a larger value for the energy consumption of computers than Kawamoto *et al.* (2001), even though the latter have a larger stock of devices.

In servers, there is a difference in the opposite direction. This is partly due to the larger stock of equipment in Kawamoto *et al.* (2001), especially in the classes of mid-range and high-end servers. In particular, the stock of higher-end servers is significantly larger in Kawamoto *et al.* (2001) than in Roth *et al.* (2002), who base their stock estimates on server market research. Kawamoto *et al.* (2001) also assume the unit energy consumption of high-end servers to be more than twice as large as Roth *et al.* (2002), who have used a figure that is typical for more recent devices. Kawamoto e*t al.*'s (2001) power draw values do appear high—for high-end (mainframe) servers, they assume the active-mode consumption to be 10 000 W!

In turn, Cremer *et al.*'s (2003) values seem to corroborate Roth *et al.*'s (2002) view of servers' power draw. The share of servers in Cremer *et al.* (2003) is 20 %, which falls between Roth *et al.* (2002) and Kawamoto *et al.* (2001) (12 % and 27 %, respectively). This relatively large percentage value depends in part upon the relatively lower consumption of the computer and display categories. In absolute terms, the consumption of servers is 3.9 TWh, which is about a third of Roth *et al.*'s (2002) 11.7 TWh—roughly proportional to the population[8].

According to Cremer *et al.* (2003), computers and displays consume proportionally less energy in Germany than in the USA (16 % and 13 %, while the shares in the other studies are 20 % or more). The power consumption values used by Cremer *et al.* (2003) are in line with the other two studies, but the operation time in active mode is notably

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[8] The German population is about 28 % of the USA's (situation in October 2006).

lower than in Roth *et al.* (2002) and also lower than in Kawamoto *et al.* (2001) for the residential sector. In addition, the share of laptops is higher (24 % compared to about 17 % in Kawamoto *et al.* (2001) and Roth *et al.* (2002)). A laptop's energy consumption is a third of a desktop's: however, this explains only about 5 % of the residual difference after the differences in population have been accounted for. Another technology difference between Cremer *et al.* (2003) and the other studies is that it includes personal digital assistants (PDAs) in the computer category. These small devices consume significantly less power than PCs. On the aggregate, the German stock of computers is smaller than the U.S. one in proportion to the population. PDAs would hence seem to replace some laptops and desktops in Germany compared to the USA, which influences the energy consumption.

Table 4 sums up the unit energy consumption parameters used in the various studies for the categories discussed here. Note that Roth *et al.* (2002) presented no values for the residential sector. Kawamoto *et al.* (2001) defined operation times in terms of hours per week. These figures have been multiplied by 52 to obtain an hours-per-year figure. Power draw values for servers have been separated according to the price class; Roth *et al.* (2002) used four classes, while Kawamoto *et al.*(2001), like Cremer *et al.* (2003) settle with three. In the display category, Roth *et al.* (2002) distinguished between different sizes of displays; consequently, there are several power consumption values.

Table 4. Components of annual electricity consumption of key ICT equipment categories used in different studies. The upmost figure in each cell is from Kawamoto *et al.* (2001), followed by Roth *et al.* (2002) and Cremer *et al.* (2003).

	Usage (h/a)			Power consumption (W)		
Equipment category	Normal	Standby	Off	Normal	Standby	Off
Desktops (commercial)	988 5131 1540	3172 375 330	4576 3254 5248	55 55 50	25 25 25	1.5 1.5 4
Laptops (commercial)	988 1001 1430	3172 4505 770	4576 3254 3290	15 15 20	3 3 6	2 2 4
CRT displays (commercial)	988 3281 1540	3172 2980 550	4576 2505 5072	75/85 61–135 80	5 14–19 15	0.5 3–5 3
LCD displays (commercial)	- 3281 1540	- 2980 550	- 2505 5072	- 2.5–31.8 22	- 0.7–10.4 5	- 0.1–1.8 2.5
Desktops (residential)	520 - 370	260 - 1250	7596 - 4998	50 - 55	25 - 25	1.5 - 4
Laptops (residential)	520 - 370	260 - 671	7956 - 5286	15 - 18	3 - 6	2 - 4
CRT displays (residential)	520 - 370	260 - 625	7596 - 3883	75/85 - 70	5 - 15	0.5 - 3
LCD displays (residential)	- - 370	- - 875	- - 3768	- - 20	- - 5	- - 2.5
Servers	5052 8760 8760	2600 0 0	884 0 0	75/1000/10000 250/650/1225/2520 150/800/2500	25/500/5000 - -	1.5/0/0 - -

4.1.2 Estimates of the current energy consumption of ICT

The most recent of the studies presented here is based on data from 2001. In absolute terms, the energy consumption of ICT has likely increased since. Cremer *et al.* (2003) predicted a 4.3 % *per annum* growth for ICT in the aggregate. Roth *et al.* (2002) also foresaw increasing energy use in two of the three scenarios they formed in the end of their report. Based on these two studies, factors affecting ICT's energy consumption can be identified. These are presented in Table 5 below.

Table 5. Trends affecting the energy consumption of ICT.

General trend	Examples and consequences
The expansion of ICT	• More households have computers and Internet access → energy consumption increases • Network coverage increases → energy consumption increases
Technology substitution	• New products consume less energy → reduction in energy consumption • New products may fulfill many functions and replace two or more old products → reduction in energy consumption • New products have more processing power → increase in energy consumption • In network infrastructure, several product generations may be functioning simultaneously → increase in energy consumption
Changing usage patterns	• The wired citizen is connected 24/7 → increase in energy consumption • New services appear that add the use of ICT → increase in energy consumption

In the following paragraphs, the current energy consumption of ICT is estimated using the USA as an example country. The comparison is based on the four key categories and the trends mentioned above. Different sets of assumptions will be used to illustrate possible states of reality:

- ”Business as usual”, or intensive use of energy-consuming devices.

- Intensive usage patterns with a larger proportion of low-power equipment.

- Moderate usage patterns, possibly with a larger proportion of low-power equipment.

Personal computers

The expansion of ICT is still ongoing. In the EU-15 countries, the percentage of the population with Internet access grew from 39 % to 53 % between 2002 and 2005. In the USA, the percentage of households with a PC moved from 50 % to 61.8 % in just three years between 2000 and 2003. Roth *et al.* (2002) predicted that the stock of PCs would increase 5 % each year from 2000 to 2010 (i.e. in 2006, the stock would be 34 % larger than in 2000); Cremer *et al.* (2003) foresaw a 30 % increase from 2001 to 2010.

Technology substitution has also occurred. In both Kawamoto *et al.* (2001) and Roth *et al.* (2002), about 17 % of PCs are laptops, while over 80 % are desktops. In Cremer *et* *al.*, the shares are 24 % and 76 %, respectively. Cremer *et al.* (2003) predicted that the laptops' share would climb to 28 % by 2005 and to 32 % by 2010. Roth *et al.* (2002) used an even higher value, 50 %, in one of their scenarios. This could be closer to reality, if PC sales statistics are used as a guideline. Table 6 presents sales data from three major manufacturers. If the lifetime of a PC is four years as predicted in Kawamoto *et al.* (2001) (as noted above, four years is probably a maximum value), then the stock of computers would have been completely renewed after 2001.

Table 6. Distribution of PC sales between desktops and laptops (in terms of sales revenue in M$/M€.)

Company	2005		2004		2003	
	Desktops	Laptops	Desktops	Laptops	Desktops	Laptops
Apple	55 %	45 %	48 %	52 %	55 %	45 %
FujitsuSiemens	45 %	55 %	50 %	50 %	N/A	N/A
HP	60 %	40 %	62 %	38 %	64 %	36 %

All researchers have estimated that laptops were used actively for fewer hours than desktops. Nevertheless, the use patterns have probably changed now that laptops have taken the place of desktops as the standard PC. It could be argued that they are nowadays used like desktops, i.e. operating more in the active and standby mode.

Finally, the trend in PCs has long been towards greater computing capacity, which usually augments the power consumption. Recent average consumption data from Motiva (2006a) in Table 7 suggest that using higher power consumption values than the earlier studies is justifiable.

Table 7. Current average power consumption values for desktop and laptop computers (Motiva 2006a).

Computer type	Active	Standby	Sleep	Off
Desktop	75 W	40 W	4 W	4 W
Laptop	30 W	10 W	1 W	1 W

Based on the above reasoning, the current electricity consumption of PCs in the USA can be derived from the existing studies. The assumption sets used are as follows.

- Case 1: PCs are used intensively both in households and in offices. For office use, the operation times in different modes are estimated to be 2555 / 730 / 5475 hours a year (in active / standby / off mode). For residential use, operation times of 730 / 730 / 7300 hours a year are assumed. These are higher than in earlier research, to illustrate the growing entertainment use of the Internet, and they also imply that computers are never plugged off. The usage patterns are the same for desktops and laptops. PCs' power consumption is in accordance with data in Table 7. The stock of PCs has grown by 30 %, and 30 % of PCs are laptops.

- Case 2: The intensive usage patterns are assumed. The stock of PCs has grown by 30 %, with 45 % of the total being laptops. The power consumption of computers is as above.

- Case 3: The stock of PCs has grown by 30 %, and 35 % of the total are laptops. The office usage patterns are assumed to be 1560 / 520 / 6680 hours a year. In the residential sector, the intensive usage patterns of case 1 are assumed. The power consumption of computers is as above. The stock of computers in each case is described in Appendix 1.

- In addition, a base case describing the situation in the USA in 2000 was constructed based on Roth *et al.* (2002) for the commercial sector. The residential sector stock was taken from Roth *et al.* and residential sector usage patterns from Kawamoto *et al.* (2001).

- The energy consumption of workstations was included in the estimates to correspond with Roth *et al.*'s (2002) categorisation. This was assumed to have grown by 30 % between 2000 and 2006 along with the overall computer stock, with no changes in the unit energy consumption. The energy consumption of workstations would then be 2.34 TWh. The results of these estimates are presented in Table 8 on the next page, with the figures without workstations in parentheses.

Table 8. Estimates of the current electricity consumption of PCs.

Case	Electricity consumption (TWh)	Change from base case
Base case	22.8	-
Case 1	27.8 (25.4)	25 % (25 %)
Case 2	24.7 (22.2)	11 % (10 %)
Case 3	23.9 (19.7)	7 % (6 %)

Reducing the operation time in the active mode seems to influence the results the most. Even with a smaller proportion of laptops than in Case 2, Case 3 presents the lowest energy consumption value. In terms of change from 2000, the results naturally change if the high usage time values in the base case are corrected. Using the values of Case 1 for the commercial sector, the base case consumption becomes 14.6 TWh. Estimates of the current consumption would then be 63—90 % higher than this.

Displays and monitors

In the displays and monitors category, technology substitution is also apparent as CRT gives room to LCD. The relatively high price of LCDs slowed down the development for a while. Today, LCD displays are in the same price range with CRTs. Cremer *et al.* (2003) estimated that by 2010, LCDs would correspond to 40% of the German display stock. Roth *et al.*'s (2002) forecast for the same time horizon is 50 % or 80 % depending on the scenario (the higher value describes a development where lowering energy consumption of ICT becomes a priority). In the former studies, the proportion of LCD displays varied between 2 % (Cremer *et al.* 2003, residential sector) and 10 % (Roth *et al.* 2002, commercial sector). The absolute amount of displays is linked to the amount of desktops and can be assumed to be roughly the same (Kawamoto *et al.* 2001). The same applies to operation times in different modes.

For displays as well as for computers, the average power consumption has risen slightly in the recent years. Motiva's (2006a) up-to-date data are presented in Table 9 on the next page. The most significant difference is in the active-mode consumption of LCD displays (31 W > 22 W). This is because the size of LCD displays available has increased. Otherwise, the values are rather consistent with those presented in Cremer *et al.* (2003).

Table 9. Average power consumption values for CRT and LCD displays (Motiva 2006a).

Display	Active	Standby / Off
CRT	82 W	4 W
LCD	31 W	2 W

For displays, the comparison cases were constructed as follows:

- Case 1: LCD displays account for 25 % of the display stock. The stock of displays is the stock of desktop computers in case 1, except that it is multiplied by 1.2 on the commercial sector as it is not uncommon that office laptop users have an external monitor. The usage patterns are the same as for desktop computers in case 1.

- Case 2: LCD displays account for 40 % of the display stock. The aggregate stock and the usage patterns are as above.

- Case 3: LCD displays account for 25 % of the display stock. The aggregate stock is the stock of desktop computers in case 3 multiplied by 1.2 for the commercial sector, but the usage patterns are like those of desktop computers in case 3.

- The base case was constructed based on Roth *et al.* (2002) (commercial sector) and Kawamoto *et al.* (2001) (residential sector). As Kawamoto *et al.* (2001) did not distinguish between CRT and LCD stocks, it was assumed that 2 % of the residential display stock were LCDs. The stock of displays by case is given in Appendix 1.

- In addition to CRT and LCD displays, Roth *et al.* (2002) included general displays in this equipment category. The stock of these devices had shown a flat trend. It is assumed that this has continued and that the consumption of general displays has remained at 3.2 TWh. The figures without general displays are in parentheses. Table 10 on the next page summarises the results.

Table 10. Estimates of the current electricity consumption of displays.

Case	Electricity consumption (TWh)	Change from base case (%)
Base case	25.2	-
Case 1	23.2 (19.8)	-8 % (-9 %)
Case 2	21.1 (17.7)	-16 % (-19 %)
Case 3	18.3 (14.9)	- 27 % (-32 %)

The movement from CRT to LCD will have influenced the energy consumption of displays significantly. In addition, the replacement of desktop computers with laptops reduces the display stock, although some laptop users still use an external display.

Roth *et al.*'s (2002) usage patterns that were used in the base case for the commercial sector can be deemed relatively intensive. They include more operation in the active mode than the comparison cases here (3281 hours a year, or nine hours a day seven days a week). Updating the unit energy consumption used in Roth *et al.* (2002) is complicated due to the various equipment categories and usage patterns used in the study, but a percentage-wise reduction in the unit energy consumption can be assumed. With a 20 % reduction, the base case consumption becomes 20.8 TWh. The different estimates for current display consumption differ from this by -11—11 %.

Servers

Servers form the third important equipment category. Cremer *et al.* (2003) predicted that they would account for the bulk of the growth in the electricity used by office infrastructure. The German researchers foresaw a 50 % increase in the server stock by 2010. They also presumed that the average consumption of servers would increase strongly. Roth *et al.* (2002) estimated the compound annual growth rate of the server stock to range from –2 % to 12.4 % from 2000 to 2005 and from –2 % to 6 % between 2005 and 2010 depending on the server category and the scenario used, resulting in a total growth of 26 to 64 % by 2010.

The current growth corresponds to the higher estimates: according to market research by Gartner (2006), worldwide server shipments increased 12.7 % from 2004 to 2005. Another market analysis, by IDC (nd, quoted in Dunn 2006), predicts that the US server stock will further increase 50 % from 2006 to 2010. The low-range servers are the primary engine for the current market growth, while the sales of high-range servers have declined during the last year or two. Mid-range server sales are starting to show signs of a downturn. (IDC 2005, 2006) Although the sales figures do not correspond to shipment data due to price competition, they are indicative as to the stock proportions of different server types.

In addition to the stock growth, Cremer *et al.* (2003) predicted that the energy consumption of servers would grow. They expected it to be 200 W for low-range servers, 1000 W for mid-range servers and 3000 W for high-range servers in 2005. Cremer *et al.*'s (2003) values were used in this calculation.

The assumptions used in estimating the electricity consumption of servers in 2006 were as follows:

- Case 1: The server stock has grown at 5 % annually since 2000. The share of low-range servers of the current stock is 80 %. Mid-range and high-end servers account for 12 % and 8 %, respectively. The power consumption values of servers are averages of Roth *et al.* (2002) and Cremer *et al.* (2003). Servers are always operating in the active mode. (Roth *et al.* 2002, Cremer *et al.* 2003)

- Case 2: The server stock in the aggregate has grown as above, but mid-range and high-end servers account for 17 % and 3 %, respectively. Power consumption and operation patterns are as above.

- Case 3: The server stock is identical to case 1, but the servers are used in a low-power mode (power consumption 75 % of the active mode consumption) for 40 % of the time.

- All servers are in the commercial sector, so there is no need to construct base case values for the residential sector. This was assumed in all three studies treated here. The stock of different types of servers in each case is described in Appendix 1.

- Roth *et al.* (2002) also include data storage devices in the server category. Their base case consumption is 1.5 TWh. This was assumed to have grown in lockstep with the aggregate server stock, to equal 1.9 TWh. The figures without data storage are in parentheses.

Table 11. Estimates of the current electricity consumption of servers.

Case	Electricity consumption (TWh)	Change from base case (%)
Base case	11.7	-
Case 1	31.5 (29.6)	169 % (190 %)
Case 2	25.8 (23.9)	121 % (134 %)
Case 3	28.5 (26.6)	144 % (161 %)

With all the three assumption sets, the result is a significant increase in server electricity consumption. Introducing the low-power mode reduces the consumption by a tenth. Cremer *et al.* (2003) estimate that 50—60 GWh of energy could be saved if servers in small and medium enterprises were turned off overnight. This translates into 13—15 % of the consumption of servers. Kawamoto *et al.* (2001), on the other hand, see hardly any consumption reduction potential by power management in the server category. They do not consider the possibility of night shutdown, probably because it is common practice to keep servers on all the time.

If the server stock had grown at only 3 % a year—which is below Cremer *et al.*'s (2003 estimate and lower than some of Roth *et al.*'s (2002) estimates, the electricity consumption of servers would still have more than doubled from 2000. Lowering the power consumption of servers should therefore be a priority if ICT's energy use is to be reduced. The work is only just being initiated: Barroso (2005) showed that in three product generations, the performance per watt of servers used at Google has remained flat. At present, additional performance implies additional energy costs.

Some of the indirect energy consumption of ICT is closely linked to servers and deserves to be mentioned here, namely the kilowatt-hours required to cool data centres. Data centres are spaces that accommodate several servers. Given that the trend in servers is towards more performance in a smaller device, the data centres store more and more units of performance, which implies an increasing heat burden. This, in turn, is clearly visible in the electricity bill. Recently, ICT professionals have expressed concern about the growing energy demand of data centres. Research by Gartner (2006, quoted in Gonsalves 2006) suggests that the storage devices, UPSs, networking controllers and air conditioning required in data centres consume as much energy as the servers themselves. Lowering the power consumption of servers has therefore become an industry priority which may unite both vendors and clients (see Burt 2006, Dunn 2006 and Spooner 2006). There have also been legislative initiatives towards encouraging energy efficiency of data centres (Burt 2006, Gonsalves 2006). It can be expected that the average power consumption of servers will decline in the future. The net impact is nevertheless difficult to predict, especially if the stock of servers keeps growing.

Communications networks[9]

The stock of communications network equipment includes many sorts of devices that may vary across studies, from modems to cellular base stations. Whatever the classification, the stock of equipment in this category has certainly increased since 2000. Internet connections become all more frequent, GSM networks expand, and UMTS coverage is being constructed. Cremer *et al.* (2003) in fact predict that it is the communications infrastructure that will expand the fastest of all ICT equipment categories. They foresee a 90 % increase in consumption in household infrastructure, over 100 % in office infrastructure[10] and over 150 % for telecommunications companies' infrastructure. Aggregated, the energy consumption of communications networks will according to them grow about 120 % by 2010.

Roth *et al.* (2002) are more conservative about the growth in infrastructure. They expect a maximum 60 % increase by 2010, and, in the most modest scenario, only 20 %. The difference between the two studies is particularly striking in mobile telephone infrastructure, where Cremer *et al.*'s (2003) predicted consumption in 2010 is about the same as in Roth *et al.* (2002), in spite of the population difference between the countries. It is not completely clear whether Roth *et al.* (2002) have included the whole of telecommunications networks in their study of non-residential ICT, but by the respective magnitudes of baseline consumption in the two studies, this seems to be the case. At any rate, allocating only a portion of the networks' consumption to the commercial sector would be complicated and involve great uncertainty.

In the range of communications network equipment, there are some whose stock has likely remained stable since 2000, such as all the components in the fixed telephone network. The greatest growth has probably occurred in the areas that Cremer *et al.* (2003) predicted, namely mobile telephone networks (especially the base stations) and

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[9] Includes both telephone and computer networks.

[10] It should be noted that Cremer *et al.* (2003) consider servers as a part of office infrastructure, and most of the growth in this broad sector comes from the server category.

Internet equipment such as switches and routers. The mobile telephone network corresponds to about 20 % of the total infrastructure consumption, but the share of switches differs between studies: according to Roth *et al.* (2002), switches account for over 20 % of the total, but in Cremer *et al.* (2003) the share is a little under 10 %. Routers correspond to about 10 % in both studies. In addition, there are some differences in equipment categorisation that render comparison and extrapolation based on these studies slightly difficult; for example, Roth *et al.* (2002) treat mobile telephone network equipment as one entity, whereas Cremer *et al.* (2003) distinguish firstly between switching equipment and base stations and secondly between UMTS and GSM technologies.

The following analysis is limited to mobile telephone networks and certain computer network components (switches and routers). It aims to discern the magnitude of changes in the energy consumption of this equipment. In order to estimate the current energy consumption of ICT infrastructure, three alternative states of affairs are constructed in the following manner:

- Case 1: UMTS coverage has been built actively. At the same time, the GSM network has been expanded. As a result, the stock of mobile telephone network equipment on the aggregate has grown by 70 %. A fifth of the current stock are UMTS equipment, whose absolute power consumption is 50 % larger than that of GSM. The stock of routers and switches increases by 70 %.

- Case 2: The UMTS and GSM network equipment stock is as in Case 1, but the energy consumption growth is moderated by a 5 % decrease in the power consumption of GSM equipment. The consumption of UMTS equipment is also lowered so that it only consumes 20 % more than GSM equipment. Similarly, the power consumption of routers and switches decreases 40 %.

- Case 3: The increase in stock and the power consumption of UMTS and GSM equipment are as in case 1. However, the power consumption is lower during the nighttime when traffic is low, resulting in a 25 % reduction in the power consumption for 25 % of the time. An equivalent low-power mode is assumed for computer network equipment.

- It is assumed that mobile network infrastructure corresponds to 20 % and routers and switches to 15 % of the total ICT infrastructure consumption. The consumption of the rest of the ICT infrastructure is assumed to remain the same.

The increases in power consumption resulting from these assumptions are presented in Table 12.

Table 12. Estimated changes in the electricity consumption of communications networks.

Case	Electricity consumption (TWh)	Change
Base case	12.8	-
Case 1	16.4	28 %
Case 2	14.7	15 %
Case 3	15.9	24 %

Some differences between Roth *et al.* (2002) and Cremer *et al.* (2003) should be noted as to trends in network infrastructure equipment stock. Roth *et al.* (2002) predict intensive growth in the stock of routers and WAN switches from 2000 to 2005 (70—120 %). Cremer *et al.* (2003), on the contrary, settle with 20 % growth. This could reflect a higher Internet saturation in Germany.

ICT on the aggregate

The most significant equipment categories have now been treated briefly. The remainder of ICT's energy consumption comes from devices like copiers, faxes, printers, UPSs and some additional categories that include minor energy consumers. These were not analysed separately in the present study. The energy consumption of the other categories will be assumed to have grown 19 % since 2000, or 3 % annually. This represents modest growth. UPSs are an exception: their stock and, consequently, the energy consumption, will grow with Internet infrastructure, like servers and routers. It will be assumed that the energy consumption of UPSs has increased by 50 %.

Besides the energy consumed by Internet equipment, Mills (1999) included 29 TWh of the energy used in the manufacturing of ICT equipment in his estimate of ICT's energy use. Later studies have not considered the manufacturing energy as an integral part of ICT's energy consumption, but have nevertheless commented upon the matter. Kawamoto *et al.* (2001) estimated the energy required in manufacturing to be 21 TWh. Roth *et al.* (2002) base their judgment on an input-output model that takes into account the energy consumed not only in the assembly of devices, but also in the resource extraction phase. They conclude that the manufacturing of all ICT equipment requires approximately as much energy as the use of non-residential ICT; that is, about 97 TWh. This estimate is considerably larger than the previous ones, suggesting that they were perhaps limited to the assembly stage. This study will not consider the manufacturing energy.

Roth *et al.*'s (2002) study has been used as the base case. However, as the active-mode operation times for displays and computers were considered to be exaggerated, the base case value was corrected by this amount. In addition, base values for the residential sector consumption based on Kawamoto *et al.* (2001) and Cremer *et al.* (2003) should be added to Roth *et al.*'s (2002) estimate. The energy consumption of residential printers, faxes and copiers is assumed to be small. After these changes, the estimated energy consumption of ICT in 2000 remained at 1.1 % of the U.S. national energy consumption. The estimates of ICT's current energy use, as calculated above, were applied to Roth *et al.*'s (2002) data from the year 2000, and the results are displayed in Tables 13 and 14.

Table 13. Estimates of the current energy consumption of ICT in the USA.

Case	Electricity consumed (TWh)	Primary energy consumed (quads)[11]	% of national total in 2006[12]
Case 1	141.1	1.39	1.4
Case 2	128.6	1.27	1.2
Case 3	128.9	1.27	1.3

Table 14. The relative importance of key equipment categories.

Equipment category	Base case	Case 1	Case 2	Case 3
Computers	16 %	20%	19 %	19 %
Displays	22 %	16 %	16 %	14 %
Servers	12 %	22 %	20 %	22 %
Communications networks	14 %	12 %	11 %	12 %

Table 13 shows that ICT's energy consumption as a percentage of total national consumption has increased some tenths of a percent. Proportionally, the increase in

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[11] 1 quad = 1 quadrillion (10^{15}) British thermal units. For the calculation, see Appendix 3.

[12] The energy consumption in the USA in the 2006 is predicted to be 103.7 quads (EIA 2006a).

energy consumption is high (37—50 % depending on the case). The proportional shares of sectors have also changed, as is evident from Table 14. Computers, servers and communications networks have all increased in importance, while displays have lost some (for a complete breakdown of the consumption, see Appendix 2). Despite the changes, the proportion of the national energy consumption used by ICT remains small, closer to one than two per cent. The 1.4 % value obtained here can be considered a maximum.

This estimate, based on values from the USA, can be thought to describe the energy consumption of ICT in an industrialised country in which ICT use is mature. As seen from the results of earlier research concerning Germany and the USA, there are differences between such countries as well. Ultimately, ICT is currently expanding the most rapidly elsewhere. Global Internet usage statistics in Table 15 give an idea of the situation.

Table 15. Internet usage statistics from different regions.

Region	Population with Internet access (%)	Internet usage growth 2001—2006 (%)
Africa	3.6	625.8
Asia	10.8	245.5
Europe	38.2	193.7
Middle East	10.0	479.3
North America	69.1	112.0
Latin America / Caribbean	15.1	361.4
Oceania / Australia	54.1	141.0
World total	16.7	200.9

The reach of the Internet gives some indications of the importance of ICT. Still, it cannot be used to estimate the amount of, for example, PCs, even less so as the usage habits differ across regions. In the poorer countries of the world, many people access Internet via a community terminal instead of their own PCs. Furthermore, these users probably spend less time online than those who own terminal devices. There is also the more fundamental problem of inadequate data, as statistics concerning the stock of ICT equipment and its use are lacking for many of the world’s countries (not to say that this only applies to developing countries—as seen above, in many developed countries estimates about ICT use have to rely on assumptions). Any estimates of energy use by ICT outside the prototypal country used here are therefore educated guesses. However, it seems reasonable to assume that ICT accounts for a smaller proportion of national energy consumption than in the industrialised countries. ICT is still taking its initial steps in many developing countries. In addition, these countries tend to concentrate on energy-intensive industrial activities, and have not yet achieved the energy efficiency of industrialised countries. In this ocean, ICT is probably a small drop.

Saying that ICT accounts for 1.4 % of the energy consumption in all the countries of the world is probably an overestimate. It will, however, be used here to illustrate an upper boundary of energy used by ICT. Compared to the energy consumed by transportation or households (see chapter 3.1.2), ICT's consumption is small—1/20 or less. The annual output of the nuclear power stations in the USA and in the France combined could well keep all of the world's ICT devices going (Wikipedia 2006). Put otherwise, the global energy consumption of ICT is 8.5 times the energy that the Finns use every year to drive their cars (Vasama 2004).

4.2 Energy consumption of mobile phone networks in Finland

4.2.1 The consumption of network infrastructure

The bulk of the electricity consumption of the mobile network comes from the base station equipment, as well as the additional consumption at the base station site. Firstly, the rectifiers, which convert the mains current to the 48 V direct current that the mobile phone network uses, increase the energy consumption at the site by about 5 % (this value applies for the new generation of devices). More importantly, the cooling of a base station leads to additional power consumption. In hot weather or in sites with several base stations, this can add 30 % to the nominal consumption. On average, cooling increases the power consumption of a site by about 20 % of the nominal consumption of the base station. Cooling and heating are also the most important source of fluctuation in energy consumption. The large cooling burden is due to the low efficiency of base stations: as much as 95 % of the electric power consumed by the devices changes into heat.

The interviewees' estimates about annual energy consumption at the base station vary. Estimates about the electricity consumption of an average base station site ranged from 10,000 kWh to over 26,000 kWh. The variability is likely due to the variation in the equipment of a base station site. Figures even higher than these could be realistic for a site with several base station devices and heavy traffic. In turn, some base stations are located inside buildings and have smaller output power; consequently, their power consumption is smaller.

Based on the various estimates obtained from the interviews and from the environmental data of the companies, the consumption of a base station site is between 15,000 and 18,000 kWh a year. According to the interviews, there are approximately 13,000 base station sites in Finland. The total annual energy consumption of the mobile phone network would then equal 195 to 234 GWh a year, or about 0.2 TWh. With about 5.5 million mobile phone users in the network[13], this equals 36 to 43 kWh per user[14], or a continuous power consumption of four to five watts. A mobile phone consumes between 1.1 and 1.6 kWh during its useful life, depending on its functionality (see chapter 4.3). The network thus consumes roughly forty times more energy than the phone. The energy consumption of the network can also be compared to the energy consumed in commuting to work by car. The average length of work trips under 100 km in Finland was 8.7 km in 1998 (Helminen *et al.* 2003: 30). The annual energy consumption of commuting thus becomes 1,310 kWh, or about 30 times greater than the mobile phone network's per customer consumption (VTT 2002, see Appendix 4 for calculation).

4.2.2 The future of energy consumption

All of the interviewees predicted that the energy consumption of mobile phone networks would grow in the future. One potential reason for this is the shift towards UMTS networks. The net impact of the shift, however, is unclear: typically, one UMTS base station does consume more than its GSM equivalent, but it also has a larger traffic capacity. One interviewee estimated that the energy consumption would double with the construction of a UMTS network. On the other hand, this network would then be able to handle significantly more data, so that increases in the volume of traffic would not increase consumption much further. Otherwise, growing traffic volumes increase consumption. The current trend is towards higher volumes of data and higher transmission frequencies. This would require a denser network with more base stations

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[13] DNA 2006, Elisa 2006: 16, TeliaSonera 2006: 4.

[14] Besides ordinary mobile phone users, organisations such as Ratahallintokeskus and the military use the mobile network. Consequently, not all of the energy consumption should be allocated to mobile phone traffic. However, separating the shares of different users is almost impossible.

and, consequently, increased energy consumption. According to one interviewee, solving the frequency shortage is a prerequisite for reducing the energy consumption.

One of the interviewees described the increase in energy consumption as inevitable. This is because the trend in base station technology is towards more capacity in smaller devices. Without corresponding efficiency improvements, this increases the heat load in the equipment bay, which in turn increases power consumption. At some point, fan cooling is not enough and air conditioning must be installed. This, in turn, lowers the efficiency of cooling, further reducing the energy efficiency of the base station site.

4.2.3 The significance of energy for operators

For the companies whose business is in operating wireless networks, electrical energy consumption represents about a third of the operational costs[15]. This makes it a significant cost item. As one of the interviewees put it, electricity is a raw material whose use must be optimised. The electricity consumption is recorded per base station site. The operators follow these figures and may even forecast consumption.

The operators have tried to reduce the energy consumption of base stations by installing new and more efficient rectifiers, by replacing old mast lights with light-emitting diode (LED) lamps and by removing unnecessary lights. One of the operators had made special efforts to reduce the power consumption of the cooling system, and had even had a Master’s thesis written on the optimal cooling practices. (Toivanen 2006)

The interest of the operators’ customers in the energy consumption is mostly price-driven, as the operators include electricity costs in the rent of the network. Two of the three interviewees did not recall any inquiries about the consumption from the customers’ side. Nevertheless, as one interviewee pointed out, the operator’s and the customer’s benefits are aligned in this matter. With low call prices and consequently tight margins, reducing energy costs is an interesting possibility for Finnish telecommunications network operators.

Despite the operational importance of energy, only one of the interviewees mentioned energy consumption among the environmental impacts of his company. He also expressed a view of telecommunications networks and ICT in general as a significant

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[15] Otherwise, operational costs consist of site rents and some minor items.

energy consumer. Another interviewee described the environmental impacts of his company as rather positive, as the services provided by ICT would reduce the need for transportation. In his eyes, the energy consumption of the network was small.

4.3 Cutting the energy consumption of ICT: device convergence

Device convergence, or incorporating several functions in one device, is a key trend in the ICT industry (Cremer *et al.* 2003). It is clearly visible in mobile phones, where digital camera and music player functions have become commonplace. On one hand, this trend has led to bigger phones whose production requires more materials. On the other hand, having one device instead of three would seem to reduce the amount of ICT products needed per person, and consequently the environmental impacts due to ICT devices.

In this study, multimedia devices comprising a mobile phone, a digital camera and an MP3 player were compared with the combination of three separate devices: a basic mobile phone, a digital camera and an MP3 player. The parameters used in the comparison were the weight and the power consumption of the device. The power consumption was calculated based on battery details and operational time per charge as follows:

$$P = \frac{Q_{battery}}{t_{operational}} \cdot V_{battery} \ ,$$

where P is power, $Q_{battery}$ is the capacity of the battery, $t_{operational}$ is the operation time of the device with a fully charged battery and $V_{battery}$ is the battery voltage.

In addition, an economic input-output life cycle assessment (EIO-LCA) angle was incorporated in the comparison using the EIO-LCA model developed by researchers at Carnegie Mellon University. Besides the life cycle environmental impact of a product itself, EIO-LCA takes into account the environmental impact generated in the economy overall (Carnegie Mellon University Green Design Institute 2006). In other words, it takes into account the systemic macroeconomy-level effects. As EIO-LCA is usually applied to manufacturing price and not to retail price, data about the gross margins for various products had to be collected. For additional information of the EIO-LCA approach, see Appendix 5.

The devices in the sample were selected according to the following criteria. In addition to the phone functionality, the multimedia devices had to contain a digital camera of at least two megapixels (Mpx) and an MP3 player. The basic phones had to be without either feature. In digital cameras, the aim was to focus on devices with three to four megapixels; however, with the current stage of technological development, cameras with higher resolutions also had to be included. In MP3 players, devices with a memory of 2 GB or less were selected. The availability of relevant data also influenced the sample selection, as not everything was available for all devices. The results of the calculations are presented in Tables 16 through 19 on the following pages. There are some differences between the power consumption values of different mobile phones in Tables 16 and 17. This may be due to technological differences: some of the phones included are WCDMA (Wideband Code Division Multiple Access) devices that tend to consume more than GSM phones, and display size also influences the consumption. In addition, different manufacturers may apply different standards in announcing the talk time or the battery details.

Table 16. Comparison data for multimedia devices.

Device model	Features	Weight (g)	Battery weight (g)	% of total weight	Battery capacity (mAh)	Battery voltage (V)	Standby time (h)	Talk time (h)	Standby power consumption (mW)	Talk mode power consumption (mW)	Average price (euros)[16]
Nokia N70	2.0 Mpx camera, video, MP3	126	21	0.17	970	3.7	264	4	14	1025	347
Nokia N71	2.0 Mpx camera, video, MP3	139	21	0.15	970	3.7	216	4	17	897	361
Nokia N72	2.0 Mpx camera, video, MP3	124	21	0.17	970	3.7	260	4	14	1002	321
Nokia N73	3.2 Mpx camera, video, MP3	116	21	0.18	1100	3.7	370	4	11	1081	474
Samsung SGH-Z710	3.2 Mpx camera, video, MP3	108	N/A	N/A	880	3.7	220	3	15	1085	576
Samsung SGH-X820	2.0 Mpx camera, video, MP3	66	14	0.21	630	3.7	260	3	9	932	325
Samsung SGH-D900	3.1 Mpx camera, video, MP3	85	17	0.20	800	3.7	250	3	12	897	417
Samsung SGH-D830	2.0 Mpx camera, video, MP3	92	14	0.15	630	3.7	190	3	12	777	449[17]
SonyEricsson W800i	2.0 Mpx camera, video, MP3	99	20	0.20	900	3.0	400	9	7	300	408
SonyEricsson W810i	2.0 Mpx camera, video, MP3	99	20	0.20	900	3.0	350	8	8	338	327
SonyEricsson W900i	2.0 Mpx camera, video, MP3	148	20	0.13	900	3.0	370	8	7	321	542
Average	-	109	19	0.18	877	3.51	286	5	11	787	413
Standard deviation	-	24	3	0.03	143	0.33	73	2	3	313	89

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[16] Average prices obtained from Hintaseuranta (2006) unless otherwise stated.
[17] Recommended price at Sonera Piste (November 2006).

Table 17. Comparison data for basic mobile phones.

Phone model	Weight (g)	Battery weight (g)	% of total weight	Battery capacity (mAh)	Battery voltage (V)	Standby time (h)	Talk time (h)	Standby power consumption (mW)	Talk mode power consumption (mW)	Average price (euros)[18]
Nokia 2610	91	21	0.23	970	3.7	300	3	12	1196	86
Nokia 2310	85	21	0.25	970	3.7	400	6	9	598	78
Nokia 1600	80	21	0.26	900	3.7	432	5	8	666	68
Nokia 1112	80	21	0.26	700	3.7	380	5	7	486	54
Sony Ericsson T300[19]	101	20	0.20	700	3.6	400	11	6	229	50
Sony Ericsson T200	85	20	0.24	700	3.7	220	13	12	199	50
Sony Ericsson T600	63	20	0.32	610	3.6	180	5	12	439	60
Average	84	21	0.25	793	3.7	330	7	9	545	64
Standard deviation	12	1	0.04	149	0.0	98	4	3	336	14

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[18] Average prices obtained from Hintaseuranta (2006) unless otherwise stated.

[19] For Sony Ericsson phones, the battery weights and the prices had to be estimated.

Table 18. Comparison data for digital cameras.

Camera model	Resolution	Weight (g)	Battery weight (g)	% of total weight	Battery capacity (mAh)	Battery voltage (V)	Photos per charge (display on)	Power consumption per photo (mWh)	Average price (euros)[20]
Canon IXUS 30	3.2 Mpx	110	17	0.15	760	3.7	140	20	288[21]
Canon IXUS 40	4.0 Mpx	130	17	0.13	760	3.7	140	20	288
Canon PowerShot A520	4.0 Mpx	180	N/A	N/A	2500	1.2	300	20	212
Fujifilm FinePix F30	6.3 Mpx	152	N/A	N/A	1800	3.6	580	11	330
Fujifilm FinePix V10	5.1 Mpx	154	20	0.11	710	3.6	N/A	32[22]	299
Fujifilm FinePix Z2	5.1 Mpx	128	20	0.14	710	3.6	N/A	32	233
Fujifilm FinePix Z3	5.1 Mpx	129	20	0.13	710	3.6	N/A	27[23]	283
Average	-	140	19	0.13	1136	3.3	290	23	276
Standard deviation	-	23	2	0.01	722	0.9	208	8	40

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[20] Average prices obtained from Hintaseuranta (2006) unless otherwise stated.

[21] For the IXUS cameras, the average price of the cheapest IXUS model in Hintaseuranta (2006) is applied.

[22] JEMAI 2006a.

[23] JEMAI 2006b.

Table 19. Comparison data for MP3 players.

Player model	Memory	Weight (g)	Battery capacity (mAh)	Battery voltage (V)	Playing time (h)	Power consumption (mWh)	Average price (euros) [24]
Apple iPod nano	2 GB	40	330	3.7	24	51	172
Apple iPod shuffle (1G)[25]	1GB	22	220	3.7	12	68	97[26]
Apple iPod shuffle (2 G)	1 GB	16	220	3.7	12	68	107
Creative MuVo V200	1 GB	33	700[27]	1.5	15	70	98
Philips GoGear SA1300	512 MB	40	300	3.0	12	75	72
Philips GoGear SA1305	512 MB	40	300	3.0	12	75	80
Philips GoGear SA1335	1 GB	40	300	3.0	12	75	99
Average	-	33	345	3	14	69	104
Standard deviation	-	10	165	1	4	9	33

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[24] Average prices obtained from Hintaseuranta (2006) unless otherwise stated.

[25] For Apple MP3 players excluding the iPod nano, the battery data was obtained from Anonymous (2006). iPod nano battery details were obtained from a retailer.

[26] Tietoasema (November 2006).

[27] The Creative MuVo V200 player uses an AAA battery. The battery details used here are estimates based on empirical observations.

To calculate the energy consumption during the equipment lifetime, the following assumptions were made:

- Each device is kept in use for three years.
- The mobile phone is used in talk mode for 1.5 hours a day and kept in standby mode for the rest of the time.
- The digital camera is used to take 1,000 photos a year.
- The MP3 player is used for one hour a day.

With these assumptions, the weight and the use-phase energy consumption during the device lifetime are as in Table 20.

Table 20. Average weight and use-phase energy consumption of different devices.

Device type	Weight (g)	Energy consumption (kWh)
Multimedia device	109 ± 20 %	1.6 ± 38 %
Basic mobile phone	84 ± 14 %	1.1 ± 55 %
Digital camera	140 ± 16 %	0.07 ± 30%
MP3 player	33 ± 31 %	0.08 ± 12 %
Three separate devices	257 ± 17 %	1.3 ± 51%

As seen from the large error margins, these results are indicative. Nevertheless, they provide a basis for the comparison. Energy-wise, the alternatives of having a multifunctional phone and having three separate devices are approximately equivalent. There is more difference, however, in the materials use side.

Research evidence suggests that the production phase accounts for most of the life cycle environmental impact of electronic products. According to Stutz *et al.* (2003), the production phase environmental impact accounts for about 90 % of the total environmental impact of the mobile phone. Inside the production phase, approximately 75 % of the environmental burden is due to component production. As regards energy consumption in particular, Toffel and Horvath (2004) estimated that the energy required to manufacture a 15-inch LCD display equals 1989 MJ (553 kWh), and that the energy consumption can be considered proportional to display size. Producing a 2.5-inch display—a common size in multimedia devices and in digital cameras—would then consume about 15 kWh. This amount alone is significantly larger than the use phase energy consumption.

The energy consumption of the production phase can also be estimated using the EIO-LCA model. The three basic devices included here can all be attributed to one single sector of the model. For the multimedia device, a combination of sectors was applied. Adding an MP3 player functionality does not increase the manufacturing costs significantly, as the basic mobile phone already contains the technology required for sound reproduction. The additional memory required to store music and images can be allocated to the camera functionality. Hence, assuming that the manufacturing costs of a multimedia device are divided in two between the camera functionality and the mobile phone functionality is a reasonable approximation. Table 21 presents the results obtained from the EIO-LCA model.

Table 21. Results of the EIO-LCA model for different device categories.

Device type	EIO-LCA sector	Additional energy consumption in sector (TJ / $1M of production)	Average gross margins (%)	Average manufacturing costs (euros)	Additional energy consumption per unit produced (kWh)[28]
Mobile phone	Broadcast and wireless communications equipment	3.7	35[29]	42	56
Digital camera	Other computer peripheral equipment	4.5	45[30]	150	250
MP3 player	Audio and video equipment	7.0	26[31]	77	170
Multimedia device	Broadcast and wireless communications equipment / Other computer peripheral equipment	3.7 / 7.0	38	260	380

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[28] Carnegie Mellon University Green Design Institute 2006.

[29] Ericsson 2006, Nokia 2006, Samsung 2006.

[30] Canon 2006, Fujifilm 2006.

[31] Apple 2006, Creative 2006, Philips 2006.

As seen from the data in Table 20, the multimedia device is the less material-intensive option compared to having three separate devices. The difference in weights is indicative of the energy consumption in the production phase (from materials extraction and component manufacturing to assembly), which in the light of previous research corresponds to the majority of the life cycle energy consumption of mobile phones and other small ICT devices.

The EIO-LCA comparison corroborates the impression that manufacturing a multimedia device consumes less energy than the three separate devices together. The results of the EIO-LCA model also indicate that the energy consumption of production is indeed greater than the energy consumed in the use phase. Thus, it would seem that the life cycle energy burden of a multimedia device is smaller than that of the three separate devices put together. This result should nevertheless be interpreted cautiously. For example, the economic sectors used for different device categories contain various products whose environmental impacts vary. The devices included in this comparison are not among the most energy-consuming in their respective sectors.

Finally, the weight-based comparison and the EIO-LCA comparison yield different results as to the differences between the two options. The weight of the multimedia device is less than a half of the weight of the three devices put together, while its manufacturing energy consumption according to the EIO-LCA model is 20 % smaller than for the three different devices put together. Weight-wise, a good part of the difference can be attributed to the digital camera which alone weighs more than the multimedia device: its optics are significantly heavier (and better) than that of the phone. The comparatively small difference in the EIO-LCA model is likely due to its systemic approach. The different devices have various common components, of which memory, display, processor and battery are among the most important. Combining their functionalities in one shell means that the manufacturing of multiple components can be avoided. However, incorporating such changes in the model is difficult. In the above case, the multimedia device was modelled by splitting its manufacturing costs between two categories. Such a rough approximation probably leaves some overlapping energy consumption in the EIO-LCA result. In a weight-based comparison, the impact of avoided components is more visible.

4.4 ICT versus traditional techniques: teleconferencing

4.4.1 Teleconferencing at Nokia

The Finnish mobile phone and network equipment manufacturer Nokia was used as an example company in the teleconferencing case. At Nokia, the concept of mobile working is applied. It includes different forms of ICT-enabled ways of working, such as working from home or at a satellite office, working at different Nokia sites or working on the move (at customer premises, in the airport, on a train etc.). Until recently, environmental arguments have not been used in promoting mobile working. (Vuorio 2006a) Lately, the energy efficiency aspect of mobile working has become more important, as Nokia strives to reduce its energy consumption (Puustinen 2006). Nokia employees also take interest in their employer's attitude towards environmental issues (Vuorio 2006a).

In the recent years, ways of working at Nokia have indeed changed towards a more mobile direction. Earlier, when a meeting was required, all participants would gather round in the same location. It was not unusual to take a flight inside Europe for a single meeting. When returning from a business travel, a pile of tasks would be waiting for the meeting participants. Today, travelling Nokia employees are able to work on that pile of tasks whilst they have idle time when travelling, be it in a hotel room or on the move. (Vuorio 2006a)

Teleconferencing is one of the tools in the mobile working toolbox. Two basic technologies are applied at Nokia: audioconferencing via mobile phones or a special conference phone, and videoconferencing. Audioconferencing can be enhanced with an online meeting tool that enables the conference participants to share files over an Intranet connection. The equipment required for teleconferencing is readily available. All office workers have a laptop computer and a mobile phone, and the network connections are in place. This is enough for setting up an audio conference. In addition, conference phones can be found in most of the meeting rooms. For videoconferencing, each Nokia site has at least one meeting room with the necessary equipment. (Vuorio 2006a)

Working at Nokia involves a considerable amount of meetings. Networking among employees is a part of the company culture. In addition, the matrix organisation structure generates meetings. In the current, globalised Nokia, this creates significant needs for travelling. Nevertheless, sharing information is the ultimate goal, and where meeting participants are located is secondary.

Audioconferencing is frequently used in the Finnish Nokia offices. Nevertheless, there appear to be differences across countries as regards the use of teleconferencing. Overall, the use of teleconferencing tools is not frictionless: while audioconferencing over the mobile phone is perceived as quite easy, adding the online meeting tool already complicates the matter. Video conferencing, in general, is rarer than audio conferencing. Promotion campaigns on teleconferencing tools have been realised, and user's manuals are available in the meeting rooms and in the company Intranet. In 2005, Nokia carried out a survey mapping the amount of time its employees spend working in Nokia premises or elsewhere, solo or in collaboration. The results of the survey will be utilised in the internal marketing of mobile working. (Vuorio 2006a)

4.4.2 Potential benefits of teleworking

The following case example illustrates the environmental savings from teleworking. Due to confidentiality reasons, actual Nokia data cannot be used here. The fictitious case company, Novator, has been constructed to resemble a global ICT company as closely as possible. The data presented are symmetric to those that would have been obtained from Nokia.

Novator has 75,000 employees, whose working and travelling habits are described below. The survey results for an average Novator officer as well as for three different officer groups are represented in Tables 22 and 23 below. Sales personnel are Novator employees who work in the customer interface, like sales representatives or account managers. Executives, in turn, are high-level managers. Other officers refer to the remainder of Novator white-collar workers: the manufacturing employees do not travel much, and are therefore left out of the analysis. The face-to-face working time is interpreted as the share of meetings. Based on the data in Tables 22 and 23, Novator has calculated the proportion of the face-to-face collaboration of its employees that involves external parties in Table 24. The calculation is described in Appendix 6.

Table 22. Working habits by mode of Novator officers.

Group	Proportion of workforce	Working time by mode		
		Individual work	Collaboration	Of which face to face
Executives	0.5 %	50 %	50 %	35 %
Sales personnel	7.5 %	40 %	60 %	35 %
Other officers	42 %	60 %	40 %	30 %
Average of the above	50 %	57 %	43 %	31 %

Table 23. Working habits by place of Novator officers.

Group	Working time by place				
	Own Novator site	Other Novator sites	External	On the move	Home
Sales personnel	50 %	10 %	20 %	10 %	10 %
Executives	50 %	20 %	10 %	10 %	10 %
Other officers	70 %	10 %	5 %	5 %	10 %
Average of the above	67 %	10 %	7 %	6 %	10 %

Table 24. The proportion of face-to-face collaboration involving external parties.

Group	External parties
Sales personnel	74 %
Executives	50 %
Other officers	25 %
Average of the above	35 %

Based on this data, Novator attempts to estimate the amount of travelling that could be replaced by teleconferencing. It assumes that meetings inside Novator are more readily substitutable than meetings with external parties. This is because teleconferencing is not well suited to building new business relationships or to building confidence between parties (Arnfalk 1999). Novator workers tend to be more familiar with each other than with external parties, which affects the likelihood of replacing meetings with teleconferencing. The substitutability also differs between employee groups: the majority of sales personnel's external meetings are with the customers and consequently more difficult to replace than, for example, the meetings that officers have with external parties. For executives, in turn, time tends to be a more valuable resource, and they are more likely to use teleconferencing techniques to save time, by giving press conferences over a video connection and the like.

Novator additionally believes that different teleconferencing techniques substitute for different types of meetings. In general, Novator employees are less inclined to use videoconferencing than audioconferencing. Videoconferencing equipment is rarer, and it is felt to be a relatively inconvenient and unnatural communication channel. However, videoconferencing could be more readily applied with external parties, whereas audioconferencing as a less formal communication channel is frequently used inside Novator.

Estimating the proportion of meetings that could be replaced with teleconferencing is not straightforward. In Arnfalk's (2002) survey of four Swedish organisations, respondents on the average imagined that, on average, videoconferencing could replace 61 % of meetings, and a complete substitution was thought to be possible. In reality, the substitutability may be significantly lower. At Ericsson, five to ten per cent of all meetings were replaced with videoconferencing around the turn of the millennium (Telia nd). British Telecom's (BT) regular surveys on its employees' teleconferencing behaviour indicate that only 0.7—2 % of teleconferencing users have used videoconferencing shortly before the studies, while audioconferencing was for most the medium of choice. The overall proportion of respondents that had used teleconferencing in the four weeks preceding the studies varies between 55 % (in the latest survey) and 92 %. In each survey, about 70 % of teleconferencing users have said that their last teleconference definitely or probably replaced a travel. (Hopkinson *et al.* 2003, James *et al.* 2005, James and Hopkinson 2006) This would imply that approximately 40 % of BT employees have replaced travelling with teleconferencing according to the most recent survey.

To make a conservative estimate, Novator assumes that 20 to 25 per cent of all meetings could be replaced with audioconferencing, and another 5 to 10 per cent by videoconferencing. Novator expects that audioconferencing is used more frequently between Novator employees than with external parties. Videoconferencing is more acceptable even with external parties because of the face-to-face contact it enables, but due to its relative difficulty of use, it is not used more frequently than that to replace meetings inside Novator. Novator's assumptions of the replaceability of meetings are found in Table 25.

Table 25. The replaceability of meetings by mode of teleconferencing.

Group	Audioconferencing		Videoconferencing	
	With Novator employees	Involving external parties	With Novator employees	Involving external parties
Sales personnel	20 %	0 %	5 %	5 %
Executives	20 %	5 %	10 %	10 %
Other officers	20 %	5 %	5 %	5 %
Average of the above	20 %	4 %	5 %	5 %

The annual amount of travel in different worker groups is introduced in Table 26. Table 27, in turn, is the amount of travel that could be substituted for teleconferencing according to the estimates of Novator.

Table 26. The annual travels per employee at Novator.

Group	Travels in Europe	Long distance travels	Total
Sales personnel	28	7	35
Executives	22	5	27
Other officers	5	1	6
Average of the above	9	2	11

Table 27. Substitution of travelling for teleconferencing at Novator.

Group	Number of employees	European travels substituted for teleconferencing	Long distance travels substituted for teleconferencing	Total
Sales personnel	5,625	2.8	0.7	3.6 (10 %)
Executives	375	5.0	1.1	6.1 (23 %)
Other officers	31,500	1.1	0.2	1.3 (21 %)
Average of the above	37,500	1.7	0.4	2.1 (20 %)

Table 28 below depicts the amount of teleconferences that would be required to achieve the desired travel reduction. These estimates have been obtained by assuming that each European journey involves three meetings, and that each long distance journey involves six meetings.

Table 28. The annual amount of teleconferences at Novator.

Group	Audioconferences	Videoconferences
Sales personnel	6	6
Executives	12	10
Other officers	3	1
Average of the above	5	2

To calculate the net environmental effect of the reduction in travel, Novator estimated the average length of typical European and intercontinental flight. Data on the power consumption of teleconferencing was also acquired. These figures are presented in Tables 29 and 30 on the next page.

Table 29. Average distances and unit energy consumption of travelling by airplane (VTT 2002).

Type of flight	Distance	Energy
	km	MJ/pkm
Europe	4,000	2.2
Intercontinental	13,000	1.5

Table 30. Power consumption of teleconferencing equipment (Vuorio 2006b).

Device	Power consumption
Mobile phone	5 W[32]
Mobile phone network	5 W[33]
Computer equipment	61 W[34]
Conference phone	30 W
Videoconference equipment	200 W

Novator assumes that the average duration of both audio and video conferences is 65 minutes. In audio conferences, either a mobile phone or the conference phone is utilised. A laptop computer for sharing documents is optional, but Novator employees tend to keep their laptop on int any case. Hence, Novator decided to include the laptop's energy consumption in its calculations. The power requirements of the various types of

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[32] The mobile phone consumes 5 W while charging. It is assumed that the charger is plugged in during the conference.

[33] See Chapter 4.2.1.

[34] It is assumed that during a conference a laptop and an attached LCD display are used. The power consumption data for computer equipment are from Motiva (2006a).

teleconferences can be found in Appendix 6. The energy impact of replacing travelling with teleconferencing is presented in Table 31, assuming that a conference phone is used for all audioconferences.

Table 31. The impact of substituting teleconferencing for travelling at Novator.

Activity	Amount	Impact on energy consumption
European travels	-63,000	-0.15 TWh
Long-distance travels	-14,000	-0.08 TWh
Audioconferences	204,000	$1.86\cdot10^{-5}$ TWh
Videoconferences	71,000	$1.42\cdot10^{-5}$ TWh
Total impact		- 0.23 TWh

As seen from the above table, the net energy effect of avoiding, on average, two journeys per Novator officer—20 % of the annual amount of travel—results in energy savings of 0.23 TWh. Replacing the conference phone with the mobile phone for half of the audioconferences would reduce their aggregate consumption to $1.65\cdot10^{-5}$ TWh. This would not have a significant impact on the net result. The energy consumption of travelling is so much greater than that of teleconferencing that changing the average duration of teleconferences to 90 minutes does not influence the result.

Cost-wise, teleconferencing offers significant saving potential as well. According to the price index of Finland's largest business travel agency, the average price of a flight in Europe is 630 euros. An intercontinental flight from Europe to North America costs 1,600 euros. (Taht 2006) With these values, the annual corporation-wide savings for Novator amount to 63 million euros. This figure does not include the savings from avoiding hotel accommodation or the impacts of sparing employee working time. Installing teleconferencing infrastructure certainly also requires investment.

5 Analysis of the research results

5.1 The use-phase energy consumption of ICT

The ongoing expansion of ICT has increased energy consumption during recent years. In three of the four major equipment categories analysed in detail in this study—PCs, displays, servers and communications networks—the energy consumption has grown over recent years. Energy consumption in other equipment categories is also likely to have increased. This is due to the increasing stock of devices and the trend towards greater processing power. Consumption reduction effects due to new, more power-efficient technologies are also evident, particularly so in the category of displays, where the advent of LCD technology has cut the energy consumption. In the PC category, the rising share of laptops has moderated the growth in energy consumption. The most alarming situation is in the server category, in which the energy consumption has grown remarkably even with modest annual growth in the equipment stock. Figure 7 below presents three possible developments from the baseline year (2000) to this moment.

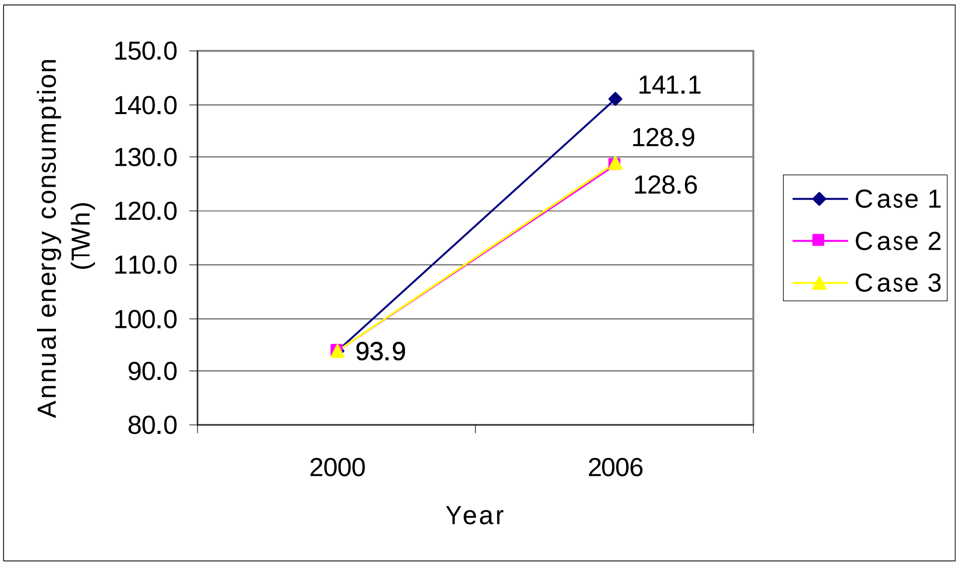

Figure 7. The aggregate energy consumption of ICT in the USA between 2000 and 2006.

In the business as usual case (Case 1), the stock of equipment has grown and the relevant technological changes have been accounted for. With these assumptions, the growth in energy consumption is 50 %. Growth can be moderated by lowering the power consumption of devices (Case 2) or by reducing the operating time of devices in the active mode (Case 3). With the assumptions concerning usage patterns and equipment stock used here, the two options yield similar results.

Even though the energy consumed by ICT has risen since the turn of the millennium, it still represents a small proportion of aggregate energy consumption. For the USA, this proportion was estimated to be at most 1.4 %. Globally, this figure is an upper limit—in different countries of the world, the percentage may vary, most likely towards smaller than larger figures. However, there is still potential for considerable reduction in the energy consumption of ICT.

5.1.1 Possible changes in ICT's energy consumption

Changes in the variables affecting energy use by ICT were simulated to demonstrate possible impacts on energy consumption in the four key equipment categories. Table 32 on the next page illustrates the changes. The value 141 TWh obtained from Case 1 in Chapter 4.1 was used as a base case for ICT’s aggregate energy consumption.

Table 32. Changes in ICT's energy consumption.

Type of change	Description	Effect on ICT's aggregate consumption
Changes in computer and display usage patterns	Base case: Commercial sector computers used for 7 / 2 / 15 h a day, residential sector computers used for 2 / 2 / 20 hours a day	-
	Residential sector computers unplugged for the night (8 h / day)	- 0.9 %
	Operation time in active mode increased 1 h / day all over	+ 4.9 %
	Office computers used 8 hours actively, 8 hours in standby mode and 8 hours in off-mode	+ 6.7 %
Changes in computer and display technology	Base case: 30 % of computer stock laptops, no PDAs, 25 % of displays LCD	-
	50 % of computer stock laptops, 10 % PDAs, 100 % of displays LCD	- 15.3 %
	45 % of computer stock laptops, 5 % PDAs, 100 % of displays LCD	- 12.6 %
	50 % of computer stock laptops, 10 % PDAs, 60 % of displays LCD	- 13.0 %
Changes in communications network technology	Base case: A fifth of the mobile telephone network infrastructure UMTS, UMTS consumption 50 % greater than GSM	-
	A third of mobile telephone network infrastructure UMTS, UMTS consumption 50 % greater than GSM	+ 0.2 %
	A third of mobile telephone network infrastructure UMTS, consumption same as GSM	- 0.3 %
	All network infrastructure operated in low-power mode for 40 % of the time	- 0.5 %
Changes in server power consumption	Base case: Server power consumption 200 / 1000 / 3000 W (low-range / mid-range / high-range servers)	-
	20 % increase in power consumption	+ 4.2 %
	20 % decrease in power consumption	- 4.2 %

Figure 8 below provides a graphic illustration. Different types of change are illustrated by different colours. The heights of the columns illustrate “best case” and “worst case” changes.

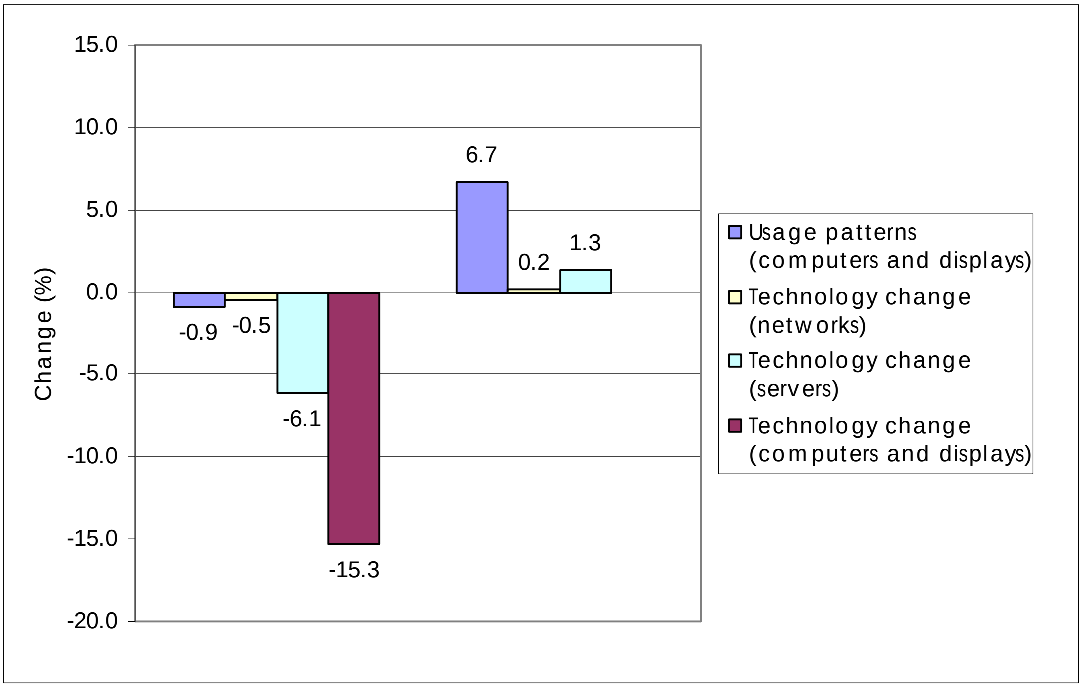

Figure 8. Possible changes in ICT's energy consumption.

5.2 Energy consumption of mobile phone networks

The interviews with telecommunications network operators illustrate two issues associated with ICT and energy: the divergence of opinions and the general notion that the ICT industry is not very energy-intensive. One of the three interviewees thought that the mobile telephone network and ICT in general were major energy consumers, while another saw his industry as environmentally friendly. Nevertheless, all interviewees alluded to the fact that the efficiency of the network could be improved. The transition to UMTS technology may change the situation as regards power consumption.

“Information society” is a keyword in the Finnish national strategy. Hence, any significant reductions or slowdowns in the growth of the amount of traffic are unlikely. Therefore, attention should be devoted to increasing the capacity of the network as efficiently as possible. While some overhead consumption can and has already been eliminated with technology updates, improving the efficiency of the base stations should become a priority in the industry. This would reduce the need for cooling, which forms the most significant additional item in the electricity bill and also causes considerable fluctuation in power demand.

5.3 Cutting the energy consumption of ICT: device convergence

The advent of devices that fulfill the function of more than one older product is also expected to reduce the energy consumption of ICT. Combining the functionalities of a camera, a phone and an MP3 player in a multimedia device nevertheless does not decrease the energy consumption in the use phase. Contrarily, the multimedia device weighs less than the three separate devices together, i.e. it contains less material. The amount of materials is also indicative of the manufacturing phase energy consumption, which for mobile phones is clearly more significant than the use phase energy consumption (Stutz *et al.* 2003). The same can be assumed to be true for other electronic devices included in the comparison. With a multi-functional device, duplication of some of the components that are included in all devices (and contribute to the manufacturing phase energy consumption) can be avoided. An example of such a component is the battery, which accounts for 13 % of the weight of a digital camera and 25 % of the weight of a basic mobile phone. In different devices, weight is distributed across components varyingly.

The importance of usage patterns on energy consumption cannot be overstated. Changes in the use time affect the energy consumption almost linearly. For example, shutting down the mobile phone for the night (8 hours a day) would reduce the energy consumption of multimedia and basic mobile phones by 9 % and 10 %, respectively.

Some energy consumption was ignored in the calculation, specifically the standby consumption of chargers. As similar usage patterns can be assumed for both multimedia and basic phones, this has no impact on the comparison of devices, but merits being mentioned. It is not unusual for mobile phone users to keep their chargers plugged in continuously. Schaefer *et al.* (2003) assumed that mobile phones are charged for three hours per week and that the charger is in standby mode for the rest of the year (8,604 hours a year). If current charger consumption values are applied, this results in an annual consumption of 3.4 kWh[35]. According to the calculations in the present research, the useful life energy consumption of a mobile phone is between 1.1 and 1.6 kWh depending on the type of the phone, and the production phase energy consumption

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[35] The standby consumption of chargers is 0.3 W (Louhi 2006) and the active consumption is 5 W (Vuorio 2006b).

ranges between 56 and 380 kWh (see Chapter 4.3). On the other hand, some MP3 players are charged via a USB cable, and some users tend to keep their computer on during charging. If the computer is in standby mode while charging, this results in a consumption of 10 to 40 W depending on the type of computer (Motiva 2006a). This consumption, however, is not necessarily idle, if the user is simultaneously performing other tasks with his computer.

Based on results from the convergence case and the mobile telephone network's energy consumption, the annual energy requirement of using a mobile phone in Finland can be estimated to be between 40 and 48 kWh per user. This includes the energy consumption of both the network and the terminal device, as well as the charger. The figure is sensitive to assumptions concerning the usage patterns.

5.4 ICT versus traditional techniques: teleconferencing

Kogg (2000) has suggested a model for analysing the contextual factors that affect meeting behaviour in organisations. This model has been applied to analyse the status of teleconferencing at Nokia in Figure 9.

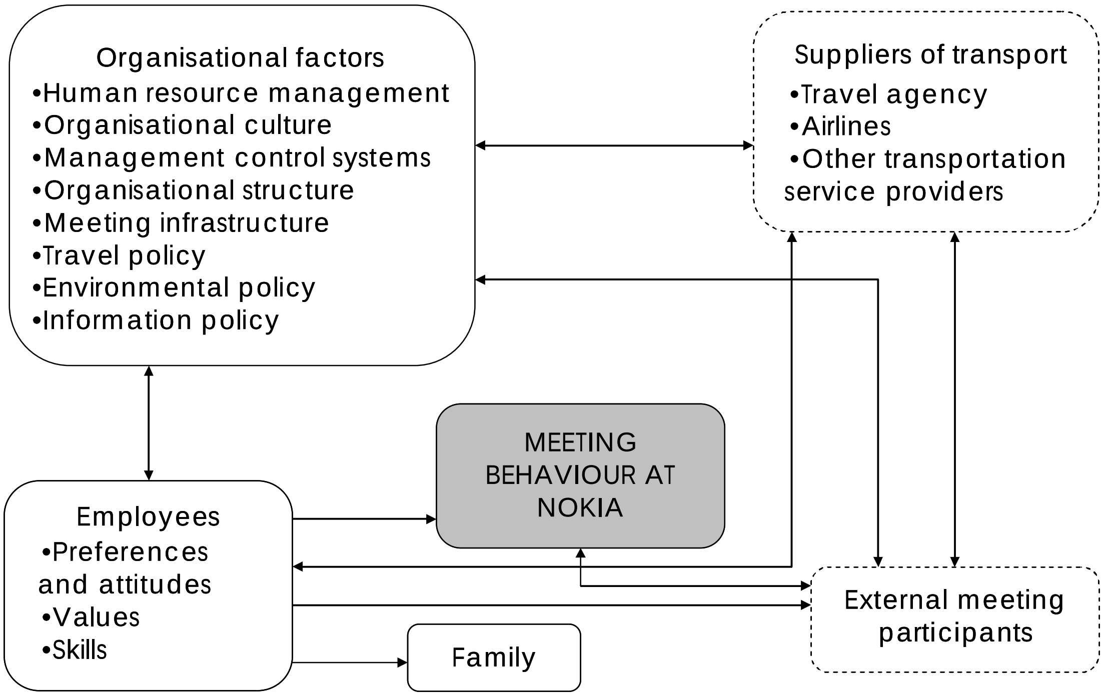

Figure 9. Contextual factors influencing meeting behaviour at Nokia. (Modified from Kogg 2000)

Organisational factors

The organisational factors at Nokia appear favourable to both traditional meetings and to teleconferencing. Meetings are a common way of working due to the structure and the culture of the organisation. Human resource and information policies have been constructed to support mobile working, but environmental policy has so far taken no position as regards meetings. The infrastructure for both traditional meetings and teleconferencing has been put in place. The use of teleconferencing tools has been promoted, and user guides for the devices are available. On the other hand, there are no organisational factors that restrict travelling. Most of the employees do not have a tight travelling budget, and travelling needs are considered case by case instead.

Employees

For many Nokia officers, being able to avoid a part of the travelling required by meetings is probably an attractive prospect. Therefore, the incentive for teleconferencing exists. Audioconferencing has already become an everyday issue for some, but for others it is still a novelty, partly due to cultural differences between the different countries in which Nokia operates. Videoconferencing, in turn, is less familiar even to people who are used to audioconferencing. According to comments from Nokia officers, videoconferencing is difficult to organise, and adds little value to communication due to low image quality. Compared to audioconferences that can be set up instantly with mobile phones, videoconferences are complicated to organise, as the meeting room must be booked in advance, and no portable solutions are available.

External meeting participants

Meetings with external participants are more difficult to replace with teleconferencing. In part, this is because teleconferencing is less formal. Furthermore, the external meeting participants do not necessarily have access to the required equipment (especially for videoconferencing).

Suppliers of transport

The availability of travelling services is good, and therefore does not constitute a barrier for travelling.

Conclusion

In sum, it seems that the teleconferencing potential at Nokia is not yet fully utilised. Audioconferencing has already gained acceptance among employees. In the future, efforts should be made to promote it in those countries where its use is still marginal. Audioconferencing could be made the communication medium of choice between Nokia employees—after all, it is based on Nokia's own technology. Nokia's opportunities for promoting teleconferencing among external partners are perhaps more limited, but the company could still try to market the option to its partners.

Videoconferencing technology appears inconvenient to use for most Nokia employees. Better-functioning, portable devices could increase its popularity, making it a true substitute for travelling in situations where audioconferencing seems too familiar or informal. This could increase the applicability of teleconferencing and, consequently, the amount of travel that can be avoided. Currently, videoconferencing as a communication channel is neither spontaneous nor mobile.

Integrating the environmental viewpoint into Nokia's travelling policy could also help in reducing travelling and saving energy. Setting a travel budget for the employees could be a first step: this would make it clear that travelling has a cost. The environmental perspective could be strengthened by introducing an emissions "tax". In this system, the travelling employees would have a fixed travel allowance. For each journey, the employees would have to offset the environmental costs by a certain sum that would be reduced from the allowance. This could lead to more careful consideration of travelling. (Vuorio 2006a) Such practices could, of course, provoke resistance among the employees. Offering incentives to reduce travelling is a less politically sensitive option. Monetary incentives could be used (e.g. bonuses equal to a proportion of the costs of avoided travels). An alternative type of incentive would be products or services with low material and energy intensity, like theatre tickets or sport services for the employee and her / his family. The resulting partnership with service providers would also enhance Nokia's involvement in society. The downside of this option is that employees who are not required to travel could perceive this as yet another benefit that is not offered to them. Naturally, any incentive system would have to be carefully constructed, involving the assignment of travel quotas and monitoring of travel behaviour.

Based on the fictitious case example calculated above, the energy savings from teleconferencing are significant. Unlike working from home, it does not entail complex rebound effects.

5.5 Estimates of ICT's energy saving potential

The energy consumption reductions due to the use of ICT are difficult to isolate. In the following, tentative estimates of a few potential reduction areas are presented. The first item considered is teleconferencing as a means of reducing cross-border business travelling. This influences the energy consumed by transportation, which corresponds to 25.8 % of the total global energy consumption (IEA 2006). It is reasonable to assume that this consumption is divided into two between personal transport and freight. Further, it is assumed that half of the personal transportation is generated by cross-border tourism. Business travelling accounts for 16 % of the global tourism (WTO 2006). As the energy comparison of teleconferencing is insignificant compared to energy consumption from travelling, replacement of travel by teleconferencing implies a practically proportional reduction in the energy consumption of business travel. A 5 % reduction in the amount of travels is adopted here as a conservative value.

The second item examined is e-commerce, and particularly its impact on the energy consumption of retailing. The net effect of e-commerce on transportation is unclear, but the wholesaling and retailing part of the supply chain presents more certain reduction potential. According to Norris *et al.* (2003), this node accounts for about 30 % of the life cycle energy burden. The energy consumption reduction in commercial space has been estimated to range from 93.7 % (Romm *et al.* 1999) to 226.5 % (Matthews *et al.* 2002b), and a 2.9 % increase in commercial space energy consumption has also been suggested (Matthews *et al.* 2002b). This study assumes that warehousing and retailing accounts for 15 % of the Other sector[36] of consumption in IEA 2006—that is, 5.8 % of the world total energy consumption. These calculations are based on a 10 % share of e-commerce from all commerce. Currently, the proportion in the USA is about 3 % (U.S. Census Bureau 2006).

Thirdly, ICT's dematerialisation potential was considered in terms of paper consumption. Information related to the energy consumption of paper production is available, which is not the case for CD production or many other electronic products. The analysis here focused on printing and writing paper. According to a case study at Telefónica, writing and printing paper consumption in the office could be reduced by 70 % by shifting to electronic documentation and applying various savings measures (Telefónica 2005). This considerable reduction can be taken as an optimal situation, where many other factors besides ICT have an influence. The most promising paper consumption reduction potential of ICT is in electronic billing and documentation. The proportion of the population with Internet access can be used as a proxy for the potential of electronic billing: globally, that percentage is now 16.7 % (see Table 15 on page 55). Using this figure presupposes the existence of electronic banking services.

To achieve an estimate of the energy consumption reduction potential related to paper consumption, it was assumed that 60 % of all printing and writing paper is consumed in offices[37]. Telefónica's estimate of the consumption reduction potential was used as an upper limit, while a reduction of 15 % was viewed as more likely. This would include the utilisation of online billing potential as well as shifting to electronic documentation inside companies. The actual energy consumption reduction was calculated using results from LCAs. These range from 30 GJ per tonne of paper for printing and writing paper manufactured in Portugal to 32 GJ per tonne of average paper manufactured in Britain (Lopes *et al.* 2003, Sundin *et al.* 2001). The actual energy consumption varies according to manufacturing country and type of paper, but 31 GJ per tonne was used here as a reasonable estimate.

Finally, better matching of production into consumption is possible using ICT-enabled electronic data interchange. For example, in conventional book retailing in the USA, the proportion of unsold books is estimated to be 35 % (Matthews and Hendrickson 2001, Matthews *et al.* 2001). Avoiding this results in a corresponding decrease in manufacturing energy consumption. By now, ICT applications have been taken into use, and the reduction potential may not be as significant in all of the economy. Therefore, a reduction of 5 % is used here as a more conservative estimate. According to IEA (2006), 26.9 % of the global energy consumption is related to industry.

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[36] The Other sector includes agriculture, public and commercial services, and some non-specified activities. It accounts for 38 % of the global energy consumption. (IEA 2006)

[37] According to FAO statistics, 103,820,010 tonnes of printing and writing paper were produced in the world in 2005 (FAOSTAT 2006).

Figure 10 below illustrates the relationship between ICT's own energy consumption and the consumption reductions. Error bars in the consumption reduction columns represent the differences between estimates. The columns representing ICT's energy consumption reduction potential are not additive as a different estimation approach has been used for dematerialisation. Nevertheless, the savings could reach the same order of magnitude or be greater than the energy consumption of ICT itself; on the other hand, ICT use could also increase energy consumption.

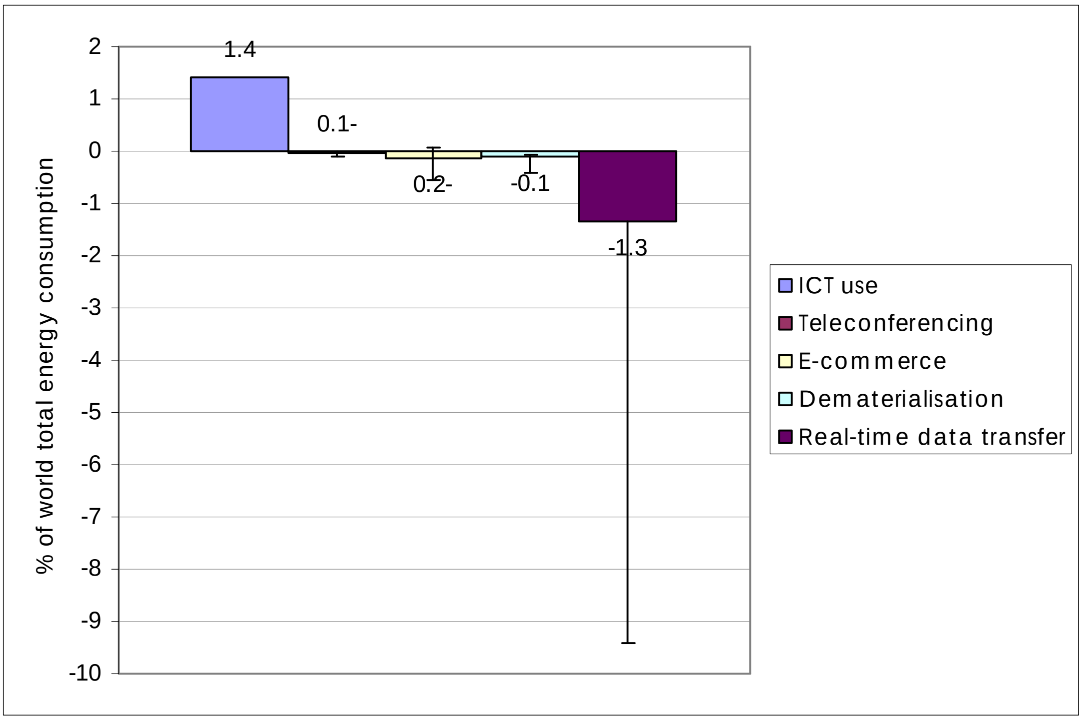

Figure 10. ICT's energy consumption compared to its consumption reduction potential.

5.6 Reliability and validity considerations

Environment-related data is often characterised by incompleteness, and this was experienced in this research as well. The quantitative results presented here should therefore not be regarded as absolute truth but rather as estimates providing a general overview of the issues studied.

The aggregate energy consumption of ICT was estimated based on three mutually reinforcing studies that were from trustworthy sources and which applied similar methods. The extrapolation performed here respected the tried-and-tested method, and changes incorporated into existing results were based on research or on industry reports to the extent possible. In this case, the reliability and the validity of the results can be considered good. The same consideration applies to the energy consumption of the Finnish mobile telephone network. Even though exact figures were not obtained in the interviews, the estimates obtained are from industry experts who have several years of experience in the field. The interview situation may have influenced the answers of the interviewees, but there is no particular reason to doubt their reliability.

The technical data used in the device convergence case are mostly from manufacturers and retailers who have direct access to the information. In the cases where power consumption-related data had to be retrieved from other sources, it was compared with values already obtained to ensure consistency. Data on the usage patterns and useful lives of the products, in turn, was based on best judgment, and this component involves uncertainty. The method of comparison applied in the research can be considered as valid for the energy consumption at the use phase. Using the weight as a proxy for production phase energy consumption is more questionable. Nevertheless, it was considered to be the best option in the absence of more detailed data.

The EIO-LCA comparison of the three ICT devices is indicative at best. Firstly, the manufacturing sectors selected contain dozens of types of equipment besides the ones that were compared in this study. Secondly, the EIO-LCA model is based on figures from the U.S. economy and takes dollars as inputs. Converting euro prices to dollars should not distort the results significantly, but the economy described in the model does not correspond to the European or the Finnish one. In addition, the manufacturing costs of the multimedia device were allocated to the two sectors with the lowest additional energy consumption. Therefore, the result may favour the multifunctional device. Despite these inaccuracies, the method provides a tentative picture of the differences between the two options.

The teleconferencing case is based on trusted research as to the energy consumption of travelling. The power consumption values, as well as qualitative information regarding teleconferencing and travelling habits were obtained from inside of Nokia. The fictitious case company was constructed to resemble a real company as accurately as possible, and the assumptions were checked by industry representatives. Some items influencing the substitution likelihood of travel, as well as the average amount of journeys per employee, had to be estimated. No extensive empirical data was available to estimate the substitutability of travels. Therefore, conservativeness was applied as a general guideline.

Finally, quantifying the energy savings that could be achieved if ICT's energy saving potential was utilised globally is a challenging task and calls for more detailed research than is possible here. The estimates provided in this study are based on earlier studies cited in the literature review and on conservative educated guesses. They provide some indication of the magnitude and direction of possible changes, but they should be viewed as initial ideas that require further corroboration.

6 Conclusion

6.1 Summary of the results

The three research questions that were postulated at the beginning of this study were answered in the course of the research. ICT’s energy consumption was estimated to be at most 1.4 % of all global energy consumption. Compared to other activities, like transport, it is not a big consumer. Nevertheless, ICT’s energy consumption has grown in the recent years and is likely to continue so. This trend could be curbed by improving the energy efficiency of equipment, shifting to less energy-intensive technology or adopting more power-conscious usage habits.

Mobile phone networks correspond to less than a tenth of the energy consumption of ICT. Still, their energy efficiency could be improved further, in particular by improving the efficiency of base stations. In Finland, the annual per customer energy burden from using a mobile phone is between 40 and 48 kWh. The network accounts for 36 to 43 kWh of this.

Most of the life cycle energy burden of mobile phones and other small ICT devices is due to the production phase. Hence, reducing this load would be the most effective way of cutting ICT’s energy consumption. Device convergence could provide one way of doing this: a mobile device comprising a phone, a digital camera and an MP3 player weighs roughly 50 % less than three separate devices with equivalent functionalities, and an EIO-LCA approach also indicates that the multimedia device would be more energy-efficient to manufacture.

This study discussed dematerialisation, e-commerce, real-time data transfer and teleworking as potential ICT-enabled ways of saving energy. They entail, however, rebound effects and behavioural changes, which makes it difficult to assess what their net impact will be. Teleconferencing as a form of teleworking was examined in this study as an ICT application which is relatively free from such effects. Its energy consumption is insignificant compared to that of travelling by air. In a fictitious case example, replacing 20 % of travelling in an organisation could result in energy savings of 0.23 TWh.

6.2 Significance of the research

The main contribution of this research is in providing an up-to-date estimate of ICT's direct energy consumption. The latest of the previous estimates is based on data from year 2001, and an updated view was in order. The findings from the cases complement the existing body of knowledge about ICT's energy savings. The tentative understanding of the possible environmental benefits of multimedia devices provided here is the first of its kind, as are the estimates of the energy consumption of the Finnish mobile phone network.

6.3 Suggestions for further research

This Master's thesis has aimed at finding out the energy consumption of ICT and balancing it against the ICT-enabled energy savings. Nevertheless, quantifying the savings from various ICT applications accurately calls for a study that is larger in scope. In addition to the savings from ICT use, the behavioural changes and macroeconomical adjustments merit further attention. This would require combining expertise in ICT, energy economics, macroeconomics and social and behavioural sciences. Building such holistic view is a laborious undertaking, but it would provide a solid basis for developing optimal ICT practices.

There are also many smaller sub-projects worth considering. Firstly, the present research proved that important data on ICT's impact on energy consumption, like life cycle assessments of products like MP3 players, are still lacking. These are a prerequisite for an accurate comparison of different devices, or of ICT-based and traditional solutions. Secondly, the energy consumption of ICT depends heavily upon usage patterns, yet there is no empirical research on this matter. An action-oriented research approach would be well suited for this kind of subject, as it would allow the construction of "best practices" as one outcome of the research. Thirdly, the impacts which the use of ICT has on people's lifestyles is an interesting field of study for the social sciences, and it is reasonable to expect that these problems will attract attention in the future.

7 References

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8 Appendices

Appendix 1. Stocks of PCs, displays and servers in the three comparison cases

Equipment category	Case 1	Case 2	Case 3
PCs	173,459,000	173,459,000	173,459,000
Desktops	121,421,300	95,402,450	112,748,350
Laptops	52,037,700	78,056,550	60,710,650
Displays	134,308,285	134,308,285	134,308,285
CRTs	100,731,213	80,584,971	100,731,213
LCDs	33,577,071	53,723,314	33,577,071
Servers	6,492,561	6,492,561	6,492,561
Low-range	5,194,049	5,194,049	5,194,049
Mid-range	779,107	1,103,735	779,107
High-range	519,405	194,777	519,405

Appendix 2. Breakdown of ICT's energy consumption by category

Equipment category	Base case		Case 1		Case 2		Case 3	
	TWh	%	TWh	%	TWh	%	TWh	%
Computers	14.6	16 %	27.8	20 %	24.7	19 %	23.9	19 %
Displays	20.8	22 %	23.2	16 %	21.1	16 %	18.3	14 %
Servers	11.7	12 %	31.5	22 %	25.8	20 %	28.5	22 %
Communication networks	12.8	14 %	16.4	12 %	14.7	11 %	15.9	12 %
Copiers	9.7	10 %	11.5	8 %	11.5	9 %	11.5	9 %
Faxes	3.1	3 %	3.7	3 %	3.7	3 %	3.7	3 %
Printers	5.7	6 %	6.8	5 %	6.8	5 %	6.8	5 %
UPSs	5.8	6 %	8.7	6 %	8.7	7 %	8.7	7 %
Others	9.7	10 %	11.5	8 %	11.5	9 %	11.5	9 %
Total	93.9	100 %	141.1	100 %	128.6	100 %	128.9	100 %

Appendix 3. Converting electricity consumption to primary energy consumption

Estimating the energy consumption of ICT as a percentage of the national total required converting the electricity consumed by ICT into units of primary energy. The primary-to-electricity conversion factor was obtained by dividing the total electricity generated by total primary energy consumption in the electric sector. The relevant data were obtained from sources EIA 2005b (total primary energy consumption) and EIA 2005c (total electricity generation). Net imports of electricity were excluded, but their impact can be assumed to be insignificant. The calculation is depicted below.

$$\frac{39{,}851 \cdot 10^{12}\, Btu}{4{,}038 \cdot 10^{9}\, kWh} = 9{,}869\, {}^{Btu}\!/_{kWh},$$

where Btu = British thermal unit.

Appendix 4. The energy consumed by an average Finn in commuting by car

Average length of single trips to work under 100 km (Helminen *et al.* 2003: 30)	8.7 km
Energy consumption of an average car per passenger kilometre (VTT 2002: Tieliikenne, Henkilöautot keskimäärin)	0.32 kWh
Energy consumption per average single trip	3.0 kWh
Energy consumption from trips to work in one year (235 working days a year assumed)	1,310 kWh
Energy consumption of the mobile phone network per customer (at most, see Chapter 4.2)	43 kWh

Appendix 5. The EIO-LCA method

The EIO-LCA method (Economic Input Output Life Cycle Assessment) is essentially a combination of two techniques: input-output analysis, familiar from economics, and life cycle assessment, which is one of the core tools in environmental engineering and management. Input-output (I-O) analysis was developed by Vassily Leontief during the first half of the 20th century, and it became popular after World War II (BEA 1999). It is based on I-O models, or matrices, that relate the production in different sectors of the economy with each other (Matthews and Small 2001). I-O models thus illustrate the interindustry relationships in an economy and enable an analyst to observe also the indirect impacts of a change in the economy (BEA 1999).

The EIO-LCA method is based on the same approach, but it focuses on environmental impacts instead of money. Perhaps the widest-used application of the method is the EIO-LCA model of Carnegie Mellon University, which is available for free on the Internet (http://www.eiolca.net). The model is based on an I-O matrix of the U.S. economy from the year 1992. The model adds to this economic data estimates of resource use and environmental impacts that correspond to the monetary flows. The environmental data is based on various sources. A core assumption of the model is that the inputs and environmental impacts are proportional to output. (Matthews and Small 2001)

Benefits of EIO-LCA as compared to a traditional LCA include the incorporation of the supply chain view and the rapidity of analysis (Matthews and Small 2001). It takes into account the production stage from the extraction of raw materials to the various manufacturing phases; on the other hand, it does not include the use or end-of-life stages of the life cycle (McMichael 1999).

Appendix 6. Calculations for estimating the energy savings associated with replacing meetings by teleconferencing at Novator

The proportion of face-to-face collaboration in different employee groups involving external participants was calculated based on the proportion of working time spent in different locations. Tables 33 and 34 illustrate the data that was used as the starting point. It was assumed that 90 % of the time spent in Novator sites other than where the employee is stationed was spent in face-to-face collaboration. Of the time spent in external locations, 85 % was estimated to be face-to-face collaboration in the sales personnel group and 100 % for the other groups. This reasoning was based on the assumption that sales personnel tend to spend longer times in customer premises, for example, implying that they would occasionally have to attend to their other tasks while still in external premises. The remainder of the working time spent in face-to-face collaboration was estimated to take place at the Novator site where the employee is stationed. Table 35 presents the results of the calculation.

Table 33. Working habits by mode of Novator officers.

Group	Proportion of workforce	Working time by mode		
		Individual work	Collaboration	Of which face to face
Sales personnel	7.5 %	40 %	60 %	35 %
Executives	0.5 %	50 %	50 %	35 %
Other officers	42 %	60 %	40 %	30 %
Average of the above	50 %	57 %	43 %	31 %

Table 34. Working habits by place of Novator officers.

Group	Working time by place				
	Own Novator site	Other Novator sites	External	On the move	Home
Sales personnel	50 %	10 %	20 %	10 %	10 %
Executives	50 %	20 %	10 %	10 %	10 %
Other officers	70 %	10 %	5 %	5 %	10 %
Average of the above	67 %	10 %	7 %	6 %	10 %

Table 35. The place of face to face collaboration in different Novator employee groups.

Group	% of face to face collaboration in external premises	% of face to face collaboration at other Novator sites	% of face to face collaboration at own Novator site
Sales personnel	100 %	100 %	10 %
Executives	100 %	100 %	10 %
Other officers	100 %	100 %	21 %
Average of the above	100 %	100 %	20 %

Then, the proportion of face-to-face interaction involving external participants was estimated. In external locations, this percentage was assumed to equal 100 %. In Novator sites, a proportion of 40 % was assumed for the sales personnel and the executives, and 15 % for the other officers. For all officers in the average, the proportion came to equal 19 %. Based on these figures, the total proportion of face-to-face collaboration involving external participants was then calculated. This proportion (in Table 36), in turn, was utilised to estimate the replaceability of meetings further in the example.

Table 36. The proportion of face-to-face collaboration involving external participants.

Group	All Novator premises	Total
Sales personnel	40 %	74 %
Executives	30 %	50 %
Other officers	10 %	25 %
Average of the above	15 %	35 %

The energy consumption of teleconferencing was calculated based on data in Table 30 on page 73. The energy consumption of the mobile phone network obtained in Chapter 4.2.1 was included in audioconferences via mobile phones. The energy consumption of the laptop was included in both forms of audioconferencing to reflect the behaviour of Novator employees. The power requirement of teleconferencing is presented in Table 37 below.

Table 37. Power requirements of different types of teleconferencing.

Type of teleconferencing	Power requirement
Audioconferencing with a conference phone	91 W
Audioconferencing with a mobile phone	71 W
Videoconferencing	200 W

Appendix 7. Interview questions for the mobile phone network operators (originally in Finnish)

1. Background information

1. Please describe briefly your responsibilities in your company.

2. Environmental management in the company

1. What are the environmental impacts of your company?
2. Is the responsibility for environmental affairs assigned to a particular person in your company?
3. Which of the following are utilised in your company: environmental strategy, environmental policy, environmental programme, environmental management system, or some other way of measuring environmental issues?
4. Have your customers shown interest in your company's environmental affairs?

3. The energy consumption of the mobile phone network

1. How carefully does your company monitor the energy consumption of the mobile phone network?
2. How important a cost is the energy consumption of the mobile phone network in your company?
3. What is the annual energy consumption of the mobile phone network?
4. Which components does the consumption consist of?
5. The calls made with mobile phones are transmitted to the fixed phone network. In terms of proportion of the energy consumption required for one call, how large would you estimate the consumption of the fixed network to be?
6. Has the energy consumption of the mobile phone network been discussed in your company communication?
7. Have your customers shown interest in the energy efficiency of the mobile phone network?

4. The future of the energy consumption

1. How would you expect the energy consumption of the mobile phone network to change in the future?
2. Which factors influence the development?
3. In the future, more diverse data from text messages to images will be occupying the network. How would you expect this diversification to affect the energy consumption?

5. Users of the network

1. How many mobile phone users are there in your network?
2. What are the usage patterns of your average customer like, in terms of minutes called and text messages sent per month?

6. Closing

1. If you'd like to express other views regarding the themes of the interview, please do so.

In the first two interviews, the following questions were used instead of questions 2.3 and 2.4:

3. What is your estimate of the annual energy consumption of the mobile phone network?
    a. per customer
    b. per call minute
    c. per one megabyte of transferred data
    d. in some other unit
4. How has the energy consumption been estimated?