The impact of information and communication technologies on electricity consumption in Germany

Clemens Cremer
Fraunhofer Institute Systems and Innovation Research
Breslauer Str. 48; D-76139 Karlsruhe; Germany
Clemens.Cremer@isi.fhg.de

Barbara Schlomann
Fraunhofer Institute Systems and Innovation Research
Breslauer Str. 48; D-76139 Karlsruhe; Germany
Barbara.Schlomann@isi.fhg.de

Michael Friedewald
Fraunhofer Institute Systems and Innovation Research
Breslauer Str. 48; D-76139 Karlsruhe; Germany
Michael.Friedewald@isi.fhg.de

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Abstract

The importance of information and communication technologies in everyday life is increasing strongly. The growing penetration of PCs in households and offices and the almost ubiquitous use of mobile communication devices are vivid examples for this development.

The key drivers influencing the penetration, usage patterns and specific energy consumption of IC-equipment were examined and a bottom-up analysis of the direct energy consumption of ICT-equipment in households and offices was made for 2001 resulting an energy demand of 38 TWh. In addition, projections for the years 2005 and 2010 were developed based on the base year consumption and the key driving forces, which showed an increase of ICT energy consumption to 55 TWh in 2010.

The energy consumption was analysed in normal operation mode, standby and off-mode. A differentiation was made between end-use appliances and the ICT-infrastructure in buildings for both residential and commercial use. This made it possible to identify the appliances and the infrastructure equipment with the highest growth in energy consumption and to examine the options and potentials for the increase of energy efficiency.

This paper gives an overview of the state and development of the energy consumption of ICT equipment as well as the key driving forces and savings potentials in this field.

Introduction

Understanding the energy consumption of information and telecommunication equipment in buildings has improved significantly over the last two to three years. A relatively large amount of work has been performed from the perspective of the possible and even quite probable explosive increase in electricity consumption by Information and Telecommunication Technology (ICT)-equipment. The previously more academic discussion received significant publicity through the highly contested article of Huber and Mills (1999) (compare, e.g. Lovins, 1999). The scientific controversy resulted in a political debate, in which the public authorities in the U.S. tried to obtain a clearer picture of the possible development of ICT energy consumption. A lot of work published since then has produced a more balanced picture (Kawamoto et al. 2000; Kawamoto et al. 2001; Roth et al. 2002).

The case is different for Germany, where only a small amount of comprehensive and detailed work has been performed on this topic, although some publications do exist (e.g. Barthel et al. 2001). From a top-down point-of-view, the energy demand for information and communication in Germany is estimated at almost 1.5% of final energy consumption or 7.1% of the electricity consumption (Geiger/Wittke 2002). Unfortunately these figures seem to be not much more than rough estimates which had to be made due to the lack of more accurate data. As for the international projections (IEA 2000), it is generally accepted that the demand for information and communication services will increase for Germany as well (Prognos/EWI 1999; Ziesing et al. 1999; Böde et al. 2000a). The growth perspectives of the internet economy and the associated projected power demand of internet application providers result in a threaten-

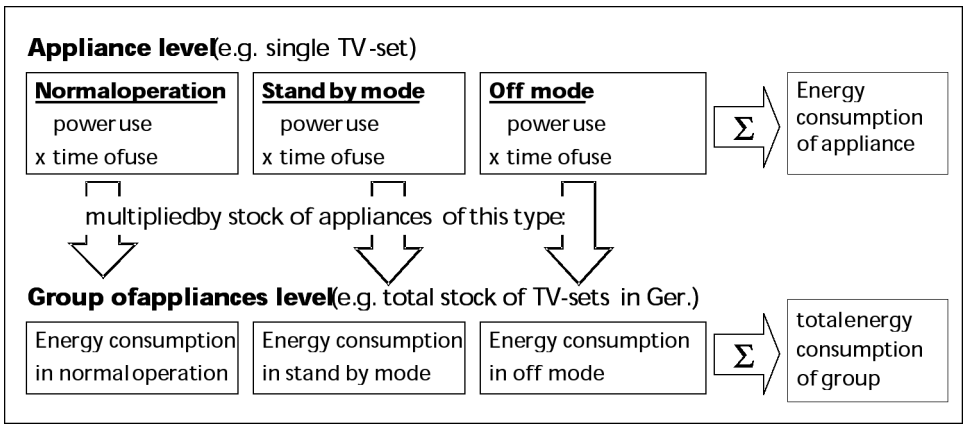

Figure 1. Model for the calculation of ICT-energy consumption

ing picture for future energy demand by ICT (see, e.g. Mitchell-Jackson 2001).

However, the future development of electricity consumption is especially difficult to estimate in the information and communication sector since it is of a very dynamic nature and has a high innovation rate. Technologies, applications and services are changing and expanding rapidly. In addition the data situation in Germany, as in other European countries, is unsatisfactory in the household and the tertiary sectors especially in the field of ICT (Diekmann et al. 2000).

Objective and methods

Against this background of perceived risk and lack of knowledge the objective of the work was:

- to qualitatively and quantitatively analyse the direct and indirect influence of ICT appliances, systems and services on energy consumption in Germany,
- to perform the work with a comprehensive scope for households and offices,
- to develop a forecast for the business-as-usual case up to the year 2010,
- to make concrete suggestions on this basis for energy policy at a national and EU level.

In order to achieve the goals set, a bottom-up approach was chosen with which the current and the future direct electricity demand of ICT appliances and their associated infrastructure was determined. Similar approaches have been used, e.g. by Rath et al. (1997); Rath et al. (1999) or by Böde et al. (2000a) for the analysis of standby power use in households, by Kawamoto et al. (2001) for an energy analysis of office equipment in households, commerce and industry and by Roth et al. (2002) in their very comprehensive analysis of ICT. The bottom-up model consists of the following components (Figure 1):

- stock of today as well as expected stock development including new appliances or uses up to 2010.
- The electricity consumption of the appliances in the different operating modes as well as the energy consumption of the supporting infrastructure systems. As in Cremer/Böde (2001), the following four operating modes are distinguished: normal operation, standby operation, off-mode, off (Table 1).
- Times of use in the various operating modes, i.e. the respective intensity of use.
- The future power demand is further influenced by the existence of (technical and behavioural) saving potentials with regard to the energy consumption in the different operating modes and their actual implementation.

The starting-point for the analysis was to establish a list with the main ICT appliances which were to be examined for Germany with regard to their current stock and energy requirements as well as the expected development up to 2010 (see Table 2). The individual appliances were grouped according to functions within a main group. A distinction was made between private households and offices as areas of use. Furthermore, end-use appliances and the associated infrastructure were examined separately. In the latter, another differentiation was made between in-house infrastructure located in households and offices and the infrastructure of the telecommunications companies (see Table 2). A major difference to other analyses or equipment surveys such as

Table 1.

Mode of operation	Definition	
standard operation	the appliance fulfils its main purpose	
ready mode	the appliance fulfils at least one function but not the main purpose	the appliance waits for a task, minor reduction of energy consumption
standby mode		major reduction of energy consumption
sleep mode		strongest reduction of energy consumption
off mode	the appliance does not fulfil any task, seems to be switched off but still uses energy	
off	the appliance does not fulfil any task and uses no energy	

Table 2a. List of appliances examined for the analysis of ICT energy consumption

Function	End-use appliances		Infrastructure (in-house)	
Main group	Households		Households	Offices
Entertainment (audio, video)	**Audio (stationary)**	**Television**	**Television**	
	Compact system	Cathode ray TV	Satellite receiver	
	Stereo system	LCD TV	Antenna preamplifier	
	Hifi amplifier	Plasma TV	Set-top box	
	Cassette recorder	TV projector	LNB	
	CD player	**Video recorder**		
	Minidisc player	Video recorder (analog)		
	Audio-DVD player	Video-DVD player/recorder		
	Clock radio	**Cameras**		
	Audio (portable)	Video camera/Camcorder		
	Radio-tape deck	Digital camera		
		Others		
		Video game console		
		Mains power supply [1]		
	Households	**Offices**	**Households**	**Offices**
Communications	**Telefony (fixed network)**	**Cameras**	**Internet-Infrastructure**	**Networking**
	Cordless phone	Video camera/Camcorder	DSL splitter	Router (19 inch rack)
	Smart phone	Digital camera	DSL modem	Hubs
	Answering machine	**Telefony (fixed network)**	CATV modem	Switches
	Fax machine	Cordless phone	Satellite modem	**Telephone system**
	Telefony (mobile)	Smart phone	PLC (powerline comm.) adapter	Private branch exchange
	GSM	Answering machine	PLC house coupler	**Others**
	UMTS	Fax machine	Router (DSL)	Intercom
		Telefony (mobile)	Telephone modem	
		GSM	**Telephone system**	
		UMTS	ISDN box	
			Others	
			Intercom	

[1] Mains power supplies are balanced for the appliances.

from the Group of Efficient Appliances (GEA) or from the German Energy Agency (dena) is the inclusion of infrastructure appliances to the study, which have been omitted before and play a significant role in the authors´view.

Stock and power requirements of ICT-equipment

For the bottom-up modelling performed, the input data and its quality is very important for the reliability and usability of the obtained results. For this reason, the strategies for data acquisition, the data sources and the estimations made for the analysis are described in detail.

STOCK DEVELOPMENT OF END-USE DEVICES IN PRIVATE HOUSEHOLDS

The base for determining the stock of ICT end-use devices in German households in 2001 and for estimating the development up to 2010 comprised data on household equipment with these appliances. The stock of devices was extrapolated using the number of private households. Following Schlesinger (2001), it was assumed that the number of households in Germany will increase slightly in the near future (especially due to the growth of one-person households) from 38.16 million in 2001 to 38.31 million in 2005 and to 38.5 million in 2010.

The following information sources were used to determine the stock of devices/the household equipment in the base year 2001:

- official or semi-official statistics (Federal Statistical Office, Eurostat, RegTP, OECD, ITU, German Federal Labour Office),
- statistics of associations,

Table 2b. List of appliances examined for the analysis of ICT energy consumption – continued

Function	Infrastructure of the tele-communications companies
Main group	
Communications	**Fixed network**
	Power demand per channel
	Power demand per DSL line
	Mobile communications
	Mobile base station GSM
	Mobile switching centre GSM
	Mobile base station GSM
	Mobile switching centre GSM
Data - processing	**Data centres/DP centres**

- statistics of market and opinion research institutes (e.g. Allensbacher Computer- und Telekommunikations-Analyse, Media-Analyse),
- statistics from relevant studies.

These data sources were systematically harmonised in order to obtain a consistent data set for predicting future stocks. For the prediction of future household equipment, saturation values could be determined for the majority of not completely new market appliances and the future household equipment calculated using a non-linear regression analysis from the past trend. The following major trends can be ascertained for the main appliances:

The number of *televisions* increases from almost 55 million in 2001 to 59.5 million in 2010, i.e. by about 8%. Since the majority of households are equipped with at least one (first) television, this increase is mostly caused by the growth in

Table 2c. List of appliances examined for the analysis of ICT energy consumption - continued

Function	End-use appliances		Infrastructure (in-house)	
Main group	Households		Households	Offices
Data processing	**Computer** Personal Computer (PC) Notebook PDA **Monitor** Cathode ray LDC **Printer** Inkjet Laser Matrix **Others** Scanner Copier (Desktop) Active boxes (PC)	**Computer** Personal Computer (PC) Notebook PDA **Monitor** Cathode ray LCD **Printer** Inkjet Laser Matrix **Others** Scanner Copier Projector		**Server** lower price range (<25 kEUR) medium price range (<100 kEUR) upper price range (>100 kEUR) **UPS** for routers for switches for servers (lpr) for servers (mpr) for servers (upr)
	Households		Households	
Intelligent home	**Household appliances** Microwave Cooker Extractor hood Coffee maker Dishwasher Refrigerator Fridge/freezer combination Freezer Washing machine Dryer Washer/dryer combination	**Heating/hot water** Small boilers Hot water boiler Continuous flow Heating system **Security equipment** Surveillance camera Motion detector Operating terminal/monitor Automatic doorlock Alarmsystem Smoke detector **Others** Time switches Sensors/actuators Lighting	**Networking technology** Gateway System Central Control Unit Intelligent home bus system	Not considered for offices.

second and third TVs in households. Even if there are no publicly accessible data on the stock of televisions according to screen technology and size, it is assumed that cathode ray TVs are increasingly substituted by Liquid-Crystal-Display-TVs (LCD-TVs).

There has been a strong rise in the number of appliances for *video media* in households over the past years. This trend can be expected to continue in the future with a further increase in the stock of video appliances by 30% up to 2010. This is predominantly due to the increased spread of video-DVD-players (digital versatile disc players) and recorders, whereas the stock of conventional video recorders will decline. However, a complete substitution of conventional videocassette recorders by DVD appliances is not expected before 2010.

The stock of *fixed network telephones* already reached a level close to saturation several years ago in Germany. Recently a clear structural shift - relevant for power consumption - within the stock of appliances away from simple telephones to so-called "smart phones" (multi-function) with many additional functions as well as to cordless phones consisting of a base station and one or more handsets has begun. This trend will continue in the near future so that further growth can be expected in the numbers of these devices.

There has been enormous growth in Germany among the number of users of *mobile communications* especially since 1999. For 2001, the number of actual active mobile users is estimated at 47 million. A continued increase of mobile communications users up to around 70 million by 2010 is expected.

The number of *computers* in German households totalled around 21.2 million in 2001, including 2.6 million notebooks. A continued increase by 30% is expected up to 2010, in which the greatest growth is in the number of notebooks. The trend towards mobile IT and telecommunications which can be observed in many sectors, can also be seen in the growing number of *PDAs* (Personal Digital Assistant).

The overall numbers of *computer monitors* increases parallel to the number of desktop PCs. Up to 2010, today's customary CRT monitors (cathode ray tube monitors) will be successively replaced by the thinner LCD displays.

POWER CONSUMPTION OF END USE APPLIANCES IN PRIVATE HOUSEHOLDS

The respective power consumption selected for the base year 2001 in normal, standby and off-mode operation is mainly based on values found in the literature or own measurements. The estimates made for 2005 and 2010 take into account both expected increases due to higher performance requirements and expected decreases in power consumption due to autonomous technical progress or already ongoing measures to increase energy efficiency.

Normal operation mode

A decrease of power consumption between 2001 and 2010 is only assumed for a very few appliance groups in *normal operation mode*. Technical trends like the integration of all functions onto one circuit board to reduce the electricity demand are usually compensated or frequently even overcompensated by increased performance or additional functions. For these reasons, a constant power consumption in normal mode between the base year 2001 and 2010 is assumed for appliances which are technically already very mature and for which there is no expected marked demand for higher per-

formance or complex additional functions. This applies to all audio devices, video recorders, cameras, fixed network telephony devices, PDAs, many peripheral devices of PC use (LCD displays, printers, scanners, active boxes) as well as copiers and projectors. The continuous drop in the power consumption of appliances observed in recent years is assumed to carry on only for mobile phones. Exactly the opposite, i.e. a future increase of power input, is anticipated for several appliances due to continued increases in performance or convenience requirements which overcompensate the technically possible consumption reductions.

Standby mode and off mode

It is also anticipated that the power consumption will remain predominantly constant in *standby mode* for most ICT end-use appliances in the household sector. A decrease, albeit a moderate one, up to 2010 is assumed for televisions and VCRs because of the manufacturers' voluntary self-commitment here at an EU level. No significant changes in power consumption are expected for the *off-mode operation* for most groups of appliances under the present conditions up to 2010.

OPERATING TIMES OF END-USE APPLIANCES IN PRIVATE HOUSEHOLDS

Independent surveys can be used to a large extent to determine the operating times for the household sector, although these only cover the normal mode of these appliances. Media studies have been carried out in the Federal Republic of Germany since the 1960s. For instance, the eighth study of the ARD/ZDF-Studie Massenkommunikation, which was first conducted in 1964, is now available for 2000 (see van Eimeren/Ridder 2001). In addition, data of Media Analyse (MA) can be used for the analysis of media operating times. The division of the remaining operating time into standby, off-mode and off is mainly based on our own estimations, which in turn are based on figures in the literature. In addition, we referred to a current survey on the behaviour of German citizens with regard to the standby operation of their electronic appliances (dena 2002).

STOCK DEVELOPMENT OF END-USE APPLIANCES IN OFFICES

Compared with the household sector, the available data on the stock of relevant ICT end-use appliances in offices, i.e. computers with all peripheral devices as well as office communication devices, are much poorer. To determine the current stock as well as its development up to 2010, a similar approach was applied as in the private households. The estimate is made using the number of employees in office occupations or similar activities[1] as well as the equipment of office workplaces with information and communication end-use appliances.

The group of those employed in office occupations or persons included with similar activities has become considerably more significant over the past few years. Today almost every third working person in the Federal Republic of Germany is employed in desk work (Troll 2000c). In 2000, this equalled around 11.75 million persons. The projection study "Arbeitslandschaft 2010 nach Tätigkeiten und Tätigkeitsniveau" compiled by the Institut für Arbeitsmarkt- und Berufsforschung (Institute for Employment Research) (IAB) in collaboration with Prognos (Weidig et al. 1999) was referred to when estimating the future development. In accordance with this, the number of employees in the office sector is likely to increase to around 12.6 million by 2010.

The best source for data on ICT end-use appliances in office workplaces in Germany proved to be the most recent 1998/99 survey of the Bundesinstitut für Berufsbildung (Federal Institute for Vocational Training) (BIBB) and the Institut für Arbeitsmarkt- und Berufsforschung (IAB) on qualifications and employment in Germany (Dostal et al. 2000; Troll 2000a-d). The information of the BIBB/IAB study thus form the main base for the estimation of the current stock and the expected market development of appliances of information and communication technology in offices. Supplementary statistics from associations[2] and market and opinion research institutes were referred to in individual cases.

The number of ICT end-use appliances in offices estimated for the base year 2001 as well as for 2005 and 2010 is the product of the number of employees and the respective degree of equipment. The following trends in development emerge:

- in the field of communication, almost all office workplaces in Germany today are fitted with *fixed network telephones*, approx. 40% still with simple telephones. Their number will decrease strongly up to 2010, whereas the number of smart and cordless phones, which are relevant for power consumption, will increase by one third from 15.8 million in 2001 to 21.7 million in 2010. In contrast, a saturation effect can be observed for *answering machines* which are predominantly widespread in small offices since these devices are being increasingly integrated. A stock increase of 3.5 to 5 million is anticipated for *fax machines*, at least up to 2005 and in spite of the substitution effect of e-mail (especially in the smallest firms and start-ups) in order to be able to maintain contact with customers via various media. In doing so, however, companies will increasingly turn to multifunctional devices. The number of *mobile phones* used for business purposes was accounted for in private households since these devices are person-related and it is very difficult to separate private and vocational use.
- It is estimated that *computers* in offices will continue to increase from around 17.7 million today to almost 24 million in 2010. However, this is entirely due to the expected strong growth in notebooks and PDAs in particular, whereas the number of desktop PCs, which are still predominant today, will probably drop slightly from 10.5

1. Research and development activities, organisation and management, trading activities with managerial tasks, legal advisors or similar, publishing and artistic work, other consultation and training activities.
2. The European Information Technology Observatory (EITO) should be emphasised here which has published a European yearbook for the information and communications technology industry since 1993, in which the development in Germany is also documented (EITO 1993ff.).

to 10 million in 2010. Accordingly, the number of monitors will not continue to increase. The share of LCD screens, which is only around 10% today, will grow to roughly 40% in this period. Only a slight increase in stock is expected for *printers and scanners* in this decade. The same applies to *photocopiers*.

POWER CONSUMPTION OF THE END-USE APPLIANCES IN OFFICES

The power consumption of the ICT appliances used in offices should not differ significantly from those used in private households as long as the performance requirements made are also comparable. In these cases, the same assumptions were made for both sectors of use about power consumption in the three different operating modes. This applies to cameras, telephones and answering machines, PDAs, matrix and inkjet printers as well as active boxes.

For other appliances, the performance requirements for offices are much greater and the appliances are of a bigger scale than those used in private households so that the electricity demand in normal, and usually also in standby mode, is correspondingly higher. This applies primarily to fax machines, laser printers and photocopiers. The monitors used in offices tend to be bigger than those at home and the power consumption in normal operation will probably be greater as a result. In contrast, for PCs and notebooks it is assumed that the capacity of today's appliances is completely satisfactory for the majority of office applications and that increasingly secondary features such as noise development or energy demand will come to the fore. Accordingly, the continued increase in power demand of computers assumed in the household sector is not expected in offices (for PCs), or not to the same extent (for notebooks).

Generally, under the present conditions in the office sector, there are no major changes in the power consumption of ICT end-use devices expected for the period 2001-2010. For some types of appliance, the power demand in standby mode only might decrease slightly, also as a result of policy measures such as introducing voluntary quality labels or procurement activities.

OPERATING TIMES OF END-USE APPLIANCES IN OFFICES

Unlike households, there are no regular surveys of the operating times of ICT appliances in offices. The operating times selected here for the various operating modes represent our own estimations based on existing figures in the literature and own estimations emanating from the assumption that the appliances are in use during the regular office hours of eight to ten hours on 220 days per year. During office hours the appliances are not permanently in use but usually permanently ready for use. No significant changes in operating times are anticipated in offices up to 2010.

INTERNET INFRASTRUCTURE IN PRIVATE HOUSEHOLDS

In contrast to the other areas, no differentiation can be made for broadband internet connections between private households and offices/enterprises as no data exists to do so. In many cases, such a differentiation is not very helpful, as the DSL-technology (digital subscriber line technology) is often used by very small enterprises, which cannot be separated from households in many cases.

The demand for fast internet access using broadband technology has increased significantly in Germany in recent years. Overall, however, these technologies are still of minor importance in Germany today, as connections via analogue modem or ISDN technology (Integrated Services Digital Network) continue to dominate. The high number of ISDN internet connections will increase further in the next few years and will then be replaced by broadband technology (BDRC, 2001). Following this analysis, the total number of broadband internet connections will increase from around 2.4 million in 2001 to 38 million in 2010. The internationally dominating DSL and cable-TV technologies will play the most important role in Germany as well with 16 million and 14 million connections respectively. Other technologies will play only a marginal role.

The power requirement of the two dominating technologies is comparable, so it was possible to account for them together.

TV INFRASTRUCTURE IN PRIVATE HOUSEHOLDS

TV infrastructure can be clearly assigned to households and has been accounted for in this sector. The evolution from analogue services to digital services also results in a change in the technology used. The infrastructure components of analogue technology were mainly limited to the antenna preamplifier and the analogue satellite receiver. For digital TV, set-top-boxes are increasingly coming into operation as the digital signals have to be transformed into analogue signals and it is not likely that this signal processing will be integrated into the TV-set to any significant extent until 2010.

Three technologies are actually used for TV reception. Roughly half the households are connected to a broadband cable network, another third uses satellite technology and the remaining 15% still uses the traditional terrestrial technology. This structure will not change substantially apart from a small growth in the market share of the first two technologies.

The number of set-top-boxes for the reception of digital TV will increase but probably not to the extent assumed during the last years. According to ARD (2001), there were about 2.3 million users of digital TV sets in 2001. For the analysis it was assumed that this number will increase to 7 million in 2010.

With the growing trend towards developing these appliances to multi media platforms, it is assumed that the power consumption of satellite receivers and set-top boxes will increase from today's 17 to 20 W to 25 W in normal operation. The usage time will increase with the wide range of services that are expected for digital TV.

NETWORK INFRASTRUCTURE IN OFFICES

The main components of the network infrastructure were categorised as:

- server computers, which are computers in the network performing a large variety of services to other computers (data storage, allocation of data bases or internet sites, processing of e-mail services). Mainframe computers have been accounted for in this category as well.
- Hubs and switches, by which the computers and peripherals are integrated into the corporate networks.

- Routers, which provide the nodes between networks with different protocols.

The availability of data on the extent to which German enterprises are equipped with these appliances proved to be very poor. The data used for this work were based on existing and freely accessible information and expert estimations. For the projections until 2010, it is assumed that today's stock will increase by 50%. This means that the prior strong growth rates of 10 to 15% per year will no longer be sustained. Nevertheless, the consequences for ICT power consumption proved to be substantial due to the high power requirement of these appliances and their permanent use in normal operation. For the medium term, it was assumed that performance and power requirements of server computers will increase, as energy efficiency plays only an ancillary role for IT-infrastructure.

Additionally, the uninterruptible power supplies for a large part of the network infrastructure have been accounted for using efficiency data of these appliances.

INFRASTRUCTURE OF PUBLIC TELEPHONE AND NETWORK COMPANIES

The analysis of the power demand of the fixed network operators was performed by accounting for the number and specific power demand of the single network channels. As the equipment is permanently operated, a differentiation between operation modes proved to be obsolete. Using the data of the regulatory authority for telecommunications and post (RegTP 1999ff; 2001), 50.3 million network channels have to be assumed for 2001, increasing to 55.5 million in 2010. The specific power consumption per channel is 2.4 W (Deutsche Telekom 2001; RegTP 1999ff, 2001). In 1997 this value was still as high as 3 W. However, only marginal reductions are assumed for the coming years. An additional power demand of 2.4 W has to be estimated for DSL connections in local exchange centres. In contrast to the standard channels, a decrease of up to one-third in the specific power requirement can be expected in the medium term.

Base stations and switching centres were analysed for the assessment of the mobile communication infrastructure. As the existing networks with GSM-technology (Global System for Mobil Communication) use a completely different technology than the UMTS-networks (Universal Mobile Communication System) currently under construction, they were accounted for separately. Based on publicly available data and interviews with experts, the number of GSM base stations is estimated to be 50 700 with another 230 switching centres. Although the UMTS networks will go into operation in 2003 or 2004, this number is not expected to decline until 2010. In addition, 80 000 base stations and 330 switching centres for the UMTS networks are anticipated for 2010. The power draw of the new technology will be as much as twice as high as the existing one, resulting in a significant impact on the overall ICT energy demand.

RESTRICTIONS OF THE STOCK MODEL AND THE PROJECTIONS

The availability of data for the stock model proved to be very heterogeneous. Technologies well introduced to households are covered relatively well by statistical data. Further, usage patterns of appliances providing media content is thoroughly surveyed by the media market research. Contrasting to this, stock data for appliances in offices, especially those not directly linked to end-users such as network equipment or server computers is hardly available at all. For these technologies, estimations based on secondary data such as equipment of work places or turnover data of the manufacturing industries had to be used, producing a much larger margin of error at these points.

The projected data generally are subject to again higher uncertainties than the data in the stock model as the innovation rate in the field of ICT equipment is extremely high. The development of a part of the end use technologies could be modelled using saturation models giving a more reliable base to the projections, whereas this was not feasible for technologies principally not linked to users such as infrastructure equipment. The diffusion rates of technology alternatives and completely new technologies had to be estimated leaving considerable space for deviation from the real development. In order to increase the base of the projections discussions with industry experts were held.

Energy consumption of ICT in Germany

According to the bottom-up analysis of the individual appliances conducted here, the total electricity demand for the use of ICT equipment in households and offices in Germany amounted to around 38 TWh in 2001 (see Table 3). This is equivalent to a share of almost 8% of the overall electricity consumption of final energy sectors in Germany, which totalled 484 TWh in 2001 (AGEB 2002). With reference to the total final energy demand, the 38 TWh denote a share of 1.4%. A further increase of the power demand for ICT by about 45% to 55.4 TWh is anticipated up to 2010. This is equivalent to an annual growth rate of 4.3%. If the total electricity consumption forecast by Prognos/EWI (1999) of 520 TWh for 2010 is taken as a base, the share of the electricity demand for ICT purposes would already amount to almost 11% in 2010. Table 3 shows the development of the electricity demand for ICT purposes differentiated according to areas of use and operating mode. This is illustrated below in more detail.

ENERGY DEMAND ACCORDING TO USE

In 2001, the energy demand for ICT is clearly dominated by end-use appliances in households; households account for about half of the total ICT electricity consumption. However, this dominance will weaken in the near future since the largest growth in consumption is not found among ICT end-use appliances - this increases by almost 30% in households, but decreases slightly in offices - but in the ICT infrastructure. An increase of the power demand in the household infrastructure by 90% is expected by 2010, it will more than double for the office infrastructure, and the power demand of the infrastructure of telecommunications companies will grow by more than 150%. This extreme growth can be clearly ascribed to the planned construction of the UMTS mobile communications networks, which have an even higher power demand than the existing GSM networks. The server computers have the largest share in the growth in demand of the office infrastructure. Both the stock of server computers

Table 3. Overview of the development in electricity demand for ICT appliances and associated infrastructure in households and offices in Germany between 2001 and 2010

2001	Electricity demand (GWh)			
	Normal	Standby	Off-mode	Sum
ICT appliances in households	10 279	6 987	1 849	19 115
ICT appliances in offices	4 575	2 584	628	7 787
Household infrastructure	1 102	2 108	192	3 402
Office infrastructure	5 153	273	0,0	5 425
Infrastructure telecommunication	2 250			2 250
Total	**23 359**	**11 951**	**2 669**	**37 979**
2005				
ICT appliances in households	13 269	7 855	1 735	22 858
ICT appliances in offices	4 330	2 759	516	7 604
Household infrastructure	2 363	2 146	186	4 695
Office infrastructure	7 454	273	0	7 726
Infrastructure telecommunication	3 560	0	0	3 399
Total	**30 975**	**13 032**	**2 436**	**46 282**
2010				
ICT appliances in households	15 296	7 708	1 459	24 463
ICT appliances in offices	4 463	2 687	479	7 629
Household infrastructure	4 060	2 212	156	6 428
Office infrastructure	10 829	273	0	11 101
Infrastructure telecommunication	5 803	0	0	5 803
Total	**40 451**	**12 880**	**2 094**	**55 425**

and the average power consumption per unit will increase strongly[3]. The more moderate increase in the power demand of the household infrastructure can be attributed to both the television infrastructure (especially to the growth in digital set-top boxes) and the internet infrastructure (especially the growth of broadband internet connections). The slight fall in the power demand of office end-use appliances expected up to 2010 is mainly due to the more energy-efficient LCD monitors being substituted for cathode ray monitors, as well as the substitution of desktop-PCs by the more efficient notebooks. Among household end-use appliances, the electricity demand continues to grow for televisions (mainly caused by longer times of use in normal and standby mode and the trend towards devices with large screens and higher frequencies) and video recorders (caused by the growing diffusion of DVD players which, however, will only slowly substitute conventional video recorders), as well as for personal computers (caused by the use of increasingly powerful appliances with higher power consumption and longer operating times).

ENERGY DEMAND IN THE VARIOUS OPERATING MODES

The growth in energy demand is primarily caused by operation in normal mode. This is mainly attributable to the fact that the majority of ICT appliances and systems in the two strongest growing consumption sectors - office infrastructure and the infrastructure of telecommunication appliances - such as servers or mobile communications systems are operated almost exclusively in normal mode.

In the applications, in which the standby mode has a high share in the total electricity demand, namely among ICT end-use appliances and the household infrastructure, a clear increase can be registered at least up to 2005. Overall, the energy demand in this mode rises by 9.0% from 2001 to 2005. This is followed in the second half of the decade by a marginal drop by 1.2 or 0.2% per year according to the calculations. This is also a result of the efforts already undertaken to increase energy efficiency which specifically concentrate on this operating mode. However, the fact that the decrease is only marginal clearly shows that their effect is not sufficient to really substantially lower the power demand for the standby mode.

Only the power demand caused in the off-mode really decreases in the period under review by 21.6% from 2001 to 2010. The biggest share of this reduction in consumption is not due to an explicit increase in efficiency, but rather that the off-mode is replaced by a standby mode in several appliances up to 2010, especially televisions. This is an effect of new concepts of use resulting, for example, from digital video broadcasting. Independent of this, an off-mode loss of 2.1 TWh (or almost 0.5% of the expected total electricity consumption) in 2010 can still be assessed as too high from the viewpoint of energy efficiency and ultimately superfluous.

3. The energy demand for the air conditioning of server rooms which is also relevant in this context is not considered in this study since this does not involve ICT appliances directly. A range from 20 to 50% of the energy demand of the server is cited in the literature as being necessary for air conditioning (Roth et al. 2002; Koomey et al 1999). If a rather cautious value of 25% of the demand for IT appliances is assumed for Germany, and it is presumed that a small proportion of simple servers are not operated in air-conditioned rooms, then around 0.93 TWh have to be added to the above cited figures for air conditioning in 2001; in 2005 this increases to 1.9 TWh and 3 TWh in 2010.

ENERGY DEMAND IN APPLIANCE CLASSES

Examining the energy demand of ICT according to the classes of appliance considered shows that more than half the energy demand from 2005 is distributed over four appliance classes and over 80% is spread over 10 of 26 classes (see Figure 2).

The three appliance classes with the greatest energy demand – televisions, servers in offices and audio devices – already held their dominating role in 2001 and retain this throughout the whole period under review. The significance of the infrastructure of the mobile communications companies and the communications infrastructure in households rises steeply in contrast. Among the former, the construction of UMTS networks becomes noticeable, as mentioned above; in the households, the extension of broadband terminals and the appliances used here have the effect of increasing energy demand.

Options and potentials for the increase of energy efficiency of ICT

For the examination of the options and potentials of energy savings in the field of ICT, it is advisable to differentiate the three operating modes normal operation, standby and off-mode. Doing so allows more general conclusions to be drawn for the standby and the off-mode for most of the ICT equipment whereas the technologies vary to such an extent in normal operation mode that the analysis has to be performed here on the level of appliances. Apart from technology-driven options to increase energy efficiency, behavioural changes and modified usage patterns can also play a role, for example, switching off office equipment regularly at the end of work, or switching PCs, screens, printers and copiers into power saving mode when not directly in use. Similar options exist for household appliances where turning appliances off or using switchable multiple socket outlets can contribute to the reduction of energy demand. In principle the technical savings potentials are estimated to be larger than behavioural driven potentials (Brohmann et al. 2000; Böde et al 2000b) so that the focus of the analysis will be on the technology options.

OPTIONS AND POTENTIALS IN OFF-MODE

As the off-mode has been defined as the mode where the appliance does not fulfil any function, is switched off, but still draws power, there are technical options to completely avoid the power demand occurring in this mode. Basically the total savings potential is as large as the total power demand in off-mode. The projected demand in off-mode decreases slightly from 2.7 TWh in 2001 to 2.1 TWh in 2010 (see Table 3), so consequently the savings potential falls in relation to this. Still this energy demand is superfluous and should be reduced further or completely avoided. Several options exist to do so:

- off-mode losses can be avoided by behavioural measures of the user. The first to be stated is the use of switchable multiple socket outlets, with which appliances can be switched off completely. The (one-time) purchasing costs will be recovered in avoided electricity costs in a time period ranging from 1.5 years for appliances with high consumption to 20 years in less favourable cases.
- Naturally, the off-mode loss could be avoided by manufacturers equipping their products with switches that disconnect completely from the grid. The main reason for using switches on the low voltage side which do not disconnect the power supply unit from the grid is the lower cost. The acquired cost information suggests that this option would be less expensive than using switched multiple socket outlets. However the manufacturers would have to bear the costs without direct benefit apart from possible advantages in marketing their products.

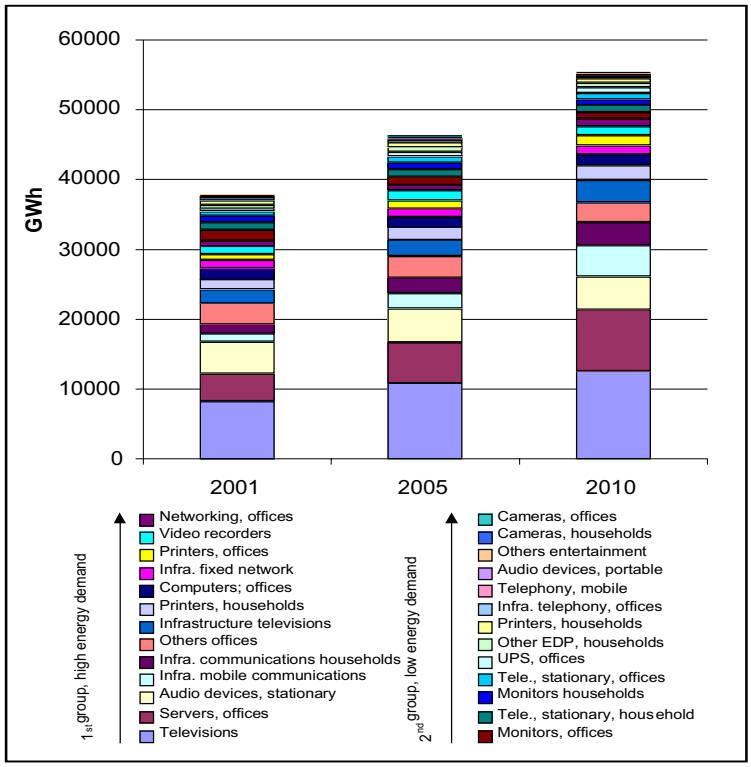

Figure 2. *Energy demand of ICT according to appliance types*

OPTIONS AND POTENTIALS IN STANDBY MODE

Completely disconnecting ICT-appliances involves a loss of convenience in many cases – e.g. losing the option to switch the appliance on again with the remote control – or it is not advisable because equipment settings such as the internal clock or the programming could be lost. In future, with digital services that are supplied by multi-media appliances, a permanent exchange of data with the internet could prevent equipment being switched off completely. For these appliances, the most important saving option is to equip them with energy efficient circuits for the power supply in standby operation. If fitted with a separate circuit for standby operation, the power draw of appliances can be reduced to less than 0.5 W, as long as only simple functions like an internal clock or the preservation of an internal memory have to be fulfilled. If more complex functions have to be fulfilled in standby mode, the energy consumption cannot be reduced as much solely by adjusting the power supplies.

Table 3-1. Savings Potentials from Increased Energy Efficiency in Standby operation (GWh per year)

	2005		2010	
	GWh	%	GWh	%
ICT end-use appliances in private households	2 090	27%	3 080	42%
Audio-appliances	540	24%	860	42%
TV, video	960	36%	1 250	53%
Telephony	230	20%	320	30%
Computers and peripherals	210	18%	400	30%
others	150	26%	250	41%
Infrastructure in private households	260	12%	490	21%
TV infrastructure	140	10%	310	22%
Internet and telecommunication infrastructure	120	15%	180	20%
ICT end use appliances in offices	260	9%	450	17%
Telephony	100	14%	190	26%
Computers and peripherals	80	10%	170	21%
others (above all copiers)	80	6%	90	8%
Total savings potentials in standby mode	2 610	20%	4 020	32%

Source: own calculations

The savings potentials in standby operation were elaborated by modifying the assumed power consumption in this mode. Depending on the type of appliance, varying achievable values have been estimated for new appliances. Generally, for those with simple functions in standby mode, a power consumption of 0.5 W was assumed. For those with more complex functions, either best practice examples were chosen or own estimations made. In addition, the stock replacement rate by new appliances was taken into account. Table 3-1 gives an overview of the determined savings potentials on this base until the year 2010. Overall the potential in the year 2010 is estimated to be around 4 TWh which represents almost one third of the electricity demand in this operation mode. The end-use devices in households account for roughly three quarters of the 4 TWh, the rest is distributed more or less evenly between the end-use devices in offices and the infrastructure in households.

OPTIONS AND POTENTIALS IN NORMAL OPERATION

Unlike the savings options and potentials in the off-mode and standby mode, where general findings can be derived for a large share of ICT appliances, the investigation of the normal operation mode requires a detailed analysis of the individual classes of appliances due to the wide variety of technical conditions. In normal operation, first of all those appliances were examined, which account for a prominent part of the total energy demand of ICT appliances in this mode in Germany. A good way to estimate savings potentials is to identify best practice examples for these appliances. As long as their benefit is comparable to that of average appliances in stock, the difference in specific power consumption in normal operation per year can be assessed as the savings potential resulting from use of best practice equipment.

In detail the following relevant savings potentials were identified for the normal operation mode:

- *TVs*: 1 TWh for the year 2005 and almost 3 TWh for the year 2010 achievable by quicker substitution of cathode ray tube TV sets by LCD TVs or almost 1 TWh in 2010 if at least a stronger diffusion of best practice CRT TV sets can be achieved.
- *Server computers:* between 50 to 60 GWh per year by switching off server computers overnight in small and medium enterprises.
- *Infrastructure of mobile communication:* savings options exist in the reduction of the energy demand for cooling and aeration in the base stations and in limiting the number of base stations.
- *Personal computers:* 600 GWh resulting from the energy efficient design comparable to the design of notebook computers including the use of mobile CPUs, which are however significantly more costly than the desktop models.

Conclusions

The analysis of ICT energy consumption in Germany resulted in a energy demand of 38 TWh for the year 2001, representing 8% of the total end-use of electricity. This energy demand will increase by 45% to as much as 55.4 TWh. The development of the direct energy consumption of ICT will therefore not contribute to fulfilling the obligations under the Kyoto Protocol. Although savings potentials were able to be identified amounting to the order of 10 TWh, there is reasonable doubt whether these will be exploited to a significant extent. Furthermore the energy increase of infrastructure components will be outstanding, a field where few options for improving energy efficiency could be quantified or even identified. Hence continued research in these fields seems advisable.

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