EUROPEAN PARLIAMENT

*Science and Technology Options Assessment*

S T O A

# Assessing the potential of ICT to increase energy efficiency and fight climate change - key technologies and prospects

## STUDY

(IP/A/STOA/FWC/2005-28/SC43)

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EUROPEAN PARLIAMENT

DIRECTORATE GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT A: ECONOMIC AND SCIENTIFIC POLICIES

SCIENCE AND TECHNOLOGY OPTIONS ASSESSMENT

# Assessing the potential of ICT to increase energy efficiency and fight climate change - key technologies and prospects

## STUDY


**Abstract**

In order to combat climate change the EU has set the aim of a 20% reduction of $CO_2$ emissions by 2020. This aim only seems achievable if a reduction in energy consumption supported by energy efficient technologies takes place. In principle, many innovative technologies are strongly linked with Information and Communication Technologies (ICT). Regarding the impact of ICT on climate change two different aspects can be distinguished. On the one hand, ICT is discussed as a technology that enables an increase in energy efficiency, a reduction of energy consumption, as well as a reduction of greenhouse gas (GHG) emissions in general. On the other hand, ICT are an energy consumer themselves. This STOA project aimed at assessing the net impact of ICT on energy efficiency/GHG emissions on the basis of data available in the literature and in technical documents. The main focus was on energy efficiency and energy consumption, but other sectors were examined as well. Results were validated by external experts.

This report illustrates that ICT is a crucial enabling technology for the mitigation of climate change. Various ICT-applications in different sectors enable energy savings, increased energy efficiency and a reduction of GHG emissions. In four selected areas, the relevance of ICT for the reduction of GHG emissions was elaborated in more detail: Electricity distribution grids (smart grids); Smart buildings, smart homes and smart metering; Transport and dematerialisation; Industrial processes and organisational sustainability. For all four selected areas significant technological progress and organisational innovations with strong relation to ICT are expected to further tap energy saving potentials in the next decades. It is shown in the report that the saving potentials related to ICT as enabling technology in these four key-areas is by far larger than the approx. 2% stemming from ICT as an energy consumer. The net effect of ICT on climate change is clearly positive. Support of ICT as well as its consequent implementation and development is essential for combating climate change.



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## DISCLAIMER

# Executive Summary

In order to combat climate change the EU has set the aim of a 20% reduction of $CO_2$ emissions until 2020. This aim only seems achievable if a reduction in energy consumption supported by energy efficient technologies takes place. In principle, many innovative technologies are strongly linked with Information and Communication Technologies (ICT). Regarding the impact of ICT on climate change two different aspects can be distinguished. On the one hand, ICT is discussed as a technology that enables an increase in energy efficiency, a reduction of energy consumption, as well as a reduction of greenhouse gas (GHG) emissions in general. On the other hand, ICT have become a significant energy consumer themselves.

The overall contribution of ICT (as energy consumer) to climate change is estimated to be around 2%. However, future growth rates in ICT are expected to be impressive, especially in the emerging countries, so the potential as well as the need for further savings will also increase. Recently, the heavily growing amount of energy consumption induced by ICT has attracted a lot of attention. The terms "Green computing" or "green ICT", both referring to environmentally sustainable computing or ICT, is mentioned quite often in newspapers as well as in technical reports and scientific journals. Taking up these discussions, this report on the potential of ICT to increase energy efficiency and fight climate change illustrates GHG saving potentials in PCs and Server farms. Further, a focus is put on new and promising concepts such as virtualisation and "cloud computing". Reasons for this selection are the fast global growth rates in PCs, server farms as well as the strong global tendency to use more and more the Internet and Internet- based applications.

ICT as an enabling technology for the reduction of GHG emissions is of even more complex nature, many relevant linkages are more implicit. This report illustrates that ICT is a crucial enabling technology for the mitigation of climate change. Various ICT-applications in different sectors enable energy savings, increased energy efficiency and a reduction of GHG emissions. In four selected areas, the relevance of ICT for the reduction of GHG emissions was elaborated in more detail:

- Electricity distribution grids (smart grids);
- Smart buildings, smart homes and smart metering;
- Transport and dematerialisation;
- Industrial processes and organisational sustainability.

For all of the four selected areas significant technological progress and organisational innovations with strong relation to ICT are expected to further tap energy saving potentials in the next decades. Many advanced approaches and visions are discussed:

- Electricity grids are supposed to become intelligent systems with flexible, controlled power flows supported by advanced information technology (EC 2006c). They will enable decentralised generation of energy and a high share in renewable energies;
- Smart meters will help in tapping energy saving potentials in smart homes; in addition, ICT-based "personal agents" might assist the user in all daily routines including saving energy;
- In the transport sector trips could be avoided by virtual meetings; intelligent transport systems will enable an highly efficient transport system;

- In the industrial sector measuring and control technologies together with the corresponding software are crucial to realise potentials for saving resources. Probably the most striking saving potential that is strongly linked to ICT can be identified for electric motor efficiency in industrial processes. But also rather "holistic" approaches for companies are being discussed.

Regarding several applications, for example in smart homes or in intelligent transport, it is likely that further penetration of daily routines by ICT, a trend that is also named "ubiquitous computing", will pave the way for more interest in, acceptance of and willingness to pay for ICT-based solutions.

It is shown in the report that the saving potentials related to ICT as enabling technology in these four key-areas is by far larger than the approx. 2% stemming from ICT as an energy consumer. For example, the Climate Group calculates in the SMART 2020 report, that, in total, ICT could deliver 7.8 Gt $CO_2e$[1] emission savings in 2020, which represents 15% of global GHG emissions in 2020 (based on a BAU estimation; The Climate Group 2008, 9). Still, it can be stated that there is a broad uncertainty on the reliability of data since ICT are in general embedded in complex systems which makes it difficult to isolate their effect. However, in this project many studies have been analysed and discussed with experts. On this basis it can be concluded, that the energy consumption of ICT is relatively small compared to the potential of ICT as an enabling technology. The net effect of ICT on climate change is clearly positive. Support of ICT as well as its consequent implementation and development is essential for combating climate change. ICT is indispensable for decoupling economic growth from GHG emissions. Because of the impressive expected growth rates in ICT applications, especially in emerging countries, it is important to focus as well on tapping the full potential for the reduction of energy consumption induced by ICT. This would even improve the clearly positive net balance of ICT on Climate Change.

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[1] $CO_2e$ is an abbreviation of "carbon dioxide equivalent" and is the internationally recognised measure of greenhouse gas (GHG) emissions. Using $CO_2e$ as a measure of greenhouse gas emissions allows the comparison of the greenhouse impact of a variety of greenhouse gases.

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# 1. Motivation and Background

After the publishing of the last IPCC report on climate change in January 2007 there are nearly no doubts left regarding an upcoming period of global warming. It is evident that the reasons are the greenhouse gas (GHG) emissions induced by human activities. Furthermore there is broad consensus that combating climate change effectively is not possible without technological innovations. As Figure 1 illustrates, around 80% of EU15 Greenhouse gas emissions stem from energy related activities (in Figure 1 the categories “energy without transport” and “transport”). This underlines the strong relationship between climate change and energy technologies.

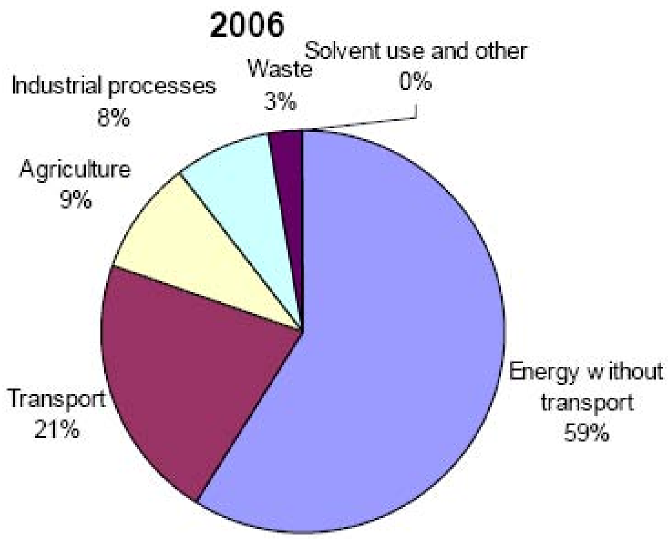


**Figure 1: Sector shares of total Greenhouse Gases (GHG) 2006 in the EU-15**

(Source: EEA 2008a; Graphic taken from EEA 2008b)

Nowadays, amongst the most important technological developments for social welfare, economic growth and environmental protection are at least the following two:

1. Technologies for the generation, conversion and distribution of energy
2. Information and Communication Technologies (ICT)

For several decades these two technological streams have been pursued in isolation. This is not the case anymore. Especially in the industrialised countries ICT supported high-tech solutions are gaining more and more importance for domestic application but also from an export perspective. In principle, many innovative technologies are strongly linked with ICT applications. Energy technologies are increasingly interwoven with developments in the ICT sector. In addition, with ICT penetrating all dimensions of everyday life, energy issues are gaining increasing importance since ICT is an energy consumer itself.

In view of this it becomes clear that information and communication technologies (ICT) are a key-technology when it comes to climate-relevant innovations. Regarding energy efficiency, the European Commission states in a recently published Communication (EC 2008): "Information and Communication Technologies (ICTs) have an important role to play in reducing the energy intensity and increasing the energy efficiency of the economy, in other words, in reducing emissions and contributing to sustainable growth".

It can be observed that successful environmental technologies do not only bring benefits to the environment but also have the potential to strengthen an economy. The European Commission also puts emphasis on this point in an optimistic way: "ICTs will not only improve energy efficiency and combat climate change; they will also stimulate the development of a large leading-edge market for ICT enabled energy-efficiency technologies that will foster the competitiveness of European industry and create new business opportunities" (EC 2008).

There are at least two different perspectives that can be applied regarding the relationship between ICT-applications and climate change: On the one hand, ICT is an energy consumer. This amount is growing rapidly with one important reason being the increasing use of ICT (PC, internet, consumer electronics etc) in the newly industrialising countries. It is estimated that the ICT industry accounts for approximately 2% or even more of global $CO_2$ emissions (Gartner 2007)[2].

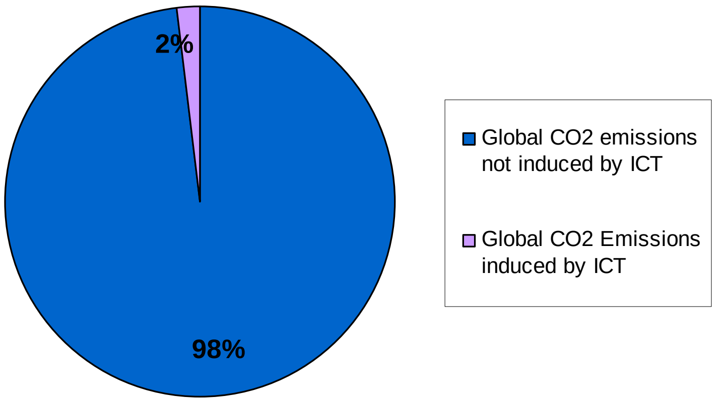


**Figure 2: Contribution of ICT to $CO_2$-emissions on global scale**

So, on the other hand, the potential for ICT to address the other 98% is striking (Figure 2; see WEF 2008): ICT is more and more considered as being an enabling technology for saving energy, increasing energy efficiency and reducing the emissions of GHG. Many experts see ICT as a key-element for the transition into a low-carbon society (WEF 2008; Collard et al 2005).

[2] Gartner's estimate of the 2% of global $CO_2$ emissions that ICT is responsible for includes the in-use phase of PCs, servers, cooling, fixed and mobile telephony, local area network (LAN), office telecommunications and printers. Gartner has also included an estimate of the embodied (that used in design, manufacture and distribution) energy in large-volume devices, namely PCs and cell phones. It also included all commercial and governmental IT and telecommunications infrastructure worldwide, but not consumer electronics other than cell phones and PCs. (Gartner 2007: http://www.gartner.com/it/page.jsp?id=503867. )

This differentiation is basically in line with the one proposed and applied by ETNO and WWF in a joint report (see Pamlin, Szomolanyi 2008), where the following differentiation is made between

- direct effects which are caused by ICT infrastructure and equipment; these effects are supposed to have a small impact and are relatively easy to measure;
- indirect effects, related to the existing use and habits enabled by ICT application; they are supposed to have significant impacts and they are hard to measure;
- and systemic effects that link performance at the micro level (e.g. organisational level) with economic, environmental, or social conditions at the macro level (e.g. regional, national, or global level). These effects are supposed to have a very big impact.

In this STOA-project, the direct effects are subsumed in the section on ICT as an energy consumer, whereas, for simplification, the indirect effects together with the systemic effects are dealt with in the section on ICT as an enabling technology. This is also done because it is not always easy to distinguish between indirect effects and systemic effects.

The overall objective of this project is to contribute to a better understanding of the net impact of ICT on energy efficiency/GHG emissions and to offer an assessment of future technical innovations of high relevance in this context. This was done by literature review and expert interviews. The project was carried out in two phases:

1. Phase I: General scoping and selection of the most relevant areas for the impact of ICT on energy efficiency and GHG emissions. A list of selected areas and promising technologies was validated by expert interviews. The selection was discussed and approved at a joint workshop of the CLIM Committee and STOA held on 15 January 2009.
2. Phase II: Promising ICT-technologies and innovations in the selected areas were described in greater detail.

This is the final report of the project. As indicated above, it highlights the most promising technologies in the selected areas. The description of each of the key-areas is structured along the following rubrics:

- Technological options and visions
- Expected reduction in GHG emissions
- Central controversies and open questions

According to the differentiation made above, Chapter 2 deals with ICT as an enabling technology for the reduction of energy consumption and GHG emissions while Chapter 3 is focused on ICT as an energy consumer.

It should be noted that assessing the impact of ICT on the environment in general as well as on energy consumption in particular is a highly complex task. As indicated in Footnote 2, the energy consumption for nearly all phases of the life cycle of ICT components is covered by the Gartner estimations on $CO_2$ emissions induced by ICT. Not explicitly covered is the energy used for treating ICT-waste. Because of the multitude of substance and elements in the hardware and the different options to deal with it (for example recycling or non-recycling; disposal or incineration) reliable estimations are difficult in this field. However, such calculations could add a little to the $CO_2$ emissions induced by ICT.

The focus of this study is on the potential of ICT to increase energy efficiency and fight climate change. But it should be mentioned that there are significant effects on the quality of the environment that can hardly be related to energy efficiency and climate change. Especially the release of hazardous substances from ICT waste is an important issue. In this context, Gartner states that more knowledge is needed regarding the lifecycle analyses of ICT components. "According to Gartner, the ICT industry needs to gain a better understanding of the full life cycle of ICT products and services, and innovate to reduce environmental impact. This does not currently happen because of the lack of a commercial or legislative need to do so"[3]. However, interesting approaches can be observed in this field. For example, the European Project EPIC-ICT is about developing a methodology to define environmental performance indicators for ICT products on the example of PCs (see www.epic-ict.org). EPIC-ICT considers all life cycle phases and all relevant environmental impacts, including energy related aspect. Policy recommendations in this area are proposed in Erdmann et al. 2004. Among them are: providing incentives for producers to design and sell ICT products with long life-span; implementing the WEEE[4] Directive more effectively; extending the depreciation time for ICT equipment.

Furthermore, the project concentrates on GHG emissions and, thus, on the mitigation of climate change. To be sure, ICT is also a crucial technology to the adaptation to climate change. But this is a wide field touching highly different applications. It is not possible to deal with these aspects in this project.

[3] (http://www.gartner.com/it/page.jsp?id=503867.)

[4] Waste Electrical and Electronic Equipment. EU legislation restricting the use of hazardous substances in electrical and electric equipment (Directive 2002/95/EC) and promoting the collection and recycling of such equipment (Directive 2002/96/EC) has been in force since February 2003.

## 2. ICT as an Enabling Technology

The main purpose of this chapter is to describe in a structured way areas where ICT-applications can be considered as an enabling technology to reduce energy consumption and/or GHG emissions.

According to the European Environmental Agency (EEA 2008b) in 2006, the total GHG emissions in the EU27, excluding net $CO_2$ removals from land-use, land-use change and forestry (LULUCF), were 5143 Mt $CO_2$-equivalent. So, the EU27 accounts for about 10.5% of global GHG emissions. But the global GHG-saving potential resulting from technologies applied in the EU is in principle not restricted to these 10.5%. Many examples illustrate that the environmental effect of technologies that are developed and implemented is not at all restricted to one region, since other countries or regions might adopt the same technology and with it the corresponding environmental effects.

Figure 3 shows that by far the most relevant GHG gas coming from European sources is $CO_2$ whereas the share of $CH_4$ is 8.2% and the one of $N_2O$ is 7.6%.

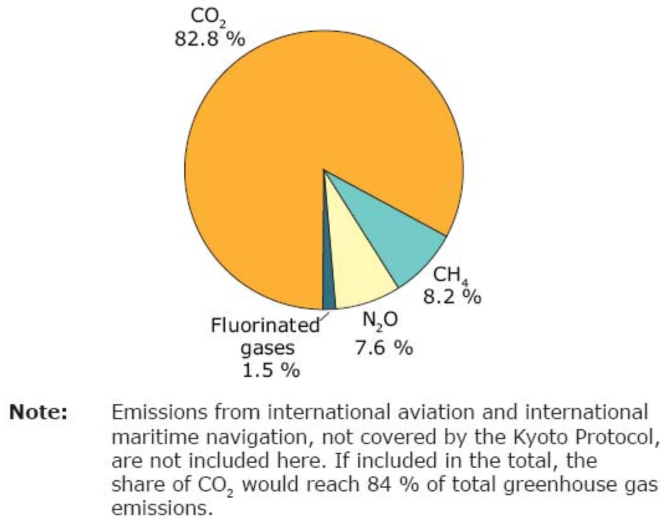


**Figure 3: Share of 2006 greenhouse gas emissions in the EU-27, by gas**

Taken from EEA 2008b; Source: EEA 2008a

Figure 4 illustrates the share in GHG contribution of different sectors in the EU27. This is useful since it makes clear that a huge variety of sources for GHG emissions exist. In all these categories ICT is involved to some extent. So, already a brief look makes it obvious that a huge variety of rather different ICT applications can be linked to GHG-relevant processes or products. The result is a highly complex picture which gives room for wide possibilities to categorize technologies or fields of activities.

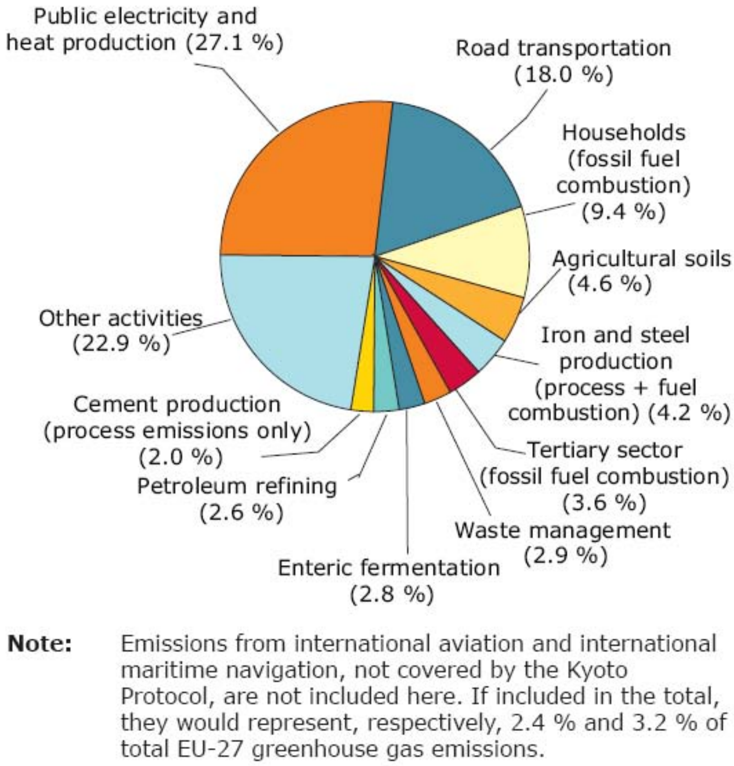


**Figure 4: Share of 2006 Greenhouse Gas emissions in the EU-27, by main activity**

Taken from EEA 2008b; Source: EEA 2008a

In the following, for orientation and as a point of reference we therefore will use a more simplified categorisation, which has already been presented in Figure 1 and is again presented here in Figure 5. This data is only related to the EU15. However, according to the European Environmental Agency (EEA 2008b) in 2006, the EU15 accounted for 81% of total EU27 GHG emissions (in comparison to 79% of the whole EU27 population). The five largest emitters of GHG emissions were all EU15 member states: Germany, the United Kingdom, Italy, France and Spain. Together, they accounted for more than 60% of the EU27 GHG emissions. Poland was the largest emitter in the EU12.

The shares indicated in Figure 5 are only a rough and weak indicator for the saving potentials that might be tapped by ICT. However, it is rather simple but clear that for applications in Europe these saving potentials are at least limited by the overall contribution of the distinctive sectors. This amount varies considerably, e.g. for energy it is 59%, whereas for waste it is only 3%. Generally, there is a high amount in energy related emission (80% in 2006, if transport is included). An export of technologies developed and implemented in Europe might lead to additional potential for saving in other regions outside the EU (see Chapter 2).

Figure 6 illustrates the share of the most relevant emissions in 2006. It becomes obvious that $CO_2$ emissions are dominated by energy use and transport. Energy use is also responsible for a significant share in $CH_4$ emissions, but waste and agriculture are the most important sources here. Agriculture is clearly dominating $N_2O$ emissions.

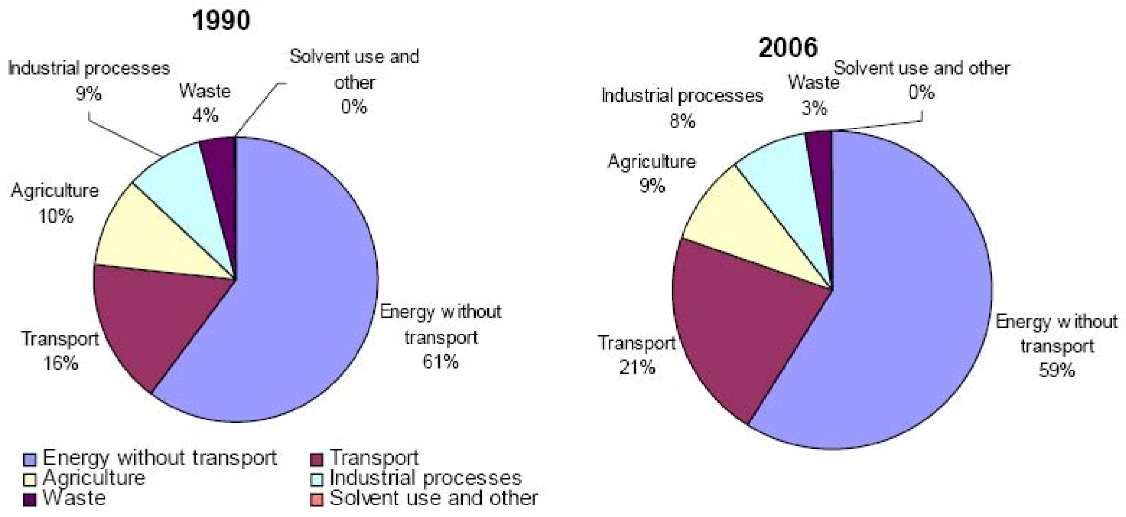


**Figure 5: Sector shares of total greenhouse gases in 1990 and 2006 in the EU-15**

(Source: EEA 2008a; Graphic taken from EEA 2008b)

It was mentioned in the chapter before that in Phase I of this project the focus was on a general scoping related to linkages between ICT and climate change as well as on a selection of the most relevant areas for the impact of ICT on energy efficiency and GHG emissions. A list of selected areas and promising technologies was compiled. On basis of the sectors used in Figure 5 and 6, this list was structured along the following 6 categories:

1. **Electricity distribution grids (smart grids)**
2. **Smart Buildings and smart metering**
3. **Transport and dematerialisation**
4. **Industrial processes and organisational sustainability**
5. Waste
6. Agriculture

This list of promising categories was validated by expert interviews. As a result, it was recommended to concentrate in Phase II of the project on the first four sectors, since these seem to be those with the most interesting potential in context of ICT and climate change. The selection was discussed and approved at a joint workshop of the CLIM Committee and STOA held on 15 January 2009. So, in this chapter about ICT as an enabling technology for the reduction of GHG emissions, promising ICT-technologies and innovations in the four selected areas are described in greater detail.

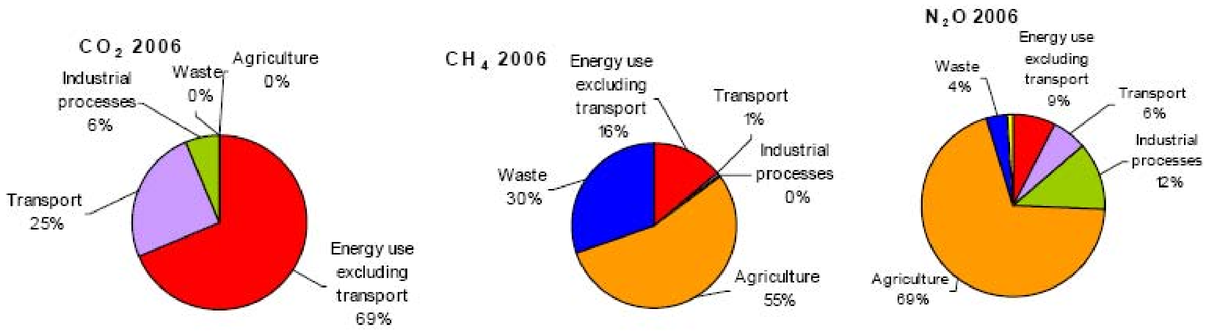


**Figure 6: Sector shares of total $CO_2$, $CH_4$ and $N_2O$ emissions in 2006**

(Source: EEA 2008a; Graphic taken from EEA 2008b)

Not further discussed in detail in this report are the following linkages between ICT and GHG emissions:

- **Waste disposal**: Considerable amounts of $CH_4$ are emitted from waste disposal sites. A substantial reduction in $CH_4$ emissions from waste management can be achieved by reducing the amount of landfilled waste and by requiring the capture of $CH_4$ emissions from landfills, for example for energy generation. ICT could be used to support the management and organisation of related measurements. However, not much information on the relevance of ICT for climate-friendly waste disposal can be found in literature. The linkage between ICT and waste disposal in most cases is discussed in the context of electronic waste. This is a serious problem but goes beyond the scope of this study.
- **Agriculture** is relevant for energy consumption and in particular also for non-energy related GHG emission such as $CH_4$ and $N_2O$. A key concept in this context surely is “precision farming” which is related to optimising farming processes supported by ICT applications. There should be a potential to reduce the usage of fertilisers and, thus, $N_2O$ emissions. However, it is not really clear to what extent climate-relevant saving potentials can be realised or if rather an increase in earning for agriculture is the main benefit (see IPCC 2007; Smith et al. 2008). The chain from ICT applications via agriculture to climate change is not discussed as a key element for realising GHG saving potentials. A linkage could be created by taking into account monitoring activities that are enabled by ICT applications (satellite systems). This might be used to better control deforestation and related activities. But still, this is a rather complicated process. Deforestation is an important source of GHG emissions. Plants are able to incorporate $CO_2$. If forests are burned this leads to a release of $CO_2$.
- **Geo-engineering:** The term Geo-engineering subsumes a wide range of technologies to deliberately manipulate the climate to counteract global warming. These include direct methods (e.g. carbon dioxide air capture) and indirect methods (e.g. ocean iron fertilization). Some of these technologies are quite uncomplicated from a purely technological point of view, such as fertilising the ocean or the production of stratospheric sulphur aerosols.

- But here, ICT is indispensable in terms of modelling processes and potential effects. Far reaching databases together with advanced computer models are urgently needed to assess these highly controversial and sensitive issues. Others technologies are based on high-tech solutions such as capturing $CO_2$ from power plants and industrial processes in order to store it under the earth (CCS). Here, ICT is needed directly in the technical process.

## 2.1 Electricity Distribution (smart grids)

### Technological options and visions

The development of smart grids and the concept of smart buildings (Chapter 2.2) overlap and are linked to each other. Whereas smart buildings are strongly related to the consumer side, "smart grids" are in particular related to the generation and distribution of energy. However, it is a central element of the smart grid vision that consumers might also become suppliers (by installing photovoltaic, for example). In addition, the equipment of consumers with so-called "smart meters" is important for the concept of smart grids. Still, the focus of this chapter is on the supply and generation of electrical energy whereas the next chapter (2.2) will deal with energy consumption in buildings, and thus place more emphasis on the "conventional" demand side.

In the last decade, "smart grid" has become quite a prominent term and is discussed as a key-technology or a combination of key-technologies for the integration of larger amounts of fluctuating and decentralised renewable energy sources in the future energy system. The idea is that smart grids (or intelligent grids) deliver electricity from suppliers to consumers using ICT. All elements of the network (producers and consumers) should be able to exchange information to guarantee an optimised co-ordination in order to save energy, reduce cost and increase reliability and transparency of the system. Furthermore, ICT is understood as an enabling technology for the liberalisation of European energy markets and as such, again, linked to a potential increase in energy efficiency (see EC 2006b).

According to the political agenda of the EU and many of its member states the share of renewable energy sources will be considerably increased in the next decades. Since many of these sources are of a fluctuating nature (e.g. wind and photovoltaics), the challenge is to integrate these sources into the grid. For the necessary near real-time monitoring and control of the grid the application of ICT is indispensable. Smart grids should involve a two-way flow of voltage as well as of information between generators and users to improve energy monitoring and data capture across the entire network. In doing so, smart grids in combination with smart metering make near real-time information on energy consumption and energy prices available. This is of special importance against the background that today's energy systems were designed in times when oversupply was needed to guarantee that enough power was available (WEF 2008). The availability of relevant data and near real-time information is the basis for a reliable predictability of energy consumption. Predictability is of utmost importance, not only in relation to energy consumption but also for the supply side, in particular when increasing amounts of renewable energy will be integrated into the power generation.

Two-way interactions make the management of the grid easier for grid operators, as they have a clearer overview of the processes taking place in the network and of the power downloaded or uploaded. Suppliers can offer their customers more flexible rates, and customers can be alerted to price signals so they can shift their consumption of energy to low-load times and profit from lower tariffs (www.e-energie.info). Furthermore, in relation to electric mobility, there is the concept that plug-in hybrid vehicles offer the ability to buy energy when it is inexpensive, store it in their batteries and sell it back to the grid when the price is going up.

So, there is the idea that price signals can be used to make load profiles more balanced, by shifting load away from peak hours. The idea is that a smart grid enables, for example, intelligent washing machines in smart buildings to start working, when the energy is cheap.

The concept of integration and linking-up of distributed power generation is also labelled 'virtual power plant' (see Figure 7). With an aggregation of distributed generators and loads, a virtual power plant can participate in electricity markets and provide ancillary services. A related and in the meantime also quite popular term is 'Internet of energy'. The underlying vision is an intelligent electronic linking-up of all components of the energy systems. This affords successful co-ordination and integration of all components as well as a harmonised infrastructure for communication (see BDI 2008). Both terms, virtual power plant and Internet of energy, underline that intelligent co-ordination and steering supported by ICT is the backbone of such clusters of distributed power installations.

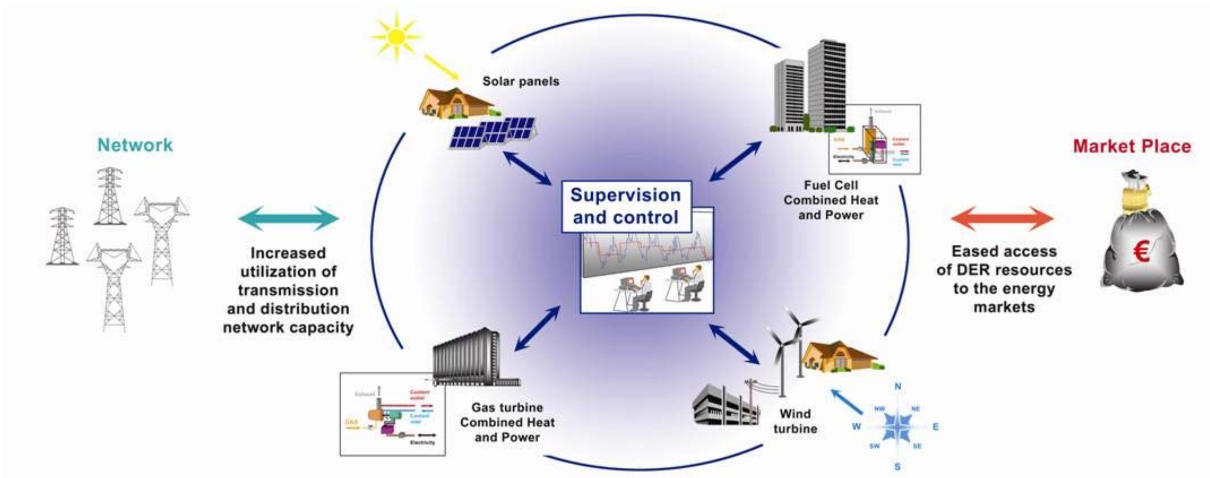


**Figure 7: Sketch of a system of decentralised energy resources (DER) connected by a smart grid.**

(source: European Project fenix; http://www.fenix-project.org)

In 2007, the European Commission presented the European Strategic Energy Technology Plan (SET-Plan) to expedite and coordinate the development and implementation of low carbon and energy-efficiency technologies (EC 2007). As a part of the SET-Plan, the transition of traditional European energy infrastructure networks and systems plays an important role in reaching European's energy targets. The objectives of the transition are to integrate the various energy systems across Europe, and finally achieve flexible, accessible, reliable and sustainable electricity networks. In this context, the concept of smart grid was promoted. A smart grid technology platform was proposed by stakeholders and also supported by the European Commission (SmartGrid 2008). In the USA, a similar approach is named GridWise. As for smart grid in Europe ICT plays a-key role for the GridWise concept (see Nair et al. 2009).

Coll-Mayor et al. (2005) summarize the similarities between the European Smart Grids concept and GridWise: “The similarities between these two visions are obvious, both of them are based on integrating new information and communications technologies, combining them with active support from electricity consumers, and leveraging the optimizing power of markets, to focus on creating an affordable and reliable power grid.” However, clear differences between the two concepts can be identified as well: Europe is strongly focused on creating a distributed environment, with a large penetration of renewable energy sources (RES) and decentralised generation (DG), while the US envisions large power stations based on clean coal technologies, where the inclusion of DG is perceived primarily as an increment in the security of the system (Coll-Mayor et al. 2005). Thus, in the USA less focus is put on decentralised generation compared to the vision formulated in the European Strategic Energy Plan where as one of several key-technology challenges for Europe to meet the 2020 targets is: “Enable a single, smart European electricity grid able to accommodate the massive integration of renewable and decentralised energy source” (EC 2007).

As indicated above, two-way interactions in a smart grid is expected to encourage home and business owners to install their own renewable sources of energy, such as photovoltaic, solar thermal, wind power or biomass. This is also discussed for non-renewable devices, such as natural gas generators with heat reclamation. Micro-generation technologies are becoming affordable for residential, commercial and industrial customers. In this context reference should be made to the broad discussion on distributed or decentralised generation of power that is going on in Europe (see also Pepermansa et al. 2005; BMVIT 2009). One main trigger for this discussion is that several environmentally friendly technologies are operated at small scale and have to be attached to the grid at low voltage levels close to the load (Vogel 2009). Another trigger is the need for investment in end-of-life grid renewal in an innovative way to better position the networks for the next 50 years of operation (EC 2006c).

In general, primary energy can be used more efficiently through the combined generation of heat and power. An efficient option for the supply of electricity and heat can be found in the use of local combined heat and power plants (CHP Plants). For example, the stationary fuel cell is discussed as a promising approach in this context. In general, such fuel cells are driven by hydrogen which – up to now – usually is produced stationary from natural gas. A study by Droste-Frank et al. (2008) concludes that fuel cell plants are particular promising in the area of small electric power units. They produce heat and electric power. Compared to other CHP they offer a higher yield of electric current per amount of fuel used. An interesting option is the integration of micro-CHP facilities in form of a virtual power plant. Large benefits are expected from a centralised control of this web of small power plants. The idea is to couple several thousand of such small power plants which mean that the control system has to cope with an immense amount of data. Again, this illustrates, that ICT applications are a highly crucial technology in this field.

Apart from that, there is the notion of monitoring power transmission lines (in particular temperature) to enable increased power transmission capacities. A higher share in renewable electricity generation should be enabled this way. For example, E.ON, a German energy transmission system operator recently presented interesting results from a one year field-test focused on increased wind power penetration (see WWF 2008).

In the paragraphs above, most of the expected benefits of smart grids are already indicated (see www.fenix-project.org; WEF 2008):

- They should enable cost effective large scale integration of renewable energies while maintaining system security;

- They should allow higher shares in fluctuating renewable sources and open the energy markets to small scale, decentralised actors;
- They should encourage home and business owners to install their own renewable sources of energy;
- They should encourage manufacturers to produce "smart appliances" to reduce energy use;
- They should be able to reduce peaks in power usage by automatically turning down appliances in homes and offices;
- On the basis of near real-time information they should reduce waste by offering better knowledge on how much energy is being used;
- They should sense and prevent power blackouts before they occur;
- They should allow a better predictability of load profiles for energy suppliers;
- Consumers should be able to monitor their energy consumption and realise saving potentials (see chapter on smart buildings);
- In connection with energy markets and corresponding price signals they should be able to induce load shedding or load shift to off-peak hours.

### Expected reduction in GHG emissions

It was illustrated above that the generation, distribution and use of energy is by far the strongest contributor to GHG emissions. In Figure 5 it is shown that 59% of GHG emissions result from the use of energy (excluding transport). In the year 2005 on a global scale about 18235 TWh electrical power was used. The demand for electrical energy is expected to rise strongly in the coming decades. According to different estimations it might be two times or even four times higher than it was in 2005 (see BDI 2006). These figures illustrate that efficient technologies are needed.

There are huge GHG saving potentials in this field by saving energy but also by substituting fossil energy sources by renewable ones. It can be stated that ICT clearly plays a key-role for the integration of renewable energy and for tapping corresponding potentials for GHG savings. The amount of saved GHG emissions depends on various interrelated factors: the reduction in consumption, increase in efficiency as well as on the share and the character of renewable energy that is integrated into the grid. A possible electrification of the transport system might further increase the power demand.

Thus, it is difficult to give reliable figures for what can be saved by the implementation of a smart grid. It depends on many different factors and on interactions between these factors. But it can be stated that smart grids are urgently needed to enable the integration of renewable sources and to tap various potentials for making the energy system more efficient.

| | Projection of installed wind power capacity 2020 [MW] [85] | | | ICT-enabled wind capacity growth 2010 - 2020 [MW][86,87] | | | Emission reduction through ICT-enabled wind power 2020 [MtC02][88] | | |
|---|---|---|---|---|---|---|---|---|---|
| | low | Medium | high | low | Medium | high | low | Medium | high |
| OECD North America | 43,304 | 166,855 | 283,875 | 2,650 | 13,776 | 24,824 | 3.7 | 19.2 | 34.6 |
| OECD Europe | 142,000 | 175,400 | 241,279 | 6,500 | 9,824 | 15,840 | 9.1 | 13.7 | 22.1 |
| OECD Pacific | 5,300 | 33,859 | 91,667 | 280 | 3,079 | 8,671 | 0.4 | 4.3 | 12.1 |
| | - | | | | | | | | |
| FSU and Eastern Europe | 7,000 | 7,462 | 13,217 | 670 | 710 | 1,291 | 0.9 | 1.0 | 1.8 |
| China | 11,402 | 40,738 | 168,731 | 690 | 3,352 | 16,151 | 1.0 | 4.7 | 22.5 |
| East Asia | 4,895 | 27,274 | 70,577 | 390 | 2,616 | 6,946 | 0.5 | 3.6 | 9.7 |
| South Asia | 6,300 | 38,557 | 60,918 | 29 | 2452 | 4,372 | 0.2 | 3.4 | 6.1 |
| Middle East | 2,400 | 8,587 | 24,221 | 190 | 809 | 2,372 | 0.3 | 1.1 | 3.3 |
| Latin America | 6,198 | 53,606 | 99,627 | 300 | 5,039 | 9,639 | 0.4 | 7.0 | 13.4 |
| Africa | 1,999 | 8,044 | 16,803 | 130 | 734 | 1,610 | 0.2 | 1.0 | 2.2 |
| Total | 230,798 | 560,382 | 1,070,915 | 11,828 | 42,391 | 91,716 | 16.6 | 59.0 | 127.7 |

**Figure 8: Calculation of emissions reduction through ICT-enabled wind power installations in cases where power system capacities for accepting wind power are not sufficient.**

Adopted from WWF, 2008, page 76.

Still, some figures can be found in the literature. The Climate Group (2008) states in the Smart 2020 report that the power sector accounted for 24% of global emissions in 2002 and could be responsible for 14.25 Gt $CO_2$e in 2020. The potential for ICT to reduce carbon emissions through smart grid technology in the year 2020 is estimated to be some 2.03 Gt $CO_2$e. According to the report these 2.03 Gt $CO_2$e can be broken down as follows:

- 0.9 Gt $CO_2$e by reducing transmission and distribution losses;
- 0.83 Gt $CO_2$e by the integration of renewables;
- 0.28 Gt $CO_2$e by reducing consumption through user information;
- 0.02 Gt $CO_2$ by demand management.

An example for calculating the impact of ICT on the share of usable renewable energy is given in Figure 8. This WWF calculation (WWF 2008, page 76) refers to wind power capacity increase, which would be limited by network constraints and be counter-measured by ICT-enabled network monitoring and dynamic line rating.

## Central controversies and open questions

It is widely consensus that most technologies that are needed for the implementation of smart grids already exist: “Practically speaking, most of the technologies required to create smarter electric grids are already available today” (WEF 2008, page 11). Still, building-up a smart grid is a technical and an organisational challenge. Several controversies exist in relation to the technological option, visions and the expected benefits.

First of all, there is controversy on whether a centralised or a decentralised network is the better solution in terms of energy security, climate security and energy prices (see for example Wagner 2007). As it was described on page 12 of this report, in principle a centralised network is based on a few large power plants, whereas in a decentralised network power supply is based on a large amount of smaller energy sources, such as wind turbines or photovoltaic. To highlight all aspects of this complex discussion would surely overburden this report. It should only be mentioned here that opponents of a decentralised system usually raise doubts regarding reliability of the network as well as regarding the potential of renewable sources. Arguments for the smart grids are already mentioned in the text above. Some experts argue that the benefits of both concepts should be combined; meaning neither a purely centralised nor a purely decentralised energy system would be the optimal solution.

Apart from this discussion on the general desirability of decentralised energy systems there are other important controversies and open questions in relation to the implementation of smart grids. Many different technologies as well as many different contributors are relevant for the development of a smart grid. What is needed is a better organisation and integration of these technologies, contributors and their activities. Standards and regulations have to be established, at the same time the system has to remain flexible enough to allow for progress and the integration of new developments. “Challenges to be addressed include the technical and commercial integration of decentralised and centralised systems, the operational management of intermittent and variable power generation sources, and the strengthening of the trans-European network where there are power flow constraints to trading” (EC 2006c).

Apart form theses controversies some open questions are left to be answered. Growing shares of renewable sources, a more decentralised structure together with a liberalisation of the energy markets will lead to an increasing number of stakeholders being involved in the future of energy supply. Amongst them are users, electricity network companies, energy service companies, technology providers, researchers, traders, generators, regulators, governmental agencies and also advanced electricity and service providers who will have the choice between own (on-site) generation, including sales of surplus to the grid, and the purchase of electricity from supplier companies (EC 2006c). A high degree in ICT based co-ordination is essential to keep such a complex system running efficiently and reliably. More knowledge is needed on how such actor constellations can be managed successfully.

Notwithstanding these open questions several European smart grid projects are running in this field[5]. Many countries have their implicit or explicit agendas for a development towards smarter or smart grids. For example Austria is working on a “Roadmap Smart Grid Austria” (BMVIT 2009). In Asia, an interesting project is running in India: Close to Hyderabad an innovative partnership between a property developer and a Solar Company incorporates renewable decentralised energy production, smart grids, home automation and electric cars (India-climate-solutions 2009). However, the predictability of load profiles and the management of a fluctuating source still is a challenge. More small and medium scale demonstration projects are needed to obtain a better empirical basis for the future development. Of utmost importance is to gain experience with the shifting and shedding of loads by price signals.

[5] (see www.energy-enviro.fi; ADDRESS at http://www.eubusiness.com/Energy/address-energy.01/; http://www.improgres.org; or: Stadtwerke Unna in Germany www.unna.de/stadtwerke+unna ).

Furthermore, the installation of small scale decentralised power devices is often the affair of private house or land owners. It would be helpful to have a clearer picture of the future development of such a small scale power generation to be able to prepare the energy networks better to cope with upcoming challenges. For example, surveys amongst house and land owners related to their future plans about installations of renewable energy technologies might help here (see BMWi 2006).

## 2.2 Smart Buildings, Smart Homes and Smart Metering

### Technological options and visions

As mentioned in the chapter above, there are considerable overlaps between smart buildings and smart grids. Whereas the Chapter on smart grids (2.1) put the focus on the supply side of electrical power, in this chapter we concentrate on the consumer side. A lot of visions regarding the future development of intelligent buildings can be observed. Again, ICT as an important means to reduce energy consumption of buildings plays a key role for the realisation of these options and visions. In households there is a wide range of linkages between ICT and energy. There are different views on the potential of ICT in terms of energy savings.

The term “smart buildings” is strongly focused on the technical side of automated building operation, whereas, according to many authors, the term “smart homes” goes much further: “A smart home is a residence equipped with technology that facilitates monitoring of residents aiming to improve quality of life and promote independence” (Demiris 2008).

In May 2009 the Karlsruhe Institute of Technology (KIT) together with the Forschungszentrum Informatik (FZI) organised a Workshop titled “Smart Homes Vision 2020 – Incentives and Needs for the Energy Consumer of the Future”. In the following, some of the results of this workshop are referred to. Smart Home Vision has been discussed for several decades (Madlener 2009). The idea of using ICT in homes to facilitate interoperability of household products and services was already discussed in the 1970s and has developed over the years. In the early 1990s the concept was extended from “building automation” to “home automation”, meaning that the focus was shifted from industrial buildings to private homes including all electric equipment used in this context.

Usually, three technical fields of application are at the centre of smart homes visions: “white goods”, “consumer electronics” and “building automation”. White goods include the following equipment: refrigerator, freezer, stove, oven, cooker, microwave, washing machine, clothes dryer, dishwasher and others. In this sector, considerable technical progress has been made regarding energy consumption and corresponding labelling directives on energy efficiency in the EU. Consumer electronics also offer a high potential to save energy. A prominent example is the standby-by problem (see Bertoldi and Atanasiu 2006). Regarding building automation, ICT is used in the organisation and management of buildings (housing, facility management) to support energy saving in heating and electricity consumption such as room heating, water heating, cooling, lighting, cooking or electric appliances (see Erdmann et al. 2004). The underlying idea is the concept of intelligent buildings, including items such as smart metering, building control systems and home automation. IT systems can be used to coordinate energy consumption by key-appliances such as heating, ventilation, air etc (WEF, 2008).

A key-concept in this context is “smart metering” which means measuring and visualising energy consumption in order to be able to detect saving potentials and corresponding options for actions. One typical measurement is the installation of online dashboards that offer real-time visibility on individual energy consumption. Furthermore there is the idea of variable pricing which has already been mentioned in Chapter 3.1. The concepts require the installation of smart meters that charge variable rates based upon demand.

This should help consumers to shift their energy consumption from high price times to low price times (load shifting), or to switch-off applications (load shedding). ICT applications appear to be helpful for supporting such processes. For example, there is the idea that consumer electronics, especially washing machines and dishwashers, start working when energy is cheap, meaning that these “white goods” are enabled to understand and react to price signals.

One option that is discussed for supporting humans in such a complex environment with much information that has to be taken into account and processed is the so-called personal agent. The concept is described by a group of researchers active in this field in the following way: “The goal of our work is to research, develop, and use highly personalized agents to complement the cognitive limitations of the human mind to facilitate the decision making process (including the gathering of information and recommendation of actions). These agents work in a collaborative manner with users to accomplish their goals. To work effectively and efficiently with a human user, the agents must learn the human user’s interests, habits and preferences (as well as those of their communities)” (Ketter et al. 2008).

Transferred to smart homes, this means that the ICT based agents will support the inhabitants. This concept was presented by Wolf Ketter at the KIT/FZI workshop mentioned above (Ketter 2009). One of the central assumptions is that people are able to buy and sell energy in online markets. It is supposed that personal agents will do this job, which requires knowledge of market predictions as well as of user preferences. The agent will try to buy electricity when it is cheap, it will control all energy consuming devices and maybe also additional services such as organising the diary or arranging an appointment with the dentist. The basis for the decision could be pricing signals as well as the habits and preferences of its user. The “perfect” agent should be able to learn the habits and preferences. The following statement by Ketter et al. (2008, page 2) illustrates that the concept of personal agents is linked to far-reaching visions: “We foresee a day in the near future when sophisticated personal agents will run continuously in the background on our behalf, exploring, monitoring, filtering, mining, collaborating and presenting relevant information for our utility, while flexible trust mechanisms will act to appropriately constrain the autonomous authority of those agents.”

In practice, this concept is confronted with several open questions. For example, if the agent is buying and maybe also selling energy on the market there is the unsolved question of responsibility in case of failures (Decker 2009). A similar situation occurs if the agent causes an accident in a smart home. Is the user responsible, the manufacturer or the person who developed the software? Further, there is the question to what extent daily routines can be anticipated and predicted in a more or less reliable manner, even if the agent were able to learn?

The idea of personal agents for homes has considerable similarities to the concept of ambient assisted living (AAL). The underlying idea is that in an aging society, elderly and handicapped people will be supported by ICT-based application (see Meyer 2008). These ICT applications will assist them in their daily activities, and, thus, help to keep up a high quality of life and to provide for security and safety at acceptable costs. Technologies used in the AAL-context are oriented towards the needs and capabilities of the actual user. In order to be accepted, they have to be integrated into the personal environment of the user. Similar to the concept of the personal agent, these technologies should be able to learn the users’ needs, habits and preferences. In consequence, the technology is adapting to the user rather than the other way around.

Regarding the approaches described above it is obvious that smart metering of energy flows is needed as a basis for decisions. The vision of personal agents works best if it is connected to the "Internet of Energy" (Chapter 2.1). In its extreme version everything has an IP address. A high degree of standardisation enables all relevant technical devices to communicate with each other – organised and controlled by the personal agent. In addition, the personal agents is able to communicate with other agents, which means that decision could either be targeted on individual interests or on collective interests. The latter would be the case, if a group of agents is making decisions supporting the overall efficiency of the system at the expense of individual members. This would mean that the agent has a considerable degree of autonomy, which is only imaginable if the user is willing to surrender responsibility to the personal agent. So, it would be crucial to understand if collective decisions could differ considerably from individual decisions, which means that there would be the possibility that the autonomous agent is not only acting for the benefit of its user but also for the benefit of the whole system. This linkage to the overall efficiency of the system is also a striking difference to the AAL concept where there is no doubt that ICT has to serve the interest of the user.

Regarding the potential of smart homes to increase energy efficiency and reduce climate change, a high degree in market penetration of the corresponding technologies is important. In principal, political settings such as emission standards or incentives for clean technologies could help to push the process of commercialisation. It is not clear, however, if such advanced equipment will be designed for mass-markets or – at least in the beginning of the diffusion process – rather for privileged groups. A related question is which societal groups are interested in smart home technologies or, in other words, if there is a realistic chance for significant market penetration in the next 10-15 years.

At the KIT Workshop mentioned above the Sinus approach was introduced and discussed in the smart homes context (see Plöger 2009). The Sinus approach offers a categorisation of societies along so-called "Sinus-Milieus". It can be used for the identification of target groups for marketing activities but also for social-science research. These Sinus Milieus distinguish different homogeneous groups of individuals who share the same aspirations in life, the same value systems and the same lifestyles. They describe coherent universes of life, of values, behaviours, which structure consumption as well as political and civic life (see Sinus 2009). About 12 such milieus are identified for Germany. According to Plöger, in Germany there are especially two milieus that seem to have a close affinity to the idea of smart homes. For the time being, the milieu called "modern performers" represent 10% of the population and the milieu called "experimentalists" 8%. Wide parts of the society do not have a close affinity to such a concept, but these two groups might serve as early adopters or "door openers" for innovative applications in this field. However, a prediction of the development of the innovation process is hardly possible, since acceptance of these technologies is influenced by a wide range of factors. Most important is the development of the technologies themselves as well as the development of attitudes towards pervasive computing and energy prices. Political incentives would surely have an impact.

## Expected reduction in GHG emissions

Saving potentials are strongly related to learning effects and changes in behaviour on the one hand, and intelligent technologies that enable – often automatically - an optimised usage of energy on the other hand. Shifting load to the off-peak hours might help save energy on the supply side, as it was described in the chapter above. However, regarding the building itself, it helps to reduce cost but not to reduce overall energy consumption of the building.

GHG emissions from buildings are mainly caused by energy usage. Figure 4 shows that nearly 10% of the EU27 GHG emissions are coming from fossil fuel combustions in households. For Germany, it is estimated that 40% of the overall energy consumption and 20% of $CO_2$ emissions are related to buildings. According to WEF (2008) the saving potential in existing buildings through the implementation of smart building energy management systems can be around 20%. For new buildings, efficiency aspects could already be included in the design, so, the potential is much greater and there are fewer barriers to fully exploit the potential. "When it comes to new buildings, it is possible to turn many from large energy consumers to net producers" (WEF, 2008, page 6). The European Commission (2008, page 7) states: "More than 40% of the energy consumption in Europe is building-related (residential, public, commercial and industrial). The Action Plan for Energy Efficiency estimates that the largest cost-effective energy savings potential lies in the residential (around 27%) and commercial buildings (around 30%)."

It is reported that even rather simple strategies can help to reduce energy consumption significantly. Many examples are related to an appropriate usage of existing technology and a corresponding change of behaviour or a learning effect. Sometimes, rising awareness for the problem already helps to reach improvements. For example, it is reported that a manager of 500 commercial buildings was able to reduce energy consumption by simply ensuring that heaters and air conditioners were not running simultaneously (example from US, Missouri, described in WEF 2008). Here, as well as in many other examples, it is crucial to increase the awareness for energy consumption and saving potentials, which could be supported by ICT. There is broad consensus that making consumption patterns visible is a crucial step for raising awareness but the exact effect of increased visibility is difficult to capture.

Darby (2006) emphasises that the general domestic energy usage is invisible to the user most of the time. People are not informed about the energy usage of the various applications they are using in the daily routines. Many studies demonstrate that a clear feedback is a necessary element in learning how to control fuel use more effectively over a long period of time. Darby (2006) identifies the following assessment of potential savings by the use of different forms of smart metering:

- Savings from direct feedback (immediate, from the meter/monitor) range between 5-15%. There is some indication that high energy users may respond more than low users to direct feedback.
- Indirect feedback is a kind of feedback that has been processed in some way before reaching the end user, normally via billing. Savings are estimated to be between 0 and 10%.
- Feedback that is disaggregated by the end-user at the electricity meter. This is relatively expensive and complicated to supply. But it allows identification of the consumption of individual applications (radio, fridge, toaster etc) and their effect on the overall consumption.

- Pay-as-you-go systems with some form of display allow customers to be more in charge of their electricity use. Savings of 10-20% are quoted for North American systems. A full evaluation of the keypad pay-as-you-go meter in Northern Ireland is under way; figures from small-scale earlier studies show savings of around 3% compared with previous usage.
- While online billing can provide a useful interactive feedback service and can incorporate analysis and advice, it is unlikely to be an adequate substitute for a direct display. Ideally, every household needs to be able to see what is happening to consumption without having to switch on an optional feedback service.

Other experience supports the notion that there is a huge potential for savings by, again, just raising awareness. In a report of the European Commission it is written: “Gains of 7% have been observed in Finnish households just by providing consumers real-time feedback on their consumption. Early trials suggest the energy savings in companies could be as high as 10%.”

### Central controversies and open questions

The following questions are discussed controversially and/or require more research and demonstration activities in order to get a better understanding of ICTs’ potential for increasing energy efficiency:

- Which degree of automation is imaginable or acceptable for consumers? What is the maximum “intelligence” of intelligent buildings?
- To what extent are behavioural changes and learning needed and achievable?
- The design of user-technology interfaces is a crucial question. Saving potentials can only be fully tapped if technology is used in an appropriate way:
- The effect of metering is not understood properly; is there a “one size fits all” solution or do we need individual solutions designed for different types of users?
- Which way of metering is best for what purpose?
- To what extent can rebound effects become a problem?
- What are the risks of the technology? In particular questions of reliability, security and privacy have to be tackled.

It is critically discussed whether smart meters are already sufficient to support inhabitants in tapping the full potential for saving energy and costs and if more sophisticated ICT is really needed. Field trials and interdisciplinary demonstration projects would be needed to get a clearer picture on that. It is crucial to learn more about users’ willingness to surrender control to an instrument such as a personal agent. As the similarity to the AAL concept or the growing linkages between consumer electronics and internet applications illustrate, the idea of a personal agent is well in line with the general trend named “ubiquitous computing”. It underlines that ICT is getting increasingly important for daily life, not only but also regarding the relation between ICT and energy consumption. Is it possible that the ongoing trend towards ubiquitous computing will help to pave the way towards a greater acceptance of highly sophisticated smart homes? Regarding personal agents, there is the crucial question formulated by Ketter et al. (2008): “Is an agent capable of optimizing individual real life human decisions?”

Another discussion circles around the potential for shifting load to off-peak hours[6] on the one hand and the potential for energy savings on the other hand. Shifting of load can be understood as an enabling technology for fluctuating energy sources since it offers better coordination between the demand and supply sides. There is lack in data on how much load could be shifted in a smart home. Since this project is on the relationship between ICT and climate change, it should be mentioned that shifting load does not necessarily imply saving energy. However, shifting load to off peak hours helps to get more balanced load profiles and could increase the overall efficiency of the energy system (see Chapter 2.1).

[6] See explanations on page 11: The underlying idea is that suppliers offer their customers more flexible rates, and customers can be alerted to price signals so they can shift their consumption of energy to low-load times and profit from lower tariffs. This could reduce peaks in power demand and, thus, the maximum of power needed in peak-periods

## 2.3 Transport and Dematerialisation

Since transport is responsible for about 20% of European GHG emissions (Figure 5) it is discussed as a crucial factor in the climate change debate. EC 2005 and other data sources illustrate that transport related GHG emissions will rise further in both, absolute and relative terms, if no trend-breaking policy is implemented (see also Schippl et al. 2008). There are basically 3 strategies that can be used to reduce GHG emissions coming from the transport sector (Schippl et al. 2008; Dalkmann et al. 2007):

1. Changing transport volumes (avoidance, substitution or optimisation of trips by technologies, organisational or behavioural changes);
2. Changing specific carbon intensity of the transport modes (cleaner fuels and propulsion technologies, improved transport flows);
3. Changing the modal split (inducing a shift of passengers and loads to more energy efficient modes of transport);

Translated into applied policy this could for instance mean: changing transport volumes could be carried out through demand management. Increasing the price of transport could have such an effect. Improving specific carbon intensity could be realised through new technologies. A modal shift to more energy efficient transport modes requires measures that increase the competitiveness of these modes.

A huge variety of ICT applications that can support theses strategies is being discussed and applied. A comprehensive analysis is given, for example, in Kompfner and Reinhardt (2008). In this report, seven types of Green IT application in the transport sector are identified, that seem to have the greatest potential for environmental benefit: eco-driving support, eco-traffic management, eco-information and guidance, eco-demand and access management, eco-mobility services, eco-freight and logistics management, eco-monitoring and modelling. It is emphasised in the report that calculating the exact effect of these measures or of combinations of them is hardly possible since most of them are still at an early stage of development and few are deployed at a larger scale.

As this list of seven types of ICT in the transport sector illustrates, there is a huge variety in the character, technical potentials and impacts of ICT applications. In addition, when looking at other reports it becomes obvious that different ways of structuring the field are possible. It is not possible to deal with all of them in this report; a selection has to be made. For example we do only mention and do not look more closely at all the important improvements in engine efficiency enabled by ICT, since this fact is rather clear and is confined to the engines themselves. Another promising approach is to achieve fuel savings by “eco-driving”, meaning that a more efficient way of driving a car is supported by ICT tools (Kompfner and Reinhardt 2008).

We decided to put the focus on a set of more complex measures of rather systemic character that we cluster along the following categories:

- ICT for a better management and organisation of transport
- ICT for a substitution of transport by “virtual mobility”

In these fields ICT-applications are a substantial part of the technological systems and huge potentials for innovations are expected.

## Technological options and visions

ICT for a better organisation and management of transport

A better organisation and management of the transport system is supposed to lead to better traffic flows, less congestion, more efficiency through better load factors and the use of less energy consuming modes of transport (see EC 2001, EC 2006a; Hummels 2006). Telematics or intelligent transport systems (ITS) are key-words in this context which are related to control and guidance, road pricing, parking, assistance, freight and fleet control and management (see Erdmann et al. 2004). There are huge potentials for energy savings. However, such measures in many cases target an increase in capacities of the existing infrastructure, which means that potential rebound-effects have to be taken into account as well: increasing capacities might lead to an increase in demand, for example because of less congestion.

For all modes of transport as well as for combinations of them ICT play a significant role but differ in character and relevance. For road transport, ICT focus on a better organisation of transport through information and communication; on the steering of traffic flows and an optimised use of infrastructure capacities (see Rothengatter 2008). The underlying idea is that real-time information that is available for the individuals via navigation systems, internet or mobile phone helps to avoid congestion and to improve traffic flows. For example real-time information about full or free parking facilities can help to reduce travel time and, thus, to reduce emissions. It might also be possible in the future to book a parking space before the trip (see Kompfner and Reinhardt 2008). In the future, vehicle-to-vehicle communication might be enabled, where cars inform each other about driving conditions and contribute to the optimised organisation of the whole system – close to the concept of swarm intelligence. Road pricing schemes tend to become a more widespread means to finance the infrastructure and to control traffic flow. Again, these systems are strongly based on ICT applications. There are many examples of the successful implementation of road pricing schemes from outside the EU (see Halbritter et al. 2008).

Furthermore, ICT is a necessary tool for the organisation of efficient car-sharing systems, which have become widespread over the last decades mainly in Switzerland, Germany and the surrounding countries. Modern car-sharing vehicles are equipped with on-board computers that are a central element in an efficient and comfortable booking system.

Regarding trucking, an increased efficiency per tonne kilometre could be achieved by an optimised logistic system. An important issue in this context are load factors, which could be improved considerably. Vehicles often run empty or carry only little load on return trips. The term “Smart Logistics” is used by The Climate Group (2008, 37) for these approaches that “comprise a range of software and hardware tools that monitor, optimise and manage operations, which helps reduce the storage needed for inventory, fuel consumption, kilometres driven and frequency of vehicles travelling empty or partially loaded.” Relevant ICT- applications include software to improve the design of transport networks, allow the running of centralised distribution networks and runs management systems that can facilitate flexible home delivery services.

More flexibility in logistic chains will be enabled by RFID (Radio Frequency Identification) technologies. Together with GPS or GSM technologies such ”tracking and tracing” methods are becoming important elements of the so-called “Supply Chain Management” in modern logistic systems. Such technologies are crucial for improving the reliability and competitiveness of intermodal transport chains especially in the long-distance sector.

In public transport ICT is important to increase the comfort and attractiveness of the entire system. In the passenger sector this can be realised with better information, improved quality and more comfortable use. Concrete measures are real-time information, online ticketing or electronic tickets (on mobile phones) which are being tested in several European cities and metropolitan areas. Also to foster intermodal transport chains (combinations of different modes of transport, for example rail, bus and taxi) an improved and comfortable access to information at any time is crucial.

ICT based road pricing systems could support a push to the rail sector. But also increasing capacities together with improved quality in the rail sector could induce a sort of rebound effect if total transport volumes are increased. Freight rail suffers heavily from a lack of common standards in European countries. ICT is needed to improve this situation. Train management systems (ERTMS) aim at improving interoperability between national networks. ERTMS which includes the European Train Control System (ETCS) is a key technology for an integrated and efficient rail transport in Europe. In the freight sector ETCS offers new opportunities to provide integrated services along the main corridors: trains can be operated across borders without changing rail cars and personnel; the technical standards in the other country are suitable and staff has been trained to operate under the conditions in such a country (Rothengatter 2008). ETCS can lead to increased capacities and an acceleration of travel times and thus, to increased competitiveness of rail transport. With a shift of loads from road to rail an increase in energy efficiency per tonne-kilometre can be achieved. This might again go along with rebound effects since the free capacities on the roads might attract additional transport.

The river information system (RIS) follows a similar approach for water transport.

“One single European sky” is an ICT-based approach for air transport: SESAR (Single European Sky ATM Research Programme) is an initiative that was set up by the European Commission to reach certain standards of harmonisation in European aviation (see EC 2006b). Regarding aviation, ICT has the potential to improve the organisational management processes at airports. A lot of energy is lost when airplanes have to circle in the air over the destination, waiting for a landing slot.

ICT for the substitution of transport by “virtual mobility”

Here, ICT are mentioned which help to avoid transport by substituting trips on the basis of ICT - by “virtual mobility” (see also ETNO 2005). Key words are tele-working or tele-commuting, video-conferences, tele-shopping or tele-learning. In the meantime, the use of ICT for a “virtualisation” or “dematerialisation” of work-routines has become an everyday task in many sectors. Some comparatively new forms of work-collaboration have only been able because of ICT-applications. In this context, the WEF (2008, page 16) points at the organisation of the work on IPCC-reports:”[…]for example, the latest reports of the Intergovernmental Panel on Climate Change were the work of 450 lead authors, 800 contributing authors and 2,500 scientific expert reviewers from 130 countries – an undertaking impossible to imagine without the collaboration and communication tools provided by the ICT sector.” Even if these forms of collaboration will surely induce travelling, since personal meetings have to take place from time to time, it is obvious that there are huge potentials to save GHG emission. Trips can be avoided or substituted by telecommunication or video-conferences.

Besides the already established tools such as e-mail or video-conferences, new technologies are emerging that have the potential to reduce the need for travel. One example is the HP Halo: “HP Halo is a virtual meeting tool that gives users a "tele-immersive" experience. It goes beyond phone and video conferencing to create a lifelike encounter so natural that many users report forgetting whether they met a colleague in person or over Halo” (HP 2008).

The concept of dematerialisation on the one hand is related to the idea that not goods but information is travelling; on the other hand it is related to a concrete substitution of material goods by ICT products. Such virtual goods often refer to the dematerialisation potential of ICT for information goods; examples are the use of e-mail and the reading of e-books instead of using letters or reading books (Erdmann et al. 2004). In addition to transport-savings, materials are saved as well as energy is saved to produce and process these materials. A prominent example that is often subsumed under the label “dematerialisation” is the answering machine that is increasingly used in a purely virtual form, for example for mobile phones: “Based on the success with virtual answering machines a target could be set that 20% of households in EU-15 countries (31 million) should have one physical product replaced by a virtual solution (in case of a virtual answering machine this would mean more than 1 million tonnes of $CO_2$ reduction)” (ETNO and WWF 2008, page 23).

Another example is the taxation or other services that can be used via internet. Neither a personal contact nor a material letter is needed anymore. Such forms of e-government could have a significant impact on reducing GHG emissions through the dematerialisation of public service delivery: “For example, many paper-based services can be moved into the digital environment and situations where face-to-face interaction has been previously required (e.g. to prove identity) can be done virtually. There are also major energy efficiency gains to be achieved in the governmental supply chain” (The Climate Group 2008, page 29)

Furthermore, tele-shopping is becoming more popular. Goods are ordered via Internet and delivered by a special service. Again, person kilometres are reduced, energy and emissions are saved.

### Expected potential for reducing GHG emissions

Many authors point at the complexity in this field which makes it difficult to carry through reliable estimations on the potential contribution of ICT on climate security. Still, a wide range of figures related to different ICT applications can be found in literature. For example, Kompfner and Reinhardt (2008, page 4) stress that the impact of ICT on GHG emission from the transport sector is very difficult to capture, but they come to the following conclusion for Europe: “Nevertheless, the Working Group believes that if all potential Green IT measures would be implemented together and within a long-term concerted European programme supported by all key stakeholders, then an overall reduction of fuel consumption and $CO_2$ emissions in the order of 25% is achievable.” In the following, some more assessments for the two categories mentioned above are highlighted.

ICT for better transport management (organisation)

Effects in the transport sector are not easy to quantify as the following example illustrates: “Under best-case assumptions, ICTs can avoid up to 17% of future freight transport, mainly as a result of the dematerialisation of the economy. A shift from products to services (virtual goods) and material efficiency gains in industrial production (production process management, PPM) lead to reduced material throughput, which in turn reduces freight transport demand. The potential is high but also highly uncertain, which to a large extent explains the large span of the overall future impact of ICTs on freight transport (-17% to + 31%)” (Erdmann et al 2004, page 24). This illustrates, that ICT does not necessarily have to lead to reduction in energy consumption in goods transport. The reason for an increase in demand is an ICT-based Intelligent Transport System, which makes transport faster, more flexible and cheaper.

For “smart logistics” The Climate Group (2008) estimates a saving potential of 1.52 Gt $CO_2$e for 2020. The following measures contribute to this saving potential:

- Optimisation of logistics network
- Intermodal shift (commercial)
- Optimisation of collection/delivery itinerary planning
- Optimisation of route planning – e.g. avoidance of congestion (commercial)
- Eco-driving (commercial)
- Reduction in unnecessary flight time (commercial)
- In-flight fuel efficiency
- Reduction in ground fuel consumption
- Reduction in unnecessary flight time
- Maximisation of ship load factor (commercial)
- Optimisation of ship operations (commercial)
- Minimisation of packaging

According to The Climate Group (2008), the majority of logistics emissions come from transport and storage. Optimising logistics using ICT could result in a 16% reduction in transport emissions and a 27% reduction in storage emissions globally

The following figures are compiled in Kompfner and Reinhardt (2008):

- On critical route sections improved traffic management can reduce traffic delay and congestion by up to 40%, with equivalent energy savings.
- A study in Southampton found that a Parking Guidance and Information System could reduce the average time spent searching for a parking space by 50% (www.scoot-utc.com).
- Traffic light synchronization has the potential to increase intersection throughput for private traffic by 15%. ACEA (2008) estimated the yearly $CO_2$ reduction potential and costs of substituting 50% of current traffic lights with modern dynamic UTC, which generates an optimal traffic flow by adjusting to traffic conditions, and came to the result that 2.4 million tonnes of $CO_2$ p.a. could be saved across the EU.

Regarding multimodality, Kompfner and Reinhardt state (2008): “If by facilitating multimodality 30% of the passenger-km were shifted from private cars to public transport, this would lead to a reduction of at least 30% in energy consumption and much more in the emission of pollutants”. On basis of WBCSD[7] data, the WWF report (2008) estimates in three different scenarios on global scale, that for light duty vehicles ICT could enable a 3% (scenario I), 20% (scenario II) or 40% (scenario III) switch to public transportation by 2030. Under these assumptions possible benefits in terms of GHG emission reductions would sum up to 57 Mt $CO_2$e (scenario I), 380 Mt $CO_2$e (scenario II) or 760 Mt $CO_2$e (scenario III) respectively. By comparing this figures with total $CO_2$ emissions of Germany in 2005, which were 852 Mt, is becomes obvious that the 40% switch to public transport would have considerable effect (reduction of 760 Mt$CO_2$e on global scale).

<u>ICT for a substitution of transport by “virtual mobility”</u>

Several estimations on ICT for “dematerialisation” exist. The Climate Group (2008, page 3) estimates that “dematerialisation” can achieve a reduction of some 0.46 Gt $CO_2$e in 2020. Measures contributing to this figure are:

- Online media
- E-commerce
- E-paper
- Videoconferencing
- Telecommunication

According to this assessment more than half of this 0.46 Gt $CO_2$e are coming from telecommuting: “For example, if a significant number of people worked from home more than three days a week, this could lead to energy savings of 20-50%, even with the increase in energy used at home or non-commuter travel” (The Climate Group 2008, page 3).

Telecommuting appears to be the best investigated measure in this field. In WWF (2008) an overview on empirical studies and their results is compiled. For example, it is mentioned that the current US telecommuters avoid emitting between 10 and 14 million tonnes per annum. The WWF study also points at potential rebound effects that are associated with telecommuting (WWF 2008, page 38):

- “Latent demand from people who decide to travel as congestion, thanks to telecommuting, decreases
- Leisure travel from telecommuters that take advantage of the commuting time saved thanks to telecommuting
- Increased urban sprawl, facilitated by the diminished need to live in proximity to offices”

Still, the WWF points at a prevalent consensus in literature saying that telecommuting reduces overall km travelled (WWF 2008).

[7] World Business Council for Sustainable Development

A study completed by WWF together with the European Telecommunications Network Operators Association (ETNO) illustrates the potential of videoconferencing to replace business travel in Europe (see Figure 9). The Climate Group (2008) refers to estimations suggesting that tele- and videoconferencing could replace between 5 and 20% of global business travel.

It should be noted that virtual meetings seem to offer the chance to reduce in particular long-distance air transport that goes along with considerable GHG emissions and is characterised by heavy growth rates.

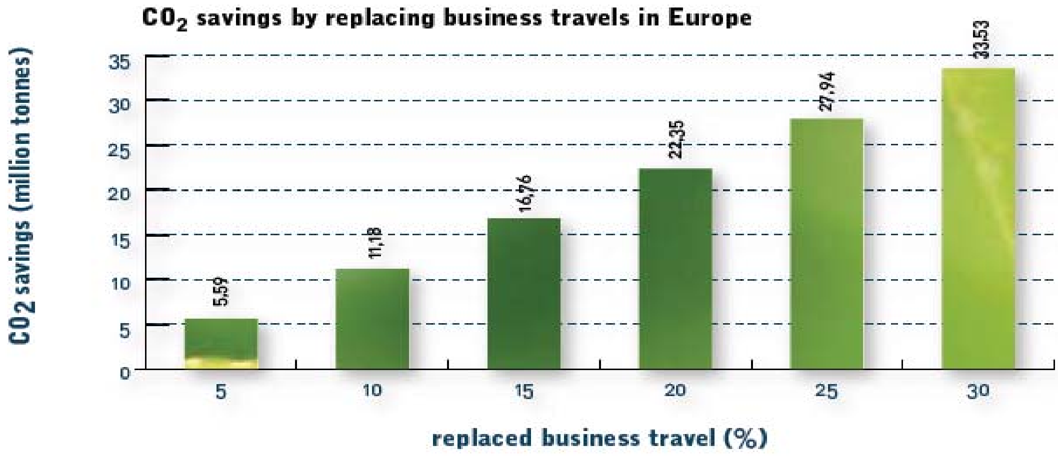


**Figure 9: $CO_2$ savings by replacing business travels in Europe.**

Source: ETNO and WWF 2008

WWF and ETNO (2008) concluded that if 20 % of business travel in the EU were replaced by audioconferencing, videoconferencing or telepresence, then 25 million tonnes of $CO_2$ might be saved annually by 2010. If 10% of EU employees became telecommuters or flexi-workers, another 22 million tonnes of $CO_2$ might be saved annually (AeA 2007).

These calculations do not take into account possible rebound effects (free capacities might attract additional traffic). But they illustrate that huge saving potentials can be identified.

## Central controversies and open questions

In general, it is difficult for many of the measures mentioned above to calculate the exact effect. Many of the measures are supposed to lead to a reduction in transport volumes on roads. Whenever this is the case, there is a danger of rebound effect taking place: the “new” capacities on the road attract additional traffic, because there is less congestion than before. Also the potential of modal shift is discussed critically. Rebound effects might also eliminate the savings.

Furthermore, there is a lot of uncertainty and controversy about the potential of so-called dematerialisation. For example, The Climate Group (2008) points out that there is uncertainty about the exact reduction because of the unpredictability of technology adoption and development (for example, the “paperless” office has failed so far).

This is especially true for tele- and videoconferencing where it is not exactly clear to what extent these tools substitute transport or just offer additional opportunities for communication – on top of exciting transport volumes. Even if there is consensus on a clearly positive net effect of these measures, it is also unclear to what extent rebound is induced. This is especially true for telecommunicating: "The dynamics, drivers, and sizes of potential indirect impacts need more rigorous analysis and field research, as data are currently lacking and as the conditions that lead to larger or smaller direct and indirect impacts of telecommuting are not fully understood" (WWF 2008, page 38).

Many ICT applications relevant for the transport sector are related to behavioural changes. Such changes are difficult to predict and calculate. More studies and demonstration projects are needed in this context.

## 2.4 Industrial Processes and Organisations Sustainability

### Technological options and visions

As indicated in Figure 5, the contribution of industrial processes to overall GHG emissions in the EU-15 was about 8% in the year 2006. It should be noted, that this 8% do only include emissions from industrial processes and not emissions from the production of power and energy carriers (which is in line with IPCC requirements for reporting). Depending on different approaches and on to what extent indirect effects are included in the calculations, figures might vary. The Climate Group (2008, page 32) states: "Industrial activity is one of the largest contributors to global emissions, responsible for 23% of total emissions in 2002 (9.2 $GtCO_2e$). It uses nearly half of all global electrical power generated, industrial motor systems using the majority (65%) and by 2020 motor systems will be responsible for 7% of global carbon emissions". Electricity consumption is included in these figures.

Most relevant industrial branches in term of GHG emissions are the chemical industry, the steel industry, the cement industry and the petroleum industry (see McKinsey 2007a and 2007b; Taylor et al. 2006). However, as already indicated in the quote above, in all industries, there is a potential to increase efficiency and save emissions.

In the European Union, the electricity consumption in the industrial sectors has grown by 9.5% in the period 1999-2004 and is expected to grow further in future. Of this consumption, 707 TWh (again 65%), was consumed by motor driven systems (European Commission 2003; De Keulenaer et al. 2004), which includes compressors, refrigerators systems, pumps, ventilations, conveyors and other equipment (Bertoldi and Atanasiu 2006). Probably the most striking saving potential that is strongly linked to ICT can be identified for electric motor efficiency. Electric motors are responsible for 10 to 20% losses of electricity consumption in the process of converting electrical energy into mechanical energy (Bertoldi and Atanasiu 2006). According to Mecrow and Jack (2008), the key challenges to increased efficiency in systems driven by electrical machines lie in three areas:

- "To extend the application of variable-speed electric drivers into new areas through reduction of power electronics and control cost;
- To integrate the drive and the driven load to maximise system efficiency;
- To increase the efficiency of the electrical drive itself."

This quote illustrates that it is by far not only the electric drive itself, but also the context in which it is used, that has to be tackled for realising saving potentials: Not only individual components but the entire system is relevant: "Moreover, the energy consumption depends more on the overall systems design and operation than on the efficiency of the individual components" (Bertoldi and Atanasiu 2006, page 52).

Regarding the energy efficiency in industrial processes, ICT is needed as an enabling technology for the optimisation of processes. Metering, monitoring and analyses of energy consumptions to raise awareness for potential savings is a key-issue based on ICT-applications. The availability and collection of real-time data is crucial in this context.

A variety of technologies is available that could lead to energy demand reduction in industrial processes, amongst them are boiler operation, compressed air usage, heating and lighting, and electric motor efficiency (see Dyer et al. 2008). For all these and many other applications in industrial processes a linkage to ICT can be identified. ICT has the potential to save any kind of resources by optimisation or substitution of processes. Further, ICT might enable the production of smaller products (miniaturisation) which again has the potential to save resources.

Measuring and control technologies together with the corresponding software in general are crucial for realising potentials for saving resources. ICT can support the analyses of energy and materials flow and might on this basis contribute to an optimisation (see SAS 2007). One example is the approach of Carbon Footprint Modelling as it is applied by SAS. The system works on three different levels: direct fuel burned, required electricity consumed and (voluntary) travel of employees. The system aims at offering new insights into the cost and carbon impacts of alternative decisions. The model can be used to measure the return of investment of sustainable decisions, e.g. such as changing 10,000 light bulbs by more efficient ones. An important incentive to use these ICT-enabled technologies and concepts is that reducing carbon emissions in general means saving costs. The related win-win potential for savings in many cases is not tapped yet. Metering and software can help raise awareness in this field and support the sustainable decision-making process. In a way, "raising awareness" has a similar effect on company level as smart metering has on the level of individuals in building (see Chapter 2.2).

Many examples illustrate that there are significant potentials to reduce carbon emissions on the company level on basis of organisational measures. In this context, the European Commission points at British Telecom as a good example, because the company has achieved a 60% reduction in its UK carbon emissions from a 1996 baseline (EC 2008). Among the measurements implemented by British Telecom is the "flexible working programme" with many employees working permanent or semi-permanent from home. Tele-conferencing is also playing a crucial role. Both measures lead to energy savings since business related travel is reduced. Apart of that, BT is a large purchaser of "green" electricity[8].

### Expected reduction in GHG emissions

It is rather difficult or nearly impossible to carry out a reliable assessment of ICTs' contribution to increased energy efficiency in industrial processes. Data can be found, but in many cases the basis for the calculations is not made transparent and/or difficult to compare or aggregate with other data. In spite of these difficulties, the WWF (2008, page 67) comes to the following tentative statement: "Since market forces provide a strong incentive to reduce costs and pursue energy efficiency strategies, and since ICT has been a major enabler for innovation and efficiency improvements in industrial production, it can be argued that a 20% gain on current emissions is a realistic target and can be achieved in a relatively short time frame, however, it remains a question whether all the savings can be attributed to ICT." The WWF assessments presented in Figure 10 also indicate significant saving potentials on basis of ICT applications in industrial processes. According to these calculations, considerable potentials for savings can in particular be identified in developing nations.

[8] See "20 KEY BT FACTS" March08

| | Baseline GHG emissions 2030 MtCO2e | Potential GHG emision reductions 2030 MtCO2e | Low ICT contribution to efficiency gains | Higher ICT contribution to efficiency gains | Potential GHG emision reductions MtCO2e | AeA's report estimate (20% of baseline emissions) |
|---|---|---|---|---|---|---|
| OECD countries | 4,243 | 470 - 1100 | 5% | 30% | 24 – 330 | 849 |
| Economies in transition | 1,540 | 250 - 510 | 5% | 30% | 13 – 153 | 308 |
| Developing Nations | 7,617 | 1300 - 3400 | 5% | 30% | 65 - 1020 | 1,523 |
| Global | 13,400 | 2000 - 5100 | 5% | 30% | 100 - 1530 | 2,680 |

**Figure 10: GHG emission reductions from industrial processes**

Source: adopted from WWF 2008

As described above, a key-potential for GHG savings lies in the energetic optimising of the countless electric engines that are used for industrial processes. The Climate Group (2008) estimates, that by 2020 10% of China's GHG emissions will come from motor systems alone. An improvement of industrial efficiency would deliver 200 Mt $CO_2$e savings.

A study by the IEA, "Tracking Industrial Energy Efficiency and $CO_2$ Emissions", suggests a technical efficiency improvement potential of 18-26% for the manufacturing industry worldwide if the best available technologies were applied. These savings would equal 5-7% of the total energy use and would reduce $CO_2$ emissions by 8-12% worldwide (see WEF 2008, page 8).

Figure 11 illustrates, that a total saving potential of 202 kWh yearly could be realised in the EU-25. Additional figures can be found in Mecrow and Jack (2008):

- "Replacing fixed-speed machines with variable speed drivers for a high proportion of industrial loads could mean a 15-30% energy saving."
- "By adopting known, proven concepts, it is possible to dramatically increase the efficiency of the systems driven by electrical machines and reduce total electricity consumption by over 7%." But the greatest gains are at the system level."

The Climate Group states (2008, page 33): "ICT could play a significant role in mitigating global carbon emissions from motor systems and industrial process optimisation, up to 970 Mt $CO_2$e in 2020." According to the Climate Group, it is the emerging countries, mainly China, where the potential for large-scale utilisation of smart motor systems will be greatest.

| | Savings potential (billion kWk/yr.) | | | | | |
|---|---|---|---|---|---|---|
| | EU-15 | EU-25 | France | Germany | Italy | UK |
| High efficiency motors | 24 | 27 | 4 | 6 | 4 | 3 |
| Variable speed drives | 45 | 50 | 8 | 10 | 7 | 6 |
| Application part of the motor systems (pumps, fans, compressors) | 112 | 125 | 19 | 26 | 17 | 15 |
| Total electricity savings potential | 181 | 202 | 31 | 42 | 28 | 24 |

**Figure 11: Energy savings in motor system**

Source: Bertoldi and Atanasiu 2006. Adopted form De Keulenaer et al. 2004

### Central controversies and open questions

First, a significant lack of data on the climate effect of technologies in production processes can be observed (see WWF 2008; The Climate Group 2008). Further research is needed to identify and quantify saving potentials.

Improved electrical engines, one of the most important levers in this context, are developed, the technology is available. The central question is what is needed to push market penetration forward. What are the market barriers (see Mecrow and Jack 2008)?

There is the open question to what extent a lack in corresponding awareness is the dominant barrier. Mecrow and Jack (2008) state, that by far the largest market barrier is the one of initial capital costs. Further, the question is discussed to what extent higher energy prices might help to overcome both barriers: economics and awareness.

# 3. ICT as an Energy Consumer

Since ICT as an energy consumer has become a relative prominent issue in public debate, this report will have a closer look on the technologies that are discussed for saving energy in this context. Recently, the terms “Green computing” or “Green ICT”, both referring to environmentally sustainable computing or ICT, are mentioned quite often in newspapers as well as in technical reports and scientific journals. In many cases, a reduction of energy consumption and GHG emissions induced by ICT is at the heart of such articles. The Climate Savers Computing Initiative (www.climatesaverscomputing.org) stipulates: “By 2010, we seek to reduce global $CO_2$ emissions from the operation of computers by 54 million tons per year, equivalent to the annual output of 11 million cars or 20 coal-fired power plants.” 11 million cars surely are an impressive number, but compared to 216 million passenger cars in total only in the EU25 in 2004, it only represents a very small step towards saving the climate. Still, these small steps are needed, especially if they offer the chance to save costs for energy consumption at the same time. So, this quote indicates that for working on the relationship between ICT and GHG emissions it is worthwhile to take a look at the ICT-sector’s own carbon- or GHG-foot print as well as at the potential to improve it.

Whereas in the nineties the energy consumption resulting from the fast diffusion of ICT was not a topic, in the meantime ICT has become responsible for a growing share of GHG emissions on a global scale. In the last years, many studies emerged tackling this issue from different angles (see for example: WWF 2008; The Climate Group 2008; Pamlin, Szomolanyi 2008; WEF 2008, AeA 2007; Cremer et al. 2003; ETEPS 2005; Industriellen Vereinigung Österreich 2008). For example, in 2002, the energy demand for information and communication technology is estimated at almost 1.5% of the total final energy consumption in Germany or at 7.1% of the electricity consumption (Geiger and Wittke 2002; Cremer et al. 2003) respectively at about 2% of global GHG emissions (see WEF 2008; Collard et al 2005; Gartner 2007).

These 2% already offer a potential for reductions; however, what appears to be even more important in this context are the impressive growth rates in the ICT-sector, especially for PCs, computers, server farms and internet penetration in general. The world’s increasing need for computation, data storage and communication leads to rapid growth in the emissions resulting from such technologies. It is estimated that by 2020, they will account for about 3% of all emissions: 1.54 Gt, which is twice the amount the United Kingdom produces today. As shown in Figure 12 the adoption and use of information and communication technologies in China, India and other developing economies are responsible for a large part of this growth (Boccaletti et al. 2008).

The World Watch Institute reports about an estimated 1.2 billion Internet users worldwide in 2006, which is a 13% growth compared to 2005. Jupiter Research in its "Worldwide Online Population Forecast, 2006 to 2011 (www.jupiterresearch.com)," estimates a 38% increase in the number of people with online access for this period. This implies that by 2011 22% of the Earth's population will use the Internet regularly, and indicates that nearly 4 out of 5 human beings are not connected yet.

In Western countries the ICT applications are much more popular than in most other countries of the world. ICT is used in several sectors and strongly linked with electricity consumption. Figures 13 and 14 give an overview of the electricity consumption in Europe.

Interestingly the industrial, residential and the tertiary sector are the sectors with the largest electricity requirement. These are the sectors where a lot of ICT applications such as of PCs, Laptops, consumer electronics or applications in technical processes can be expected and these are also those with the largest growth rates in the projections.

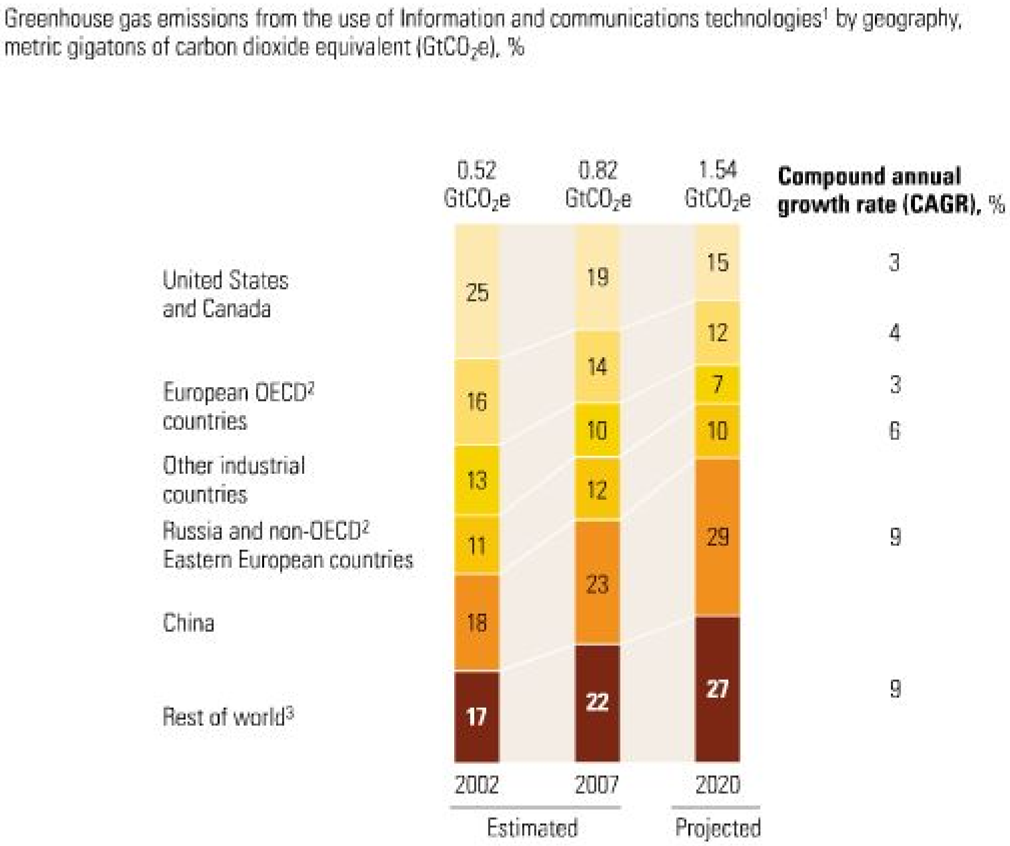


**Figure 12: GHG emissions from the use of ICT[9] by geography**

Source: Boccaletti et al. 2008

ICT covers a huge variety of applications and technologies. E.g. Figure 15 shows the variety of office equipment and its share in power consumption. The figure illustrates that most of the power consumption in offices can directly be related to computers (67%).

In the meantime, many efforts to make ICT more energy efficient are emerging worldwide and are often labelled as "Green IT" (see www.infineon.com). Potential measures to reduce GHG from ICTs' electricity consumption cover the full range from very simple solutions to highly sophisticated innovations. All these measures are not only attractive because of their potential to reduce GHG emissions, but also (or even mainly) because they are able to reduce the cost of electricity consumption.

[9] Includes laptops and PCs, data centres and computing networks, mobile phones, and telecommunications networks.

[2] Organisation for Economic Co-operation and Development.

[3] Includes Brazil, Egypt, India, Indonesia, and South Africa.

| | 2000 | 2010 | 2020 | 2030 | Growth Rates 2000-2030 |
|---|---|---|---|---|---|
| Industry | 1042,2 | 1199,9 | 1318,5 | 1396,5 | 1 |
| Residential | 694,6 | 880,5 | 1097,5 | 1272,3 | 2 |
| Tertiary | 651,9 | 856,2 | 1032,4 | 1144,4 | 1,9 |
| Transport | 68,8 | 78,7 | 73,9 | 71 | 0,1 |
| Energy Sector | 267,9 | 298,8 | 312,2 | 317,2 | 0,6 |
| Trans. and distr. losses | 200,3 | 195,1 | 195,39 | 190,7 | -0,2 |
| (Net Imports) | -24,9 | -26 | -24,7 | -25,6 | 0,1 |
| **Electricity Generation** | **2900,8** | **3483,2** | **4005,19** | **4366,5** | **1,4** |

**Figure 13: Electricity Requirement (TWh) by Sector in the EU-25**

Source: DG TREN (EC 2005, 25)

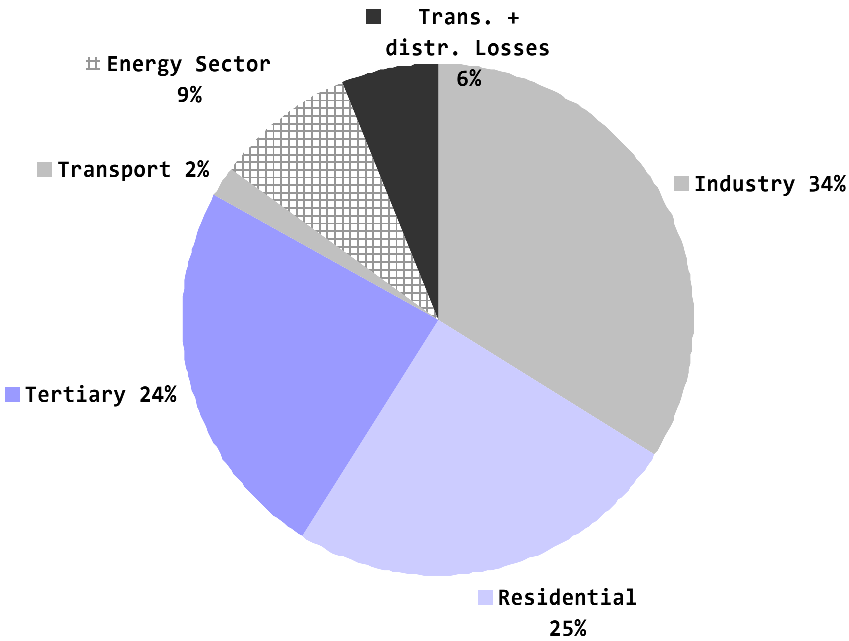


**Figure 14: Share of Electricity Requirements by sector in EU-25**

Source: DG TREN (EC 2005), modified by author

A very simple possibility is to switch off ICT applications when they are not used and to avoid energy consuming stand-by functions. For example in 2006, the US PC Energy Report states: "Over the course of a year, generating the power to leave a computer on overnight creates 920 pounds of $CO_2$. If 60% of the country's work PCs are used this way – and 50% use "hibernation" or "sleep" mode – then 14.4 million tons of carbon dioxide is being pumped into the atmosphere each year, needlessly" (US PC-Energy-Report 2007). Further, the GHG emission induced by ICT can be improved by increasing the energy efficiency of e.g. hardware elements (see subparagraph "PCs and server farms). In addition, the saving potentials are discussed with reference to more sophisticated concepts such as "virtualisation" or "cloud computing" which are covered below.

Due to this fact, we suggest to concentrate on the GHG savings potential in PCs and server farms in this report, which means that physical measures such as improved heating or cooling conditions or more efficient hardware solutions should be taken into account. In addition, special focus should be put on new and promising concepts such as virtualisation and cloud computing, because of the fast global growth rates in PCs, server farms as well as the strong global tendency to use the Internet and internet-based applications more often.

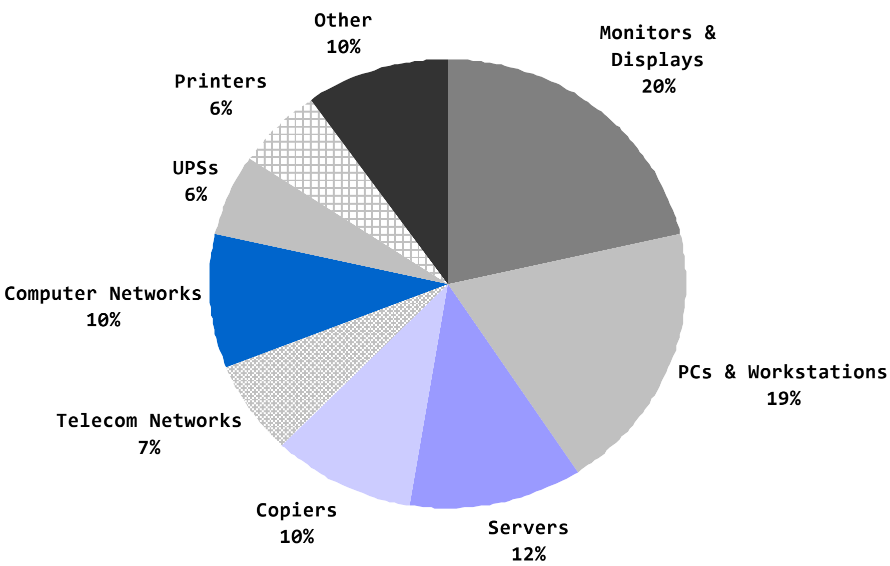


**Figure 15: Relative Power Consumption of Office ICT Equipment for the year 2002**

Source: Intel 2002, modified by author

## 3.1 PCs, server farms (and the internet)

### Technological options and visions

Due to the intensive use of the Internet in private households the power requirement has grown considerably and is expected to grow even more in future. In 2003 Germany had a power requirement of 6.8 billions kWh for internet usage; in 2010 it is estimated at 31.3 billions kWh. End devices of private households and companies as well as the energy requirements for the Internet's infrastructure at server locations were taken into account. The worldwide power requirement for Internet infrastructure operations was rated at 123 billions kWh for 2005, not including electrical appliances of end users. Because of the growing internet even in developing countries, the power requirement will probably increase even more. Nowadays nearly 0.8% of the worldwide power generation is needed for the Internet. For example, a simple Google search from a desktop computer generates about 7 grams of $CO_2$. Boiling a kettle generates about 15 grams (FoxNews 2009).

An examination of residential power consumption results in the fact that a PC consumes about 1% of the total power in an average US home and even more in offices. This indicates that power management in homes and still more in offices enable positive side effects, which become more and more desirable (Intel 2002). The introduction of power management technologies is one of the reasons for the currently reduced power usage of ICT products. Power management is a feature that turns off the power or switches the system to a low-power state when inactive. As shown in Figure 16, power management enables a significant reduction of the average power requirements.

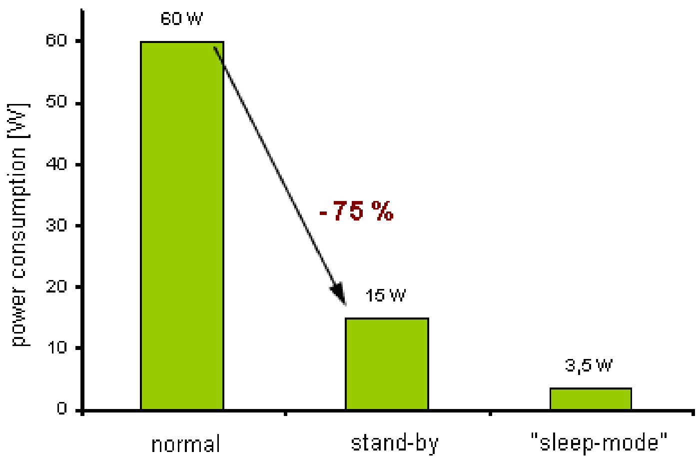


**Figure 16: Average power consumption of PCs in different operating status**

Source: DENA 2009, modified by the authors

One power management standard for computers is the Advanced Configuration and Power Interface (ACPI). In addition to the power management the user has different approaches to green computing like e.g.

- Storage (Smaller form factor (e.g. 2.5 inch) hard disk drives often consume less power per gigabyte than physically larger drives[10]),
- Displays (TFT-display: ~ 40-60W, Cathode Ray Tube: ~90-135W, source: www.pc-erfahrung.de),
- Video Card (A fast graphics processing unit may be the largest power consumer in a computer. Energy efficient display options include e.g. using motherboard video output – typically low 3D performance and low power[11]),
- Power supply unit (the component that supplies power to the other components in a computer): PSUs are generally 70-75% efficient. An industry initiative called 80 PLUS certifies PSUs that are alt least 80% efficient (see www.80plus.org),
- Algorithmic Efficiency: The efficiency of algorithms has an impact on the amount of computer resources required for any given computing function and there are many efficiency trade-offs in writing programs.

Server farms are a collection of computer servers usually maintained by an enterprise to accomplish server needs far beyond the capability of one machine. Server farms often have backup servers, which can take over the function of primary servers in case of a primary server failure. Server farms are commonly used for cluster computing. Many modern supercomputers comprise giant server farms of high-speed processors connected by Ethernet or custom interconnects.

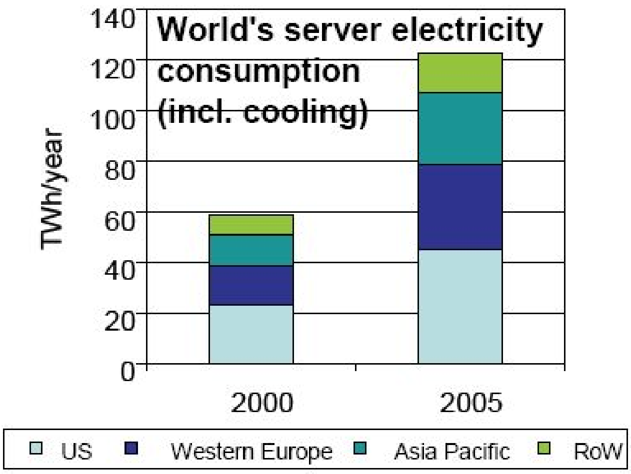


**Figure 17: Increase in power consumption of data centers**

Source: Koomey (2007) (RoW: Rest of the World)

[10] Read more at http://www.silentpcreview.com/article145-page1.html

[11] http://www.xbitlabs.com/articles/video/display/power-noise.html

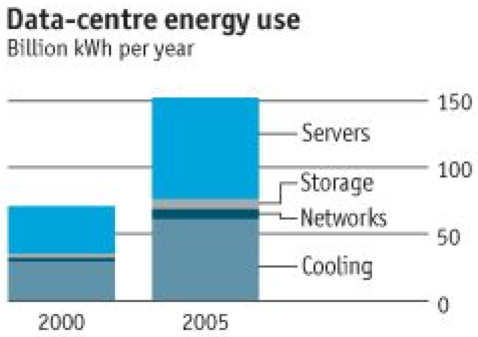


**Figure 18: Increase in power consumption of data centers**

Source: Economist (2008)

Another common use of server farms is web hosting, which is sometimes referred to as web farms. Server farms and cellular networks taken together, consume as much electricity as produced by 27 power plants with an output of 1 GW each (www.eia.doe.gov). This is equivalent to $CO_2$ emissions of approximately 130 tons per year. In 2005 “only” 27 millions server nodes were located in server farms – compared to over 200 million hosts in the entire internet. The total amount of electricity consumed by the internet, thus, will actually lie far above that of the server farms alone. In server farms (web server and mobile communication systems) a rise of power consumption of 16-20% per year has been observed in the last years, as shown in Figures 17 and 18.

As a result of this development, server farms meanwhile consume approximately 180 billion kWh of electricity per year (~ 130 million Mt $CO_2$) (Fettweis, 2008 and GHG Calculator, www.epa.gov). The WEC predicted a doubling of the consumption for 2050 (WEC 2007).

Servers typically waste 30-40% of the power they consume by converting it into heat. As a result, offices, homes and data centres have increased demands on air conditioning which in turn increases the energy requirement and associated costs; therefore they are often discussed in the context of energy savings. The Commission (EC 2008) states that currently 15-20% of the money, spent to operate data centres are lost for powering and cooling.

## Expected reduction in GHG emissions

Newer networking technologies are generally more efficient. Older technologies like dialup and traditional wire line connections use 3.56 kWh per Gigabyte (GB). Newer technologies, including fibre and power lines, use 0.77 kWh/GB, while cable uses 0.72 kWh/GB and DSL sips a low 0.17 kWh/GB. Also, in an effort to cut down the energy consumption of the internet, academics and researchers have developed a strategy to delay data flowing into a network by just a few milliseconds. That is long enough to smooth out bursts and lulls in the data flow, and allows network hardware run at a consistently lower speed which offers the possibility of energy savings of around 50 percent[12] .

[12] http://www.thaindian.com/newsportal/health/delaying-data-can-cut-down-energy-consumption-of-the-internet_10045529.html

The Climate Server Computer Initiative stipulates an increase of the effectiveness of power-management features in computers as well as an implementation of aggressive power-management policies, so in an average business desktop 60% of the electricity consumed can be saved, with no compromise to productivity. For example, the 80Plus is a programme to integrate more energy efficient power suppliers into desktop computers and servers (www.80plus.org). Furthermore, computer scientists have created a device that will put computers in a doze, which could mean energy savings of 60-80%. The experts have developed a plug-and-play hardware prototype for PCs that includes a new energy saving state known as "sleep talking". This new sleep talking allows a PC to remain in sleep mode while continuing to maintain network presence and run well-defined application functions (like peer-to-peer file sharing, instant messaging e.g.).

One key challenge facing server development is the potential of reducing cooling needs and at the same time decreasing the overall power consumption of servers (e.g. new processors). Another step to lower the energy consumption respectively reduce the $CO_2$ emissions of server farms is using renewable energy like solar or wind. An example is AISO (Affordable Internet Services Online) Inc. Located in the sunny Mojave Desert. AISO was built as an environmentally friendly data center and now hosts over 15.000 websites from companies all over the world. AISO's 120 solar panels provide 12kW of power – much more than most solar solutions but still too little to power a data center. In addition AISO installed solar tubes to "sunlight" the data center during the day, insulated the walls with recycled cellulose and used virtualisation software (see chapter 2.2) to reduce the number of servers heavily. This initiative helped to cut costs considerably[13].

## Central controversies and open questions

There are several open questions and controversies in this field:

- How to reach a higher shares and efficiency in renewable energy-powered server farms (goal: base stations which can be powered solely based on renewable energy sources like solar and wind)?
- What is the potential of improving the energy efficiency of components?
- Which potentials will be offered by new network architectures (trade-off between the power consumption analogue and digital hardware blocks)?
- What is the potential of raising awareness for energy savings offered by strategies for distributing computing and data storage, to enable next generation peer-to-peer and content distribution services at minimum energy consumption?

[13] www.itmanagement.com/features/Solar-Powered-Datacenters/

## 3.2 Virtualisation

### Technological options and visions

Virtualisation is very much the word of the moment, however, as the name suggests, the concept of virtualisation refers to a virtual machine (sometimes called pseudo machine), meaning that many virtual machines are simulated on a single physical machine. The primary objective of virtualisation is to provide a so-called Hardware Abstraction Layer (HAL) between hardware and software; between the computing, storage and network infrastructure and the operating systems and applications that use them. This virtualisation layer or Hypervisor between hardware and software isolates the user from the physical hardware – computational power and storage capacity. Typically, virtualisation is done on a physical existing given hardware platform by a so-called host software (a control program), which creates a simulated computer environment (virtual machine) for its guest. The guest software itself is running as if it were running on a stand-alone machine, it is not limited to user applications. It is possible to run many different virtual computers on one single physically existing hardware system.

The true benefits of virtualisation become clear when it is extended across an enterprise, linking hundreds of physical computers and storage devices in a virtual infrastructure. Additional potential benefits are e.g.

- Reduced cost: Decreasing the number of servers and related hardware can cut the need for data centre space, power, cooling and ongoing support costs
- Decreased operational support: Virtualisations enable new applications rather quickly (vmware 2008)
- More efficient use of computing resources and
- Improved management.

A more visionary notion on the geographical location of such physical platforms is the following: The location could be in regions where plenty of – also fluctuating - renewable energy is available (sun or wind), given that the location is supported by energy storage facilities (hydrogen for example).

### Expected reduction in GHG emissions

As mentioned above, energy consumption is a crucial issue for IT organisations, whether the goal is to reduce costs, save the environment (by reducing the $CO_2$ emissions and the resource consumption) or keep data centres running. Ten server workloads running on a single physical server is typical, but some companies are consolidating as many as 30 or 40 workloads onto one server. Reducing the number of physical servers through virtualisation cuts power, costs for cooling and provides more computing power in less space. As a result, energy consumption typically decreases up to 80%. Every server that is virtualized saves 7,000 kWh of electricity and four tons of carbon dioxide emissions per year (vmware 2008). For example, with more than a million workloads running on VMware Infrastructure, the aggregate power savings are about 8 million kWh, which is more than the heating, ventilation and cooling electricity consumed in New England in a year[14].

[14] http://www.eia.doe.gov/emeu/reps/enduse/er01_new-eng_tab1.html

This represents a reduction of 80 million tons of $CO_2$ emissions per year (presumed that the companies have an average of three years excess capacity). The impact of virtualisation on energy consumption is so significant that utilities in North America are paying customers for removing servers through consolidation. By the consolidation direct energy savings can be as high as $300 USD per server and $4 million per physical site (vmware 2008).

A nice gimmick to calculate the benefits of virtualisation depending on the number of servers is the "virtualisation cow" (see www.aint-that-the-truth.com). Figure 19 illustrates the benefits of virtualisation using the example of 1200 servers.

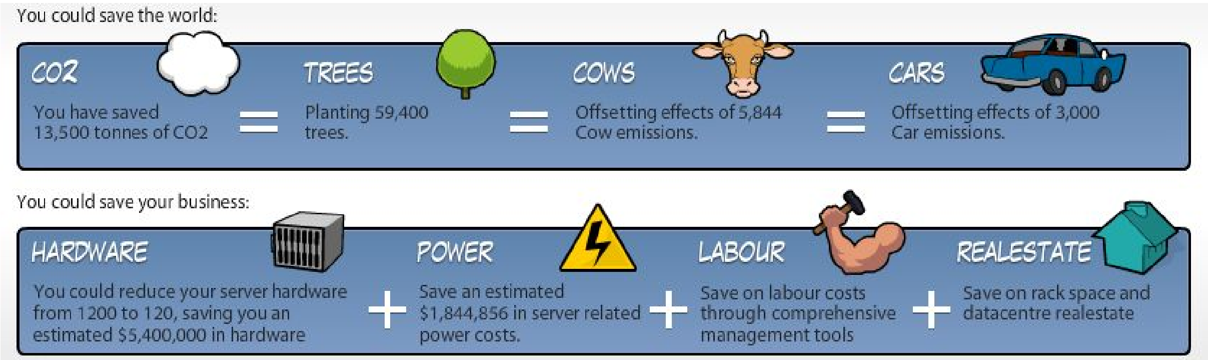


**Figure 19: Benefits of virtualisation for 1200 servers**

Source: Aint-that-the-truth.com 2009, modified by author

### Central controversies and open questions

- Concerns are raised over the security of data
- Bandwidth problems are a challenge and are caused by co-locating multiple workloads on a single system with one network path
- Technical implementation for the increase of hardware performance
- No simple or powerful tools to manage virtualisation

## 3.3 Cloud Computing

### Technological options and visions

Cloud Computing is a new and promising term for a long-held dream of computing as a utility, which has recently emerged as a commercial reality and can be defined as the combination of multiple discrete computers into larger metacomputers. Besides this, Cloud Computing is a computing paradigm in which tasks are assigned to a combination of connections, software and services accessed over a network. This network of (virtualized) servers and connections is collectively known as the 'cloud'. Whether it is called cloud computing or on-demand computing, software as a service, or the Internet as platform, the common element is a shift in the geography of computation. "Data and programs are being swept up from desktop PCs and corporate server rooms and installed in the computer cloud" (Hayes 2008). That means clouds are designed to provide services to external users.

The advantages of Cloud Computing to both end users and service providers are well understood. Service providers enjoy greatly simplified software installation, maintenance and centralized control over versioning; end users can access the service "anytime, anywhere", share data, collaborate more easily and keep their data stored safely in the infrastructure. Users need not have knowledge of, expertise in, or control over the technology infrastructure "in the cloud" that supports them. The concept of Cloud Computing incorporates infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS) and other recent technology trends.

Computing at the scale of the cloud allows users to access supercomputer-level power. The vast processing power is made possible through distributed, large-scale cluster computing, often in concert with server virtualization software and parallel processing. Cloud Computing can be contrasted with the traditional desktop computing model, where the resources of a single desktop computer are used to complete tasks, and an expansion of the client/server model. However, Cloud Computing is simply a buzzword used to repacked grid computing (or the use of a computational grid) and utility computing (when a cloud is made available in a pay-as-you-go manner to the general public like Amazon Web Services). Like Grid Computing, Cloud Computing requires the use of software that can decide and distribute components of a program to thousands of computers. New advances in processors, disk storage, broadband, and certainly fast and inexpensive servers have all combined to make Cloud Computing a compelling paradigm.

### Expected reduction in GHG emissions

The effect of cloud computing on GHG-savings strongly correlates with market penetration of the technology. Industry analysts have made highly optimistic projections on how Cloud Computing will transform the entire computing industry. For example, Gartner says, that Cloud Computing will be as influential as E-business and has the potential to change the status quo in the IT market (Gartner 2007). As shown in Figure 20, Gartner estimates that Cloud Computing will be founded in the next five years. Because of the predicted market potential this offers a high reduction potential of GHG emissions. According to a recent Merrill Lynch research note[15], Cloud Computing is expected to be a "$160 billion addressable market opportunity, including $95.0 billion in business and productivity applications and another $65.0 billion in online advertising".

[15] http://financialpost.com/money/story.html?id=562877

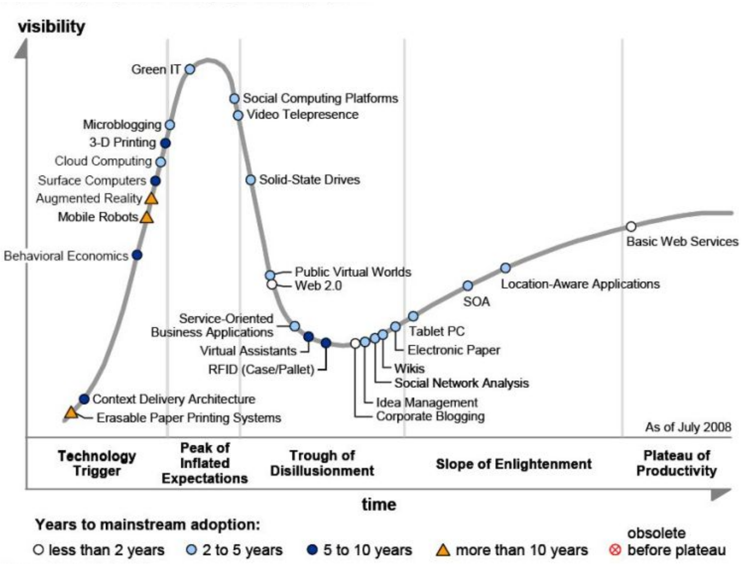


**Figure 20: Relative Power Consumption of Office ICT Equipment for the year 2002**

Source: Gartner 2008

## Central controversies and open questions

The future of Cloud Computing seems to be unclear. It's not just that servers must respond to hundreds or thousands of requests per second; the system must also coordinate information coming from multiple sources, not all of which are under the control of the same organisation. The pattern of communication is many-to-many, with each server talking to multiple clients and each client invoking programs on multiple servers. At present, service providers have inflexible pricing, generally limited to flat rates or tariffs based on usage thresholds, and consumers are restricted to offerings from a single provider at a time. Also many providers have a proprietary interface to their services thus restricting the ability of consumers to swap one provider for another. For a successful development of Cloud Computing, it is required that the services follow standardised interfaces. This would enable services to be commoditised and thus, would pave the way for the creation of a market infrastructure for trading in services. Finally, Cloud Computing raises questions about privacy, security and reliability, so Cloud Computing uptake has only recently begun and many systems are in the proof-of-concept state.

# 4. Concluding Remarks

This report illustrates that a wide range of ICT-related technological options and developments in quite different fields exist, that already contribute or have the potential to contribute to a significant reduction of GHG emissions and, thus, to the mitigation of climate change. On the one hand, it was shown that ICT is a highly crucial enabling technology for the mitigation of climate change. Various ICT-applications in different sectors enable energy savings, increased energy efficiency and a reduction of GHG emissions. In four selected areas, the relevance of ICT for the reduction of GHG emissions was elaborated in more detail. It was shown that these saving potentials are by far larger than the 2% stemming from ICT as an energy consumer. The Climate Group calculates in the SMART 2020 report, that, in total, ICT could deliver 7.8 Gt $CO_2$e emissions savings in 2020, which represents about 15% of global GHG emissions in 2020 (based on a BAU estimation; The Climate Group 2008, page 9). According to theses calculations, the 7.8 Gt $CO_2$ are mainly covered by ICT applications in the following fields: Smart Motor Systems (0.97Gt), Smart logistics (1.52Gt), Smart buildings (1.68Gt) and Smart Grids (2.03Gt).

In view of ICT as an enabling technology, it was shown in all of the four selected areas that significant technological progress and organisational innovations with strong relation to ICT are expected to further tap energy saving potentials in the next decades. Many advanced approaches are discussed:

- Electricity Grids could become intelligent systems with flexible, controlled power flows supported by advanced information technology (EC 2006c, page 23). They will enable decentralised generation of energy and a high share in renewable energies;
- In smart homes, ICT based "personal agents" might assist the user in all daily routines, also by saving energy;
- In transport; trips could be avoided by virtual meetings; Intelligent transport systems will enable an highly efficient transport system;
- Also in the industrial sector, measuring and control technologies together with the corresponding software are crucial for realising potentials for saving resources. Probably the most striking saving potential that is strongly linked to ICT can be identified for electric motor efficiency.

On the other hand, there are measures and concepts which are reducing the energy consumption of the ICT itself. The overall contribution of ICT to climate change is estimated to be around 2%.

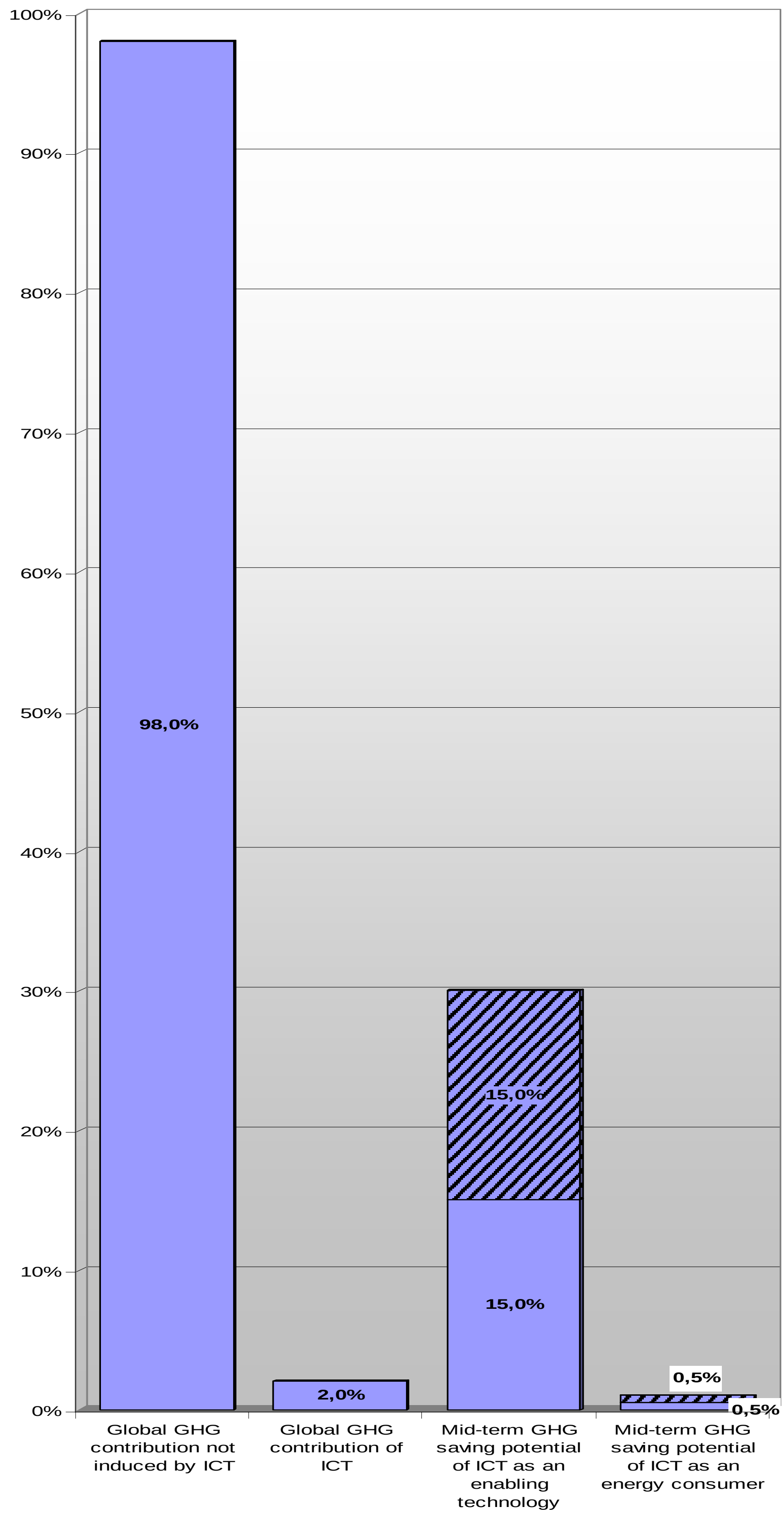


**Figure 21: Tentative assessment of ICT contributions to reduce GHG emissions in a mid-term perspective** (until approx. 2020). In particular the dashed parts of the bars are only rough estimations.

In Figure 21 a tentative assessment of ICT contribution to reduce GHG emissions in a mid-term perspective (until app. 2020) is presented. In particular the dashed parts of the bars are only rough estimations. The two bars to the left illustrate that the approx. 2% ICT-contribution to GHG emissions are rather small compared to the overall amount. The bar to the right indicates that there are saving potentials. It was highlighted in chapter three that future growth rates in ICT will probably be impressive, especially in the emerging countries, so the potential as well as the need for savings will also increase. Figure 17 shows that the global power consumption of data centres doubled between 2000 and 2005 – a five years period only. Even if the 2% are a comparatively small amount, these saving potentials are important because of the expected growth rates. So, it is crucial to focus as well on tapping the full potential for the reduction of energy consumption induced by ICT. Recently, the heavily growing amount of energy consumption induced by ICT has attracted a lot of attention. The terms "Green computing" or "green ICT", both referring to environmentally sustainable computing or ICT, is mentioned quite often in newspapers as well as in technical reports and scientific journals

Strong growth is as well projected for global energy consumption in general (IEA 2006). The third bar in the chart illustrates the potential contribution of ICT as an enabling technology for the reduction of GHG emissions in a mid term perspective. Important reference is the 15% calculated by The Climate Group (see above). Especially if a higher share of renewable energies would be implemented in this period, the potential might be even higher; however, what is indicated in the dashed section of the bar is a rough estimation not based on solid data. But it can be concluded that the energy consumption of ICT is relatively small compared to the potential of ICT as an enabling technology. The net effect of ICT on climate change is clearly positive.

Looking at the published knowledge in this field, it becomes obvious that there is broad uncertainty on the reliability of data, since ICT are in general embedded in complex systems, which makes it difficult to isolate and quantify their impacts. In this project many studies have been analysed and discussed with experts. On this basis, it can be stated that the support of ICT as well as its consequent implementation and use is highly essential for combating climate change and, at the same time, to retain a high standard of living in industrial countries and give people in developing and emerging countries the chance to raise their standard of living.

ICT is indispensable for decoupling economic growth from GHG emissions. Only with a high degree of organisation and co-ordination activities is a successful realisation of the following three basic strategies for mitigation of climate change imaginable.

1.) A reduction of energy consumption;

2.) An increase of energy efficiency;

3.) An integration of renewable energies.

Many ICT-related options, ideas and vision are discussed in the context of these three strategies. Most of them rely on a better availability and communication of information. This improved availability and communication of information needs technology, "Information and Communication Technology", to be widespread and effective.

This project, as well as many other studies that have recently been published, is designed in a "comprehensive" way, by looking at the whole range of ICT application in the light of climate change. On basis of this approach it is possible to illustrate, that the various linkages between ICT and GHG emissions are of quite different character and nature.

Looking at the four selected key-areas on the enabling side, smart homes, smart buildings, transport and industrial processes, it becomes obvious that a wide range of different information and communication technologies are needed. The three strategies mentioned above are of different importance in the selected key-areas. So it is clear that there is not one general solution which could be pushed by one or two policy measures. However, this study makes clear that general progress in ICT can help to realise many of the options mentioned above, as long as this progress makes, at least in the mid-to long-term, ICT cheaper, smaller or increasingly productive and more easily usable. Looking at the immense importance of ICT for mitigation of climate change, which has been verified with this report, it can be stated that further general progress in ICT is needed to combat climate change. For several applications, for example in smart homes or in intelligent transport, it is likely that further penetration of daily routines by ICT, a trend that is also named "ubiquitous computing", will pave the way for more interest in, acceptance of and willingness to pay for ICT-based solutions. For instance, if concepts such as ambient assisted living (AAL) prove their advantages and achieve widespread diffusion, the users will become familiar with ICT-applications that are supporting daily routines

Apart from the general statement on innovation and progress in the ICT sector, there is a set of policy measures (and areas) that are of special importance for several areas. Amongst those are emission trading, implementation of the top runner model, energy efficiency labels as well as mandatory audits and information strategies. Price signals are the decisive lever in many concepts and visions. They are crucial for realising many technological options. These policy measures have to be adapted to the different areas of application and the corresponding, also country specific, socio-technical environment to make them work effectively. Furthermore, very specific measures are required for several applications and contexts. As it was show in the section on transport, for some measurements possible rebound effects need to be considered carefully.

The collection of different ICT-based applications in this report illustrates that, with the help of ICT, GHG emissions in general and energy consumption in particular could be reduced heavily, at least from a technical point of view. However, identifying and quantifying saving potentials is one thing, realising them is another issue. The realisation of options, the implementation of technological alternatives depends heavily on the socio-technological environment, on individual preferences as well as on political situations and strategies. What is also needed are changes in behaviour, habits, in awareness levels and corresponding political measures to realise and develop these potentials. Action and activities are needed including innovative policies as well as research and development activities.

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# 6. Annex: Important linkages between ICT and Climate Change

| Technological Approach | Character / Lever | Expected benefits and saving potential | Crucial Questions and scientific controversies | R&D and policy strategies |
|---|---|---|---|---|
| **Energy generation and distribution: Smart Girds (Internet of Energy)** | Smart grids enable two-way flow of information and voltage<br><br>All elements of the network (producers and consumers) should be able to exchange information<br><br>Enables reliable predictability of energy consumption<br><br>Key-technologies for the integration of larger amounts of fluctuating and decentralised renewable energy sources | ICT plays a key role for the integration of renewable energy and for tapping corresponding potentials for GHG-savings<br><br>The reduction potential for carbon of the smart grid technology in the year 2020 is estimated to be some 2.03 Gt $CO_2e$ (Climate Group 2008) | Technical reliability and organisational challenges of smarts grids and distributed generation<br><br>Technical, organisations and political obstacles for the implementation of smart grids<br><br>Potential of renewable energies that can be tapped in Europe<br><br>Exact Climate effect of smart grids | Demonstration projects or lighthouse projects to obtain a better empirical basis for the future development<br><br>Better organisation and integration of different technologies and contributors (Standardisation of systems)<br><br>Research on technical and commercial integration of decentralised and centralised systems<br><br>Research on the transmission capacities of networks |
| **Intelligent buildings** | Entails smart metering, building control systems, home automation | Savings potential up to 15% (Darby 2006) | Consumer behaviour is difficult to predict / Effects of price signals | Demo activities for better understanding of consumer behaviour |

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|---|---|---|---|---|
| | Measuring and visualising (rising awareness) energy consumption to detect saving potentials and corresponding options for actions<br><br>Enable two-way flow of information (see smart grids) | | Design of user-technology interfaces<br><br>Effect of metering: do we need individual solutions designed for different types of users?<br><br>Questions of reliability, security and privacy have to be tackled | Empirical test of acceptability, user-technology interfaces and effect of price signals<br><br>Test of meters |
| **Technological Approach** | **Character / Lever** | **Expected benefits and saving potential** | **Crucial Questions and scientific controversies** | **R&D and policy strategies** |
| **Transport: Telematics** | Real-time information available for the individuals via navigation systems, internet or mobile phone<br><br>Communication between vehicles possible<br><br>Control and guidance, road pricing, parking, assistance, freight and fleet control and management | avoid congestion and improve traffic flow → reduction of travel-time and emissions<br><br>reduction of 25% of fuel consump-tion and $CO_2$ emissions for EU (Kompfner and Reinhardt 2008)<br><br>Estimated saving potential for “smart logistics” is 1.52 Gt $CO_2$e for 2020 (The Climate Group 2008) | Understanding Consumer behaviour in complex systems<br><br>More knowledge on the potentials to be expected from guidance and control mechanisms needed | More demonstration projects<br><br>Better management and organisation of transport |

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|---|---|---|---|---|
| | | 16% reduction in transport emissions and a 27% reduction in storage emissions globally (The Climate Group 2008) | | |
| **Transport: Virtualisation** | Video conferences, HP Halo, Telework, Teleshopping, online banking | ETNO/WWF: If 20 % of business travel in the EU were replaced by audioconferencing, videoconferencing or telepresence, then 25 million tonnes of $CO_2$ might be saved annually by 2010.<br><br>If 10 percent of EU employees became telecommuters or flexi-workers, another 22 million tonnes of $CO_2$ might be saved annually (AeA 2007) | Potential of modal shift is discussed<br><br>More knowledge on possible rebound effects is needed | Promoting the substitution of transport by “virtual mobility” |
| **Technological Approach** | **Character / Lever** | **Expected benefits and saving potential** | **Crucial Questions and scientific controversies** | **R&D and policy strategies** |
| **Transport: Dematerialisation** | Not goods but information is travelling | Avoidance of production and transport of goods and raw materials | Controversy on the potential of dematerialisation is discussed | More studies and demonstration projects on behavioural changes |

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|---|---|---|---|---|
| | Concrete substitution of material goods by ICT products: e-mail, e-books; virtual answering machine, taxation or other services that can be used via internet | | Consumer behaviour in terms of technology adoption is difficult to predict and calculate | A target could be set that 20% of households in EU-15 countries (31 million) should have one physical product replaced by a virtual solution (in the case of a virtual answering machine this would mean more than 1 million tonnes of $CO_2$ reduction)" (Pamlin, Szomolanyi 2008 |
| **Industrial processes** | Optimisation of processes leads to a reduction in energy consumption<br><br>Measuring and control technologies are crucial for realising potentials for saving resources<br><br>In particular electric motors in industrial processes offer saving potentials | The Climate Group (2008) estimates that by 2020 10% of China's emissions will come from motor systems alone. An improvement of industrial efficiency would deliver 200 Mt $CO_2$e savings.<br><br>Emissions saving potential up to 20% is estimated (WWF 2008) → worldwide potential of GHG emission reductions from industrial processes is 2000-5100 Mt $C0_2$ in 2030<br><br>Saving energy means saving costs as well | Lack of data on potentials<br><br>Research on Market penetration, market barriers (initial capital costs?) needed | The significant lack of data on the climate effect caused by industrial processes should be ameliorated<br><br>Demonstration projects needed to convince potential early adoptors of new technologies |

| Technological Approach | Character / Lever | Expected benefits and saving potential | Crucial Questions and scientific controversies | R&D and policy strategies |
|---|---|---|---|---|
| **Data centres / server farms** | Energy needed for servers and cooling of server farms<br><br>Higher efficiency of renewable energy-powered server farms | In 2005, around 1% of the worldwide power consumption was needed for servers, their cooling and their accessories<br><br>Power consumption of the approx. 50.000 data centres in Germany totalled at 8.67 TWh in 2006 ( = three mid-sized coal power plants (Borderstep) | Sensor networks<br><br>New network architectures (trade-off between the power consumption analog and digital hardware blocks)<br><br>Improving the energy efficiency of components up to the level where energy autarchy can be reached | Use of high temperature electronics and alternative energy backup solutions, instead of batteries<br><br>Energy aware strategies for distributing computing and data storage, to enable next generation peer-to-peer and content distribution services at minimum energy consumption |
| **Virtualisation** | many virtual machines are simulated on a single physical machine and allow more efficient usage of computer resources<br><br>One larger server can host many guest virtual machines, which enables savings of energy and raw materials | Estimated energy consumption decreases by 80%. Every virtualized server saves 7,0000 kWh and 4 t $CO_2$ / year (Vmware)<br><br>→ Estimations for Mt $CO_2e$: Reduction of 80 Mio t $CO_2$ emissions / year worldwide | Security of data<br><br>Bandwidth problems are a challenge, and are caused by co-locating multiple workloads onto a single system with one network path<br><br>Increase of hardware performance | Many systems are in the proof of concept state > should be further promoted |

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|---|---|---|---|---|
| **Cloud Computing** | The delivery of computational resources from a remote location: strongly internet-based development and use of computer technology. Includes software as a service" concepts meaning that software and data are located on a server that is accessed from a web-browser via internet | Saving energy and resources | Cloud Computing raises questions about privacy, security, and reliability of data | Many systems are in the proof of concept state > should be further promoted |