Comparative inventory model of conventional end-user devices and thin clients

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Abstract

In the German technology program IT2Green, heterogeneous approaches for the improvement of the energy efficiency of ICT systems are developed. IT2Green shows the considerable environmental improvement potential in the field of high efficient data centres and telecommunication infrastructure (load-adaptive operation and utilization of renewable energy).

At the same time, storage "in the cloud" and "Software as a Service" applications become more widely used in the business and private sector. Such applications reduce the necessary hardware at the user side, but increase the data traffic for the telecommunication networks and the computing load in data centres.

Against that background, the paper investigates the improvement potential of a thin client-based ICT system. We will present a respective inventory model for a comparative long-term assessment of a conventional and a thin client-based ICT structure. A case study for PCs, notebooks and thin clients in a home and an office environment is investigated. Results for energy consumption in the use phase show that thin clients perform a lot better than PCs. However, notebooks are even more energy efficient than thin clients which results from the use additional display and servers when working with a thin client. When looking at the life cycle greenhouse gas (GHG) emissions, thin clients and notebooks are in the same range, both causing significantly less GHG emissions than PCs.

Introduction

Various studies [Koomey 2007; GeSI 2008; Stobbe 2009; Lange 2009, 2010, 2011; Hintemann 2010] indicate that information and communication technology (ICT) including end-user equipment in homes and offices, switches, routers and optical links in telecommunication facilities as well as centralized server and storage systems in data centre are a significant source of increasing electricity and resource consumption.

A study by Fraunhofer IZM and Fraunhofer ISI for the German Federal Ministry of Economy and Technology [Stobbe 2009] estimated that the ICT-related electricity consumption in Germany reached about 60 TWh in 2010. This amount translates into 10 % of the total German electricity consumption [UBA 2012]. With about 60 % (or more than 35 TWh), end-user equipment in the 40 million private households caused the largest share. The end-user equipment in offices and ICT in data centres had an even share of about 10 TWh each. The share of the telecommunication sector has been calculated to be 10 % or 6 TWh.

With respect to the future development the Fraunhofer study predicted a further increase in overall electricity consumption of ICT in Germany. The interesting point however is the change in the distribution of the ICT-related energy consumption. While the end-user equipment will maintain their level (although changes occur in the internal structure), the data centre and telecommunication sector is increasing in overall energy consumption. There are quite a few technical and economic factors influencing this development. The technical development and particularly the miniaturization along the line of Moore's Law improve the energy efficiency of electronic systems periodically. This positive trend is still valid, although technical and economic limits are conceivable and have been addressed in literature [Koomey 2009, Rupp 2011].

The main reason for the overall increasing energy consumption of ICT is however the still growing number of devices, the increasing utilization of the internet and the intensive production and consumption of digital videos in particular. According to the Cisco Visual Networking Index [Cisco 2011], the fixed line and mobile IP traffic will increase from 31 Exabyte per month in 2011 to 110 Exabyte per month in 2016. The global consumer internet traffic video alone will reach 45 Exabyte per month in 2016 being equivalent of 41 % of total IP traffic. Another interesting survey by Cisco, the Global Cloud Index [Cisco 2012], analysed and predicted the data centre and cloud traffic for the same time period. According to this study the global data centre traffic will grow nearly four-fold from 2011 to 2016 and will reach 554 Exabyte per month in 2016. In conclusion, data centre traffic is not only an indicator of the intensifying use of data centres; it also indicates the continuously growing demand with respect to data processing and storage capacity as well as bandwidth and latency.

This increasing utilization of ICT and related demand in performance is currently compensating the technical improvement potential in terms of energy consumption. While it is quite simple to calculate that the electricity consumption of ICT increases to some extent proportionally with the number of products and daily hours of use, it is much more complicated to calculate the impact on energy consumption of the growing data traffic and cloud computing application.

Furthermore, it is important to recognize the nowadays relatively short active use cycles of ICT equipment as well. The generally fast turnovers in technology still improve to some extent the overall environmental performance of larger ICT equipment such as enterprise servers or routers. But with increasing energy efficiency and in light of the resource consumption for the production of ICT it becomes apparent to consider the total environmental footprint of ICT. It is therefore necessary to focus the environmental assessments and subsequent product improvements (ecodesign) on the whole life cycle of a product and the complex system in which the product is integrated.

In this paper we will describe the concept and application of a multi-level inventory model which has been applied for the environmental assessment of network-based ICT systems. This model is reproducing the data traffic path (back and forth) from the end-user equipment via the telecommunication network to the server and storage systems in data centres. It incorporates technical, operative, and economic data in order to support a layered, life cycle oriented assessment of the ICT's environmental impact on a technical and economic level. Based on the example of a comparative environmental assessment of personal computers, notebooks and thin clients we will demonstrate the application of this multi-level inventory model.

Specific characteristics of ICT and related environmental assessments

The term Information and Communication Technology (ICT) will be used in this paper for describing the hardware and software that allow end-users to access and utilize the internet. On a system level, ICT are complex chains of equipment that are linked in networks. On a product level, ICT is based on electrical, electronic, optical, and mechanical devices that provide the functionality for an analogue or digital input/output and the processing, storage and transmission of data. In terms of equipment, ICT comprises of stationary and mobile end-user devices, local and wide area network equipment, as well as servers and storage systems. Larger ICT systems in data centres or telecom facilities require a considerable support infrastructure. This may include power distribution units (PDU), uninterruptable power supply (UPS) as well as equipment for heating, ventilation and air conditioning (HVAC).

The assessment of environmental impacts related to ICT and the utilization of the internet needs to reflect this complex technical sphere. The characteristic feature of ICT is the network and the respective interaction of linked network elements. This interaction needs to be incorporated in the inventory model of the environmental assessment on various levels. An example can be given for the data transmission. A certain amount of data transport and transmission speed translates into bandwidth requirements. If the bandwidth requirements increase, changes may occur in respect to the number or type of network equipment, the actual network topology and routing. These changes are consequently influencing the inventory model and will affect the respective environmental impact analyses. The following paragraphs describe the objective and principles of the multi-level inventory model that is utilized for the environmental assessment of complex ICT systems.

Objective of the multi-level inventory model

The multi-level inventory model intends to reproduce the complexity of existing ICT systems including networks and data centres. In theory the model-based approach should allow for an adequate approximation of reality. However, the granularity and precision of the model and the subsequent environmental impact assessment depends on the availability of actual data. As a matter of fact, data availability is the true bottleneck considering that ICT is not only a permanently changing system like a living organism but also highly sensitive with respect to user data and data security.

In order to compensate for these variable conditions (data gaps) and achieve a justified approximation, the multi-level inventory model incorporates profound technical and operational knowledge, market data, and available use-related information. The inventory model is basically a consequent LCA approach with individual equipment modules that are linked and structured for aggregation on sectoral level.

The technical and operational knowledge is for instance supporting the identification of metastable elements as a constant in the model. According to a large telecommunication provider the core network's peak throughput capacity and routing rules for example, are adjusted on national level typically only once a day. Load adaptive core networks are not yet realized, but might be an option with the transition to fully IP and new optical technologies in the mid-term. Due to this understanding it is possible to allocate a constant energy consumption and equipment footprint to the core transport network. This also means that nowadays the core network does not fluctuate considerably in its daily energy consumption and that there is therefore no correlation between the individual data traffic of end-users and the core network. The identification of such cause-effect relationships is important. In the model, cause-effect relationships translate into constants, threshold values, and scaling factors.

The multi-level inventory model is not only a useful tool for the identification of significant environmental impacts but also for the analysis of improvement options and strategies. The various aggregation levels and therefore options for incorporating existing data are supporting cross reference analysis. The idea is to use the vertically layered and horizontally networked structure of the inventory model for the identification and evaluation of those ICT elements that contribute significantly to the environmental and economic impacts. The main characteristics of the multi-level inventory model are:

- Network based model following data traffic path.
- Layered structure with individual technology and equipment data at the bottom and multiple aggregation layers on top.
- Top-down and bottom-up parameterization possible (technical, environmental and economic data).
- Considerable analytic and cross check capability.
- Intended use for technology impact analysis, ecodesign support, and evaluation of improvement options.

Elements and principle structure of the multi-level inventory model

Similar to a conventional life cycle assessment it is necessary to define at first the scope and boundaries of the multi-level inventory model. The term "multi-level" indicates that the scope of the inventory is easily extendable under the condition that the data sets can be linked and computed. One condition is that the same impact categories are utilized and that the individual parts are scalable e.g. through stock data, time dimensions, or performance indicators. The overall scope and selected impact categories determine to some extent the functional unit. The multi-level inventory model distinguishes between:

- Economical scope: e.g. private household, enterprise, national or global level.
- Technical scope: e.g. single equipment, aggregated equipment, support infrastructure/overhead.
- Time scope: e.g. annual, single life cycle, multiple life cycle.

The multi-level inventory model consists of a hierarchical structure with the equipment or product level at the bottom and various aggregation levels stacked on top. The aggregation levels reflect the averaging of similar equipment (product groups) as well as the combination and interaction of different equipment defining a system. Figure 1 illustrates the principle structure.

ARCHITECTURE LEVEL

The top layer of the multi-level inventory model basically defines the network architecture and respective communication technologies. This level provides the basic technical structure and distinguishes individual networks, service sectors and larger facilities or services. Horizontally, the model distinguishes between:

- The end-user sector and respective equipment including personal computers, mobiles, local area network and customer premises equipment.
- The telecommunication network including fixed line and mobile access network, the metro or aggregation network, as well as the core or transport network.
- The data centre with server, storage and network equipment.

For the assessment of internet or cloud services each of these parts need to be technically described, quantified and scaled to the other two parts. On this level it is possible to define the scope for a specific analysis. The data on this level are aggregated results from the lower levels.

TOPOLOGY AND UTILIZATION LEVEL

Below the architecture level the model combines the individual topology and utilization schemes. On the topology level, we define aggregated hardware. This includes specific network, data centre and end-user equipment. The model utilizes stock data for selected product groups or equipment categories. The support infrastructure or overhead is also considered on this level and applies, for instance, factors such as power usage effectiveness (PUE). This level also describes the links and scal-

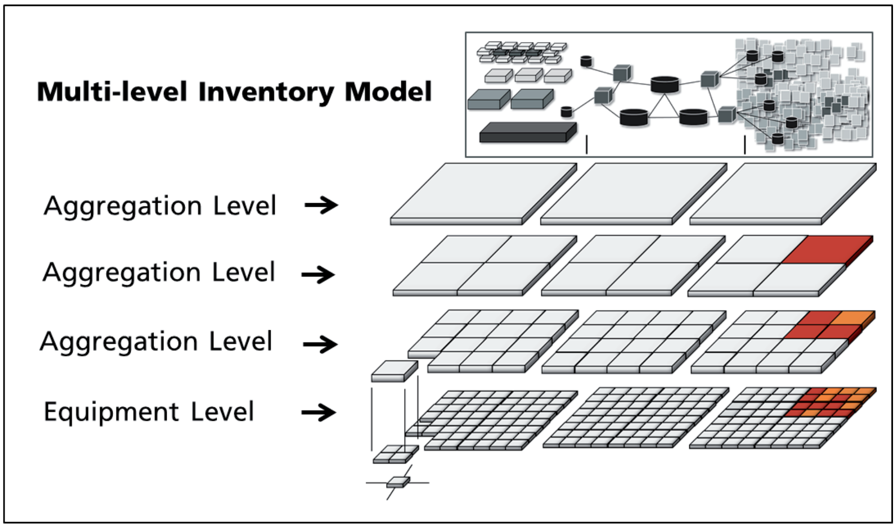

Figure 1. Multi-level inventory model.

ing factors e.g. between individual network elements based on throughput capacity. The topology level is closely linked to the utilization. The utilization adheres e.g. to the volume of data traffic, typical equipment load, maintenance cycles and product lifetime.

EQUIPMENT LEVEL

On the equipment level, individual or slightly aggregated product life cycle assessments are employed. This is the foundation of the multi-level inventory model. On this level we compile technical data such as typical product configurations (e.g. processor, storage, network, and display), power consumption per modes or load utilization as well as power supply efficiency. The environmental impact of all life cycle stages including production, distribution, and end-of-life are considered for instance by calculating the carbon footprint. On the equipment level it is possible to investigate individual devices, components or processes.

Thin Client Case Study

Cloud computing and thin clients are interwoven concepts that are currently changing the way ICT hardware and software are designed and employed. The characteristics of cloud computing have been defined by the following five features [Norkus 2012]:

- On-demand self-service
- Resource pooling
- Rapid elasticity
- Measured services
- Broad network access

The cloud computing services provided are ranging from Infrastructure as a Service (IaaS) where customers still control platforms and application to Software as a Service (SaaS) where the customer is only selecting and customizing his own application demand. Thin clients are hardware and software reduced interfaces that allow accessing cloud services (run on servers and storage systems) via a local or wide area network and link them to a display. The thin clients are assumed to be more energy and resource efficient than conventional personal computers and even notebooks.

In the following case study, we will investigate the environmental implications of a thin client and cloud computing concept when implemented in home or office environments. The objective of this case study is to compare for a single product scenario the energy consumption per year and per life cycle for PCs, notebooks and thin clients. In order to indicate an order of magnitude, the results for individual products are extrapolated to market scale.

The overall model can be basically divided in three parts:

- End-user equipment
- Server
- Telecommunication network

Each of these parts has to be assessed, quantified and scaled to the other two parts. The individual data and assumptions on the three parts are described in the following sections.

Thin clients need an infrastructure consisting of a server for computing and a storage network. For the office scenario it is assumed, that modern office systems have already a server-based storage system in place and user data is not stored locally. Therefore, the office scenario for thin clients includes only the additional server for computing. The product systems to compare are:

- PC and display
- Notebook
- Thin client, display, plus:
  - Home scenario: servers for computing, centralized storage
  - Office scenario: servers for computing

LAN Routers will be included in the calculation to cover all products installed at the end-users home or office for online activities, but no difference will be made between PCs/notebooks and thin clients as pure offline use of PCs is not very common any more.

END-USER EQUIPMENT

Use Pattern

To estimate the yearly energy consumption, average use patterns for the different product groups are needed. The use patterns used in this model are derived from Stobbe 2009. For the thin clients comparably shorter time for transition into standby is assumed. Therefore the use pattern for thin clients is based on the notebook use pattern (see Table 2 and Table 3).

For a realistic use pattern, it is assumed that the products are not used 365 days per year. For the office scenario, 240 working days per year and therefore 240 days of use are assumed. For the home scenario, two weeks holidays per year without PC use are assumed, so the scenario is based on 350 days/a usage. LAN routers are an exception. They are assumed to be always on (24 h/day, 365 days/a). Non-use days are not set to zero energy consumption but were calculated as 24 h in off mode.

Power Consumption per Mode

Different sources state different power consumption for the equipment. The actual consumption depends on the individual product and the performance parameters. High performance PCs normally have a comparable high energy consumption in active/idle. The consumption in active mode depends not only on the hardware but to a large share on the installed software and the applications used. The following Table 1 states figures by Stobbe 2009, Knermann 2011, Fichter 2011 and average values of products listed at EU Energy Star[1]. Energy Star values include (except for displays) the whole product range listed in the data base. The average value for displays includes products with a display size between 17 and 30 inch.

1. EU Energy Star: www.eu-energystar.org (product list for desktop computer, notebook computers and Thin Clients exported 12/29/2012).

Table 1. Power consumption according to Stobbe 2009, Knermann 2011, Fichter 2011 and averaged Energy Star values.

Product	Active/idle [W]	Standby [W]	Off-Mode [W]	Source
Router	4.0			Stobbe 2009
W-LAN Router	10.0			Stobbe 2009
PC	117.0	10.0	2.5	Stobbe 2009
	63.0	8.0	2.0	Fichter 2011
	132.3	6.5	2.5	Average values of workstations listed by EU Energy Star
	41,7	2,3	1,1	Average values of desktop PCs listed by EU Energy Star
Notebook	35.0	3.0	1.0	Stobbe 2009
	28.0	3.0	0	Fichter 2011
	10.8	1.1	0.6	Average values of notebooks listed by EU Energy Star
Display	30	1	1	Stobbe 2009
	20.4	0,5	0,4	Average values of displays between 17 and 30 inch listed by EU Energy Star
Thin Client	11.0	2.0	0.7	Fichter 2011
	11.5	1.9		Knermann 2011
	12.0	1.8	1.3	Average values of thin clients listed by EU Energy Star

Servers for Thin Clients

When assessing the additional energy consumption caused by server use for thin clients, the following figures are important:

- Use pattern of the server
- Energy consumption of the server
- Number of clients per server

Based on these figures, the respective server share power consumption per client can be derived. The values for this power consumption per client vary in literature due to different reasons: fast technology development on the one hand (e.g. new and more efficient server hardware); individual installations of the thin client concept based on the specific needs of the company on the other hand (e.g. how many clients per server, individual PUE[2] of the data centre).

Knermann states an energy consumption of 2,413.8 kWh/a per terminal server (incl. cooling overhead) and 130 clients per terminal server (2011), which results in a yearly consumption of 18.6 kWh/a per client. These figures are based on an existing installation at Fraunhofer UMSICHT. Fichter 2011 states an energy consumption of 87.3 kWh/a per client. This is based on a yearly energy consumption of 3,968 kWh (incl. overhead) per terminal server and the following share rate:

- 50 clients per terminal server for server-based computing (90 % of time)
- 25 clients per terminal server for hosted virtual desktop (10 % of time)

The number by Fichter 2011 is more than four times higher than the figure stated by Knermann 2011. The considerable difference between these figures results from:

- Lower power consumption of the terminal server in Knermann 2011
- Lower PUE (1.7 compared to 2.0) in Knermann 2011
- More clients per terminal server (130 compared to 50) in Knermann 2011

Both concepts are for thin clients in an office environment where centralized storage already exists for conventional PCs. Therefore the figures do not include the consumption of the in-house network and centralised storage. This is assumed to be the same for the PC and the thin client model.

However, for a home scenario centralised storage has to be included as this would not be already in place for PCs or notebooks. Figures from Kemper 2012 include server and storage energy consumption. He states a yearly consumption of 26.9 to 53.9 kWh/a for new server equipment (based on the Energy Star use pattern for thin clients).

Home Scenario

For the home scenario, it is possible that more clients could be handled by one server due to the shorter daily use time and the more widespread time of use compared to the typical "office hours". Although the end-user time frames also follow typical patterns, it is usually more widespread. Graphs by DE-CIX show for instance, that even during night, the average traffic does not drop below 0.5 Tbit/s.[3] This could lead to a better utilization of the servers for an home scenario compared to an office scenario and therefore to a further reduced energy consumption per client.

Nevertheless, figures stated by Kemper 2012 were used as best available figures. The upper value for new server equipment is used to include centralised storage as well as cooling overhead.

2. Power usage effectiveness.

3. DE-CIX: Traffic Statistics 1-month graph, http://www.de-cix.net/about/statistics/ (accessed: 01/01/2013).

Table 2. Energy consumption and time per mode (home scenario).

Product	Active		Standby		Off-Mode		Power consumption
	[W]	[h/d]	[W]	[h/d]	[W]	[h/d]	[kWh/a]
Router	4	24		0		0	35
W-LAN Router	10	24		0		0	88
PC	90	4	2	7,5	1	12	152
Display	21	4,5	1	8	0,5	12	34
Notebook	28	4	1	8	0,5	12	44
Thin Client	12	4	2	8	1	12	27
Server consumption per client							54

Table 3. Energy consumption and time per mode (office scenario).

Product	Active		Standby		Off-Mode		Power consumption
	[W]	[h/d]	[W]	[h/d]	[W]	[h/d]	[kWh/a]
Router	4	24		0		0	35
PC	90	6,2	2	8,8	1	9	143
Display	21	7,1	1	10,4	0,5	6,5	40
Notebook	28	7,1	1	10,4	0,5	6,5	52
Thin Client	12	7,1	2	10,4	1	6,5	30
Server consumption per client							19

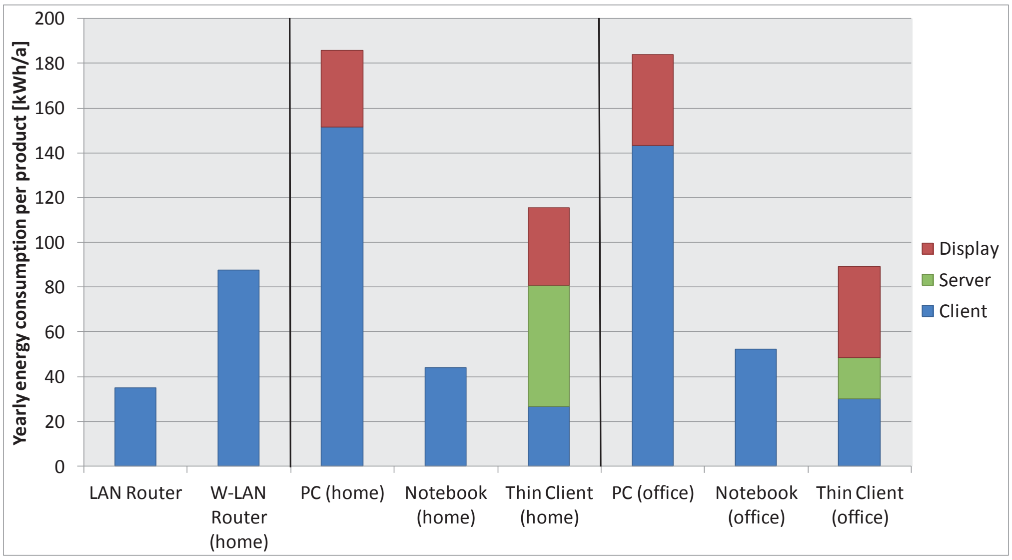

Figure 2. Yearly energy consumption per product.

Office Scenario

For the office scenario, energy consumption as stated by Knermann 2011 is used for the calculation to represent a state-of-the-art implementation of thin clients.

Power Consumption

Based on these sources, assumptions for the energy consumption were derived. The figures are mostly based on Energy Star values, to reflect recent products on the market although this might not in all cases reflect the actual market structure (e.g. number of high performance products, display sizes for notebooks). For the displays, it is assumed that installed products are mostly in the range of 20 inch. Therefore, very small and very large displays were excluded when assessing the average value in the Energy Star data base. However, figures by Energy Star represent idle values. The actual values during use are higher depending on the actual utilization. Table 2 states the power consumption and use pattern used and the aggregated energy consumption per year.

The results show that for both – home and office scenario – thin clients perform a lot better than PCs. PCs (incl. displays) consume about twice the energy of the thin client (incl. server, display). At the same time, it can be seen that notebooks have even lower yearly energy consumption (more than factor 4 difference between notebook and PC). The thin client itself has less energy consumption than the Notebook, but this is outweighed by the additional power consumption of the server and storage system as well as the additional display needed.

It can be seen that the additional power consumption for server varies between the home and the office scenario. This is due to the additionally needed centralised storage systems for the home scenario which is assumed to be installed in an office scenario anyhow, independent from the actual end-user product (PC, notebook or thin client).

If the notebook would be used with a dock-in station (and therefore with an additional display), the energy consumption of notebook and thin clients would converge. In an office scenario with a state-of-the-art server concept, the energy consumption would then be in the same range.

For a home environment, where an additional centralised storage is needed and dock-in stations for notebooks are more seldom, notebooks would be the better choice from the energy perspective.

Life Cycle Impact

Life cycle assessments of PCs, notebooks and servers show that the main contribution to the global warming potential comes from the life cycle phases "use" and "raw material acquisition/manufacturing". In most ICT cases, it can be stated that for stationary products with high energy consumption, the main contributor is the use phase, for smaller mobile products, the relative impact of the manufacturing phase increases.

One important aspect for the thin clients is that there is less electronic hardware needed by the end-user. However, the hardware demand shifts from the end-user to the data centre where additional servers are needed.. To show the overall impact of the different technologies, the results for the use phase are converted into CO_2-eq. emissions and compared with available CO_2-eq. emissions for the production of the hardware.

More and more manufacturers publish carbon footprint values for their products. These numbers, as well as scientific publications are used to estimate the range of carbon footprints for average products (see carbon footprint values published e.g. by Apple[4], Dell[5], EuP Lot 3, Knermann 2011). The differences between the published values have different reasons: Actual hardware differences between the assessed products are partly reflected, but also does the use of different data bases, the age of data and individual assumptions for each study influence the result significantly.

The following Figure 3 and Figure 4 show the greenhouse gas (GHG) emissions caused by the use and manufacturing phases. The use phase emissions are based on the above described use pattern for four years usage. The emissions related to manufacturing are presented as range to reflect the different figures stated by literature.

It can be seen that the manufacturing of thin clients itself causes less GHG emissions than the manufacturing of PCs and notebooks due to less electronics in the hardware. The emissions associated with servers are also comparably low as the total emissions of the server manufacturing are divided by the number of clients.

It can be seen that the use phase emissions of the PC outweigh the total emissions of thin clients and notebooks. The emissions of notebooks and thin clients are in the same range. Due to the high uncertainties, it cannot be stated which product is preferable.

4. Apple environmental reports: www.apple.com/environment/reports.

5. Carbon Footprint of Dell Desktops, Laptops, Mobile Devices and Servers: content.dell.com/us/en/corp/d/corp-comm/environment_carbon_footprint_products.

Stock Model and Replacement Scenarios

Home Scenario

For the CPE[6], one router per subscriber is needed. According to the Federal Statistical office of Germany, there are 83.3 internet accesses per 100 households in Germany (in 2011). Based on the 40.4 Mio households, this results in 33.7 Mio subscribers in Germany [destatis 01, destatis 02].

The number of PCs is also based on the "Continuous Household Budget Surveys" of the German Federal Statistical office. Based on these figures, it was assumed that there are 77.7 stationary PCs and 67.5 Notebooks per 100 households in 2011, which results in 31.4 Mio PCs and 27.3 Mio Notebooks [destatis 01, destatis 02]. The thin client concept is not yet established in households, therefore there are no installed products yet.

Office Scenario

The stock assumptions for the office scenario were based on Stobbe 2009 who estimates 16.6 Mio PCs and 5.8 Mio notebooks in German offices.

Based on the power consumption per year described above and the stock model, the energy consumption is scaled to market level in Germany. In Figure 5 and Figure 6, this is reflected by "BAU".

The above described yearly energy consumption identified the significantly lower power consumption of thin clients and notebooks. To show the improvement potential on market scale, different replacement scenarios are shown. Figure 5 and Figure 6 show the total energy consumption per year based on the current stock (2011) and when 30 % or 50 % of the PCs in use are replaced by thin clients or notebooks.

The replacement of desktop PCs by thin clients or notebooks could reduce the total energy consumption significantly. Home applications have a higher absolute improvement potential due to the higher stock. The relative saving potential in home and office application is similar.

The development of the stock in German households shows that the number of notebooks increased in the last years relatively to the number of PCs and absolutely [destatis 01]. The results of this case study show that the drift towards notebooks has a positive effect from an energy point of view.

For office environments, where centralized storage systems are already in place and mobile devices are not always a suitable choice, thin clients are preferable to PCs.

TELECOMMUNICATION NETWORK

The energy consumption and environmental impact of telecommunication networks has been assessed in the past based on different inventory models [e.g. Baliga 2008, 2009; Lange 2009, 2010, 2011; Hooghe 2011]. Existing studies differentiate between fixed line and mobile access networks, metro/aggregation networks and the core/transport network. The assessment

6. Customer premises equipment.

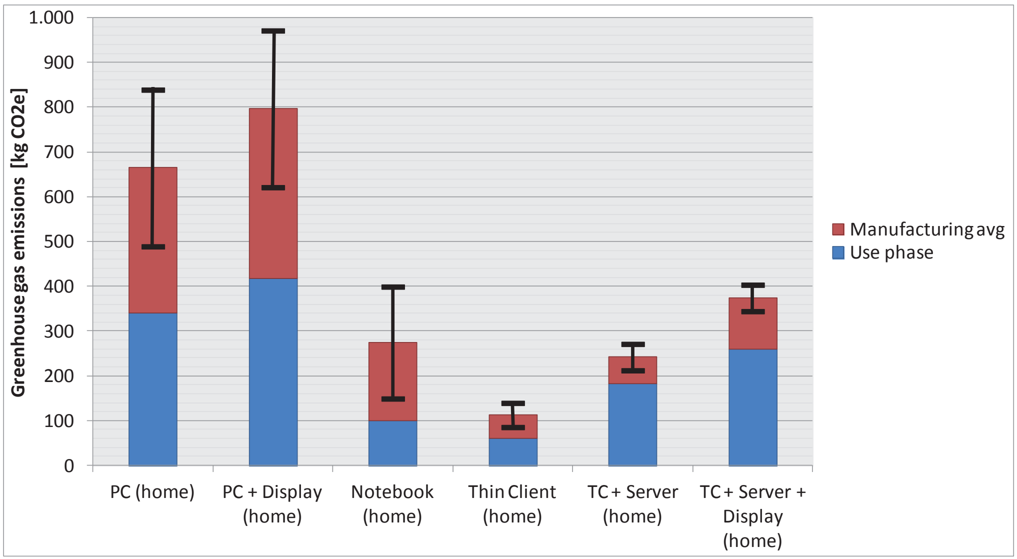

Figure 3. Greenhouse Gas emissions based on 4 years use time (home scenario).

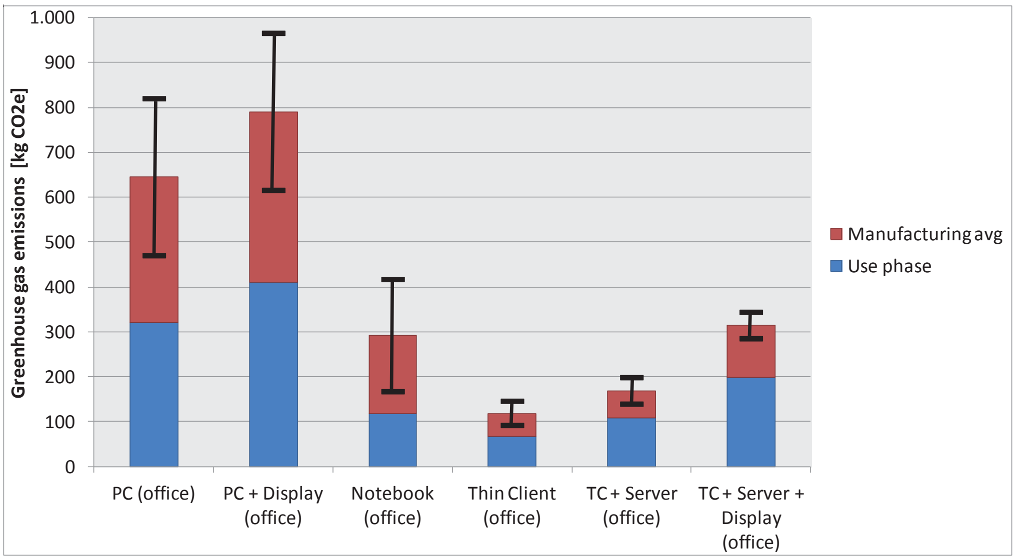

Figure 4. Greenhouse Gas emissions based on 4 years use time (office scenario).

methods and respective inventory models (network models) are diverse. At the present, no homogeneous network inventory model has been developed. Despite the methodical differences, most studies come to the conclusion that the energy consumption of the access networks correlates in general with the number of subscribers and the implemented technology. In the core network the energy consumption correlates with the peak data traffic and amount of legacy equipment that is still implemented.

Figure 7 shows the selected network model consisting of four main levels: the user's home network (CPE), the access network, the aggregation network, and the core or transport network.

The average data traffic as well as peak loads increased continuously over the past decade. This trend is expected to continue in the next years [Cisco 2011]. According to DE-CIX, the average data traffic increased from 0.4 Tbit/s in 2009 to 1.5 Tbit/s in 2012. The peak data traffic increased even further from 0.5 Tbits/s to 2.3 Tbits/s within the same period[7]. In order to handle the current increase of average data traffic and peak loads the capacity of the access, aggregation and core networks has been increased by implementing new technologies and additional hardware. In some cases, this new hardware replaces legacy hardware, so the replacement with new high-performance, but also more energy efficient hardware can be neutral or even positive from the energy point of view. However in most cases, the networks (and performance) expansion results in additional hardware which also means additional energy consumption.

For the power consumption of telecommunication networks and especially wired networks, there are not many figures available. According to Lehmann 2011, German landline operation of Deutsche Telekom alone consumes approximately 2 TWh

7. DE-CIX: Traffic Statistics 5-year graph, http://www.de-cix.net/about/statistics/ (retrieved: 12/11/2012).

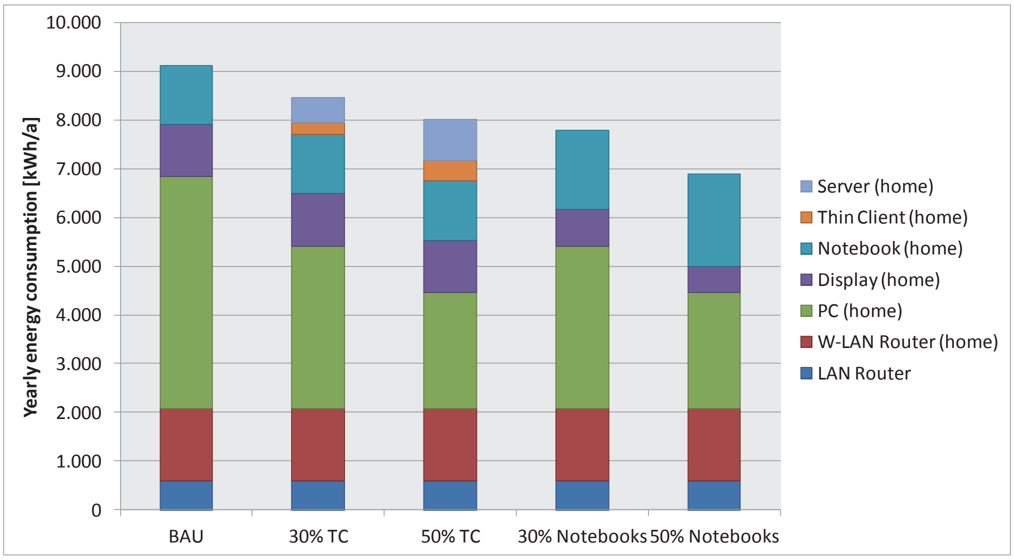

Figure 5. Yearly energy consumption of total stock and replacement scenarios (home scenario).

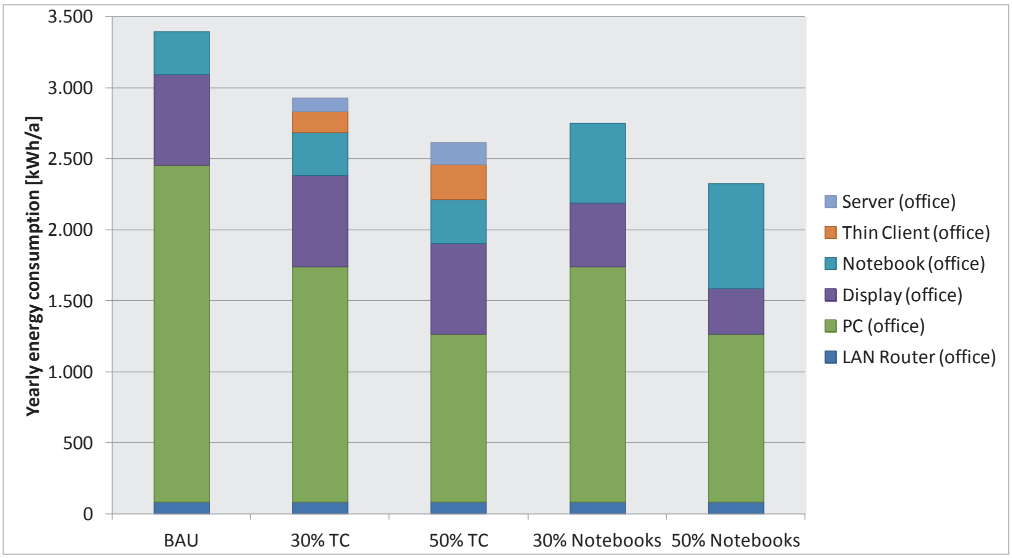

Figure 6. Yearly energy consumption of total stock and replacement scenarios (office scenario).

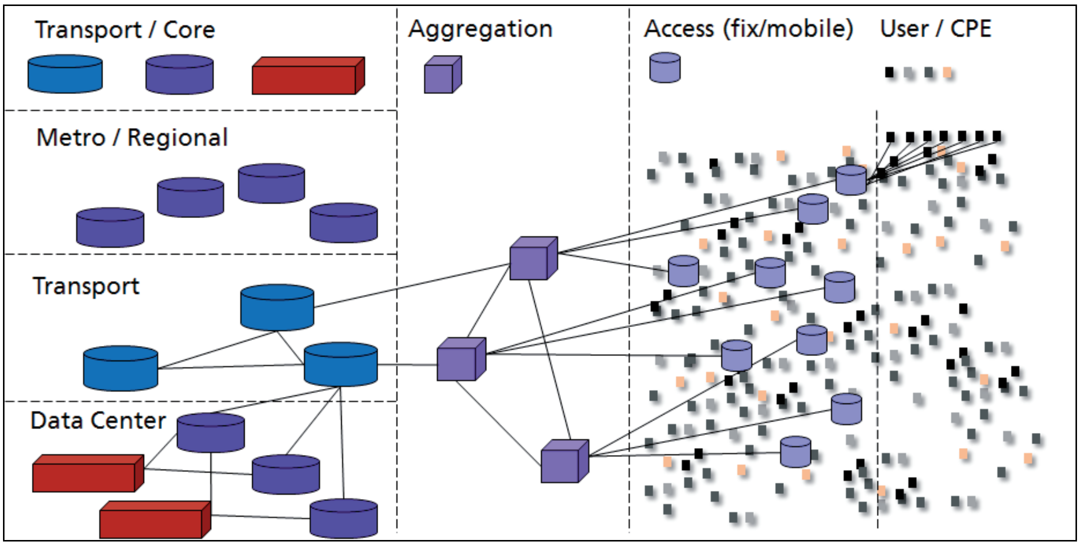

Figure 7. Network model.

Table 4. Telecommunication network equipment and related power consumption.

	Core Network	Metro/Aggregation	Access Network	End-user/CPE
Equipment Stock (Germany)	~50 Units IP/MPLS Router, Optical Link,	~10^4 Units 12-14 Nodes to Internet	~10^5 Units Skalierung: ca. 1 : 200–2,000	~10^8 Units CPE + PC, Notebook, Thin Client
Equipment Power (W)	200–20,000 W (not load adaptive)	1,000–5,000 W (not load adaptive)	500–2,500 W (not load adaptive)	10–300 W (load adaptive)

per year. Stobbe 2009 estimated an energy consumption of 3.3 TWh/a for the German wired telecommunication networks in 2010. The magnitude was confirmed by industry stakeholders. The energy consumption of the telecommunication networks is dominated by the access and aggregation level, but the impact of the optical transport level and backbone will increase [Lange 2011] due to the ongoing growth of peak traffic and the therefore needed expansion of hardware.

Bolla 2011 states an energy consumption of 414 GWh/a as a forecast for 2015, based on the Italian network. If this number would be scaled to the German number of households, this would result in about 950 GWh/a, which would be a lot less than the number stated by the Deutsche Telecom alone, although this is presented as the business-as-usual scenario by Bolla 2011. With "Green technologies" the network consumption could be reduced to 271 GWh/a for the Italian network (or 625 GWh/a scaled for the German network) [Bolla 2011].

Based on existing literature, a very rough approximation for the network energy consumption is made. According to Baliga 2009, packets traverse an average of 12–14 hops between source and destination in current networks. As this number refers to an "international" request (e.g. visiting a website, email by international providers), seven nodes are assumed for traffic connected with a regional data centre. According to the Code of Conduct for Network equipment, an access node consumes about 8.75 W per 100 Mbit/s. Based on product energy consumption data published in product data sheet by Juniper[8], an average power consumption of IP routers is ~0.7 W per 100 Mbit/s. This would result in a yearly power consumption of 117 kWh for a 100 Mbit/s access and 29 kWh for a 25 Mbit/s access per subscriber.

In comparison, the consumption of the German telecommunication network broken down to the number of products (home and office: 81 Mio units) would result in 41 kWh/a per subscriber. This second calculation confirms roughly the first estimate.

Life Cycle Impact

The life cycle impact of the telecommunication networks is dominated by the energy consumption in the use phase. The other life cycle phases (equipment manufacturing and deployment) have only a small impact due to very long use phase. According to Malmodin 2012, the life time of transmission equipment varies between 7 and 20 years and cables are in place up to 40 years. The LCA performed for the Swedish IP core network (which basic assumptions apply also for the German network), shows that the use phase causes about 78 % of the life cycle CO_2-eq. emissions, deployment 12 % and equipment manufacturing almost 10 %[9] [Malmodin 2012].

Conclusions

Existing models and data are not sufficient to determine a realistic electricity consumption of telecommunication networks. However, based on the generic figures stated for the German telecommunication network correlated with the energy consumption of the end user equipment, it can be seen that broken down to individual product, the telecommunication network consumption is about 40 kWh/a per product/user. This includes all consumer and business traffic, including mail, videos, file sharing, data centre-to-data centre traffic as well as the general provision of subscriber access. Therefore the energy consumption of networks has a comparably low share of the overall energy consumption of thin client computing concepts as the additional traffic through thin clients is quite low compared to the existing (and still growing) traffic by "normal" internet use.

For the general use of PCs and online services, the network and data centre energy consumption is nevertheless important on a national level. Energy consumption of the networks depends on the available bandwidth and not (so much) on the traffic. The data traffic increases with and without cloud computing (due to video and other big data), but also the number and utilization of data centres and servers increases with cloud computing and the use of "internet-based" services.

TELECOMMUNICATION NETWORKS

The hardware demand of the core network depends on the peak load. The environmental impact of telecommunication networks is dominated by the use phase. A load-adaptive operation of the network, intelligent routing and the link to renewable energy would reduce the carbon footprint of the networks.

THIN CLIENTS

Thin clients have the potential to reduce electricity consumption and GHG emissions, if

- The power-to-performance ratio for servers will improve further.
- The life time of thin clients can be significantly increased compared to PCs.
- Short latency (bandwidth and speed from chip to terminal) and locally provisioned services (forward caching) have the potential to make cloud computing and thin clients more efficient.

8. Juniper: Routing Products, http://www.juniper.net/de/de/products-services/routing/.

9. "Global scenario" with world average electricity emissions factor of 0,6 kg CO_2e/kWh (for comparison: Germany 2011: 0,559 kg CO_2e/kWh [UBA 2012]).

The life time of thin clients could be significantly increased compared due to PCs as changes in the hardware and software demand could be "outsourced" to data centres. Update traffic could be reduced when systems are centralized in data centres. On the other hand, upload traffic would increase with thin clients.

For home scenarios, thin clients are at the moment neither from energy nor from reliability point of view preferable to notebooks. Nevertheless, other forms of cloud computing are already widely in use and will grow further. A comprehensive model which can realistically determine the effect of all levels (end-user product, data centres and telecommunication networks) would help to understand and evaluate such computing concepts at all levels.

References

Baliga 2008; Jayant Baliga, Robert Ayre, Wayne V. Sorin, Kerry Hinton, Rodney S. Tucker: Energy consumption in access networks, OFC/NFOEC, 2008.

Baliga 2009; Jayant Baliga, Robert Ayre, Kerry Hinton, Wayne V. Sorin, Rodney S. Tucker: Energy Consumption in Optical IP Networks, Journal of Lightwave Technology, Vol 27, No. 13, July 2009

Bolla 2011; Raffaele Bolla, Franco Davoli, Roberto Bruschi, Ken Christensen, Flavio Cucchietti, Sure Singh: The Potential Impact of Green Technologies in Next-Generation Wireline Networks: Is There Room for Energy Saving Optimization? IEEE Communications Magazine, August 2011

Cisco 2011; Cisco White Paper: Cisco Visual Networking Index: Forecast and Methodology, 2010–2015; June 2011

Cisco 2012; Cisco White Paper: Cisco Global Cloud Index (GCI) – Data center and cloud traffic forecast 2011–2016, 2012

CoC 2008; European Commission, Directorate-General JRC Joint Research Centre: Code of Conduct on Energy Consumption of Broadband Equipment, Version 3; November 2008

destatis 01; German Federal Statistical Office: Ausstattung privater Haushalte mit Informations- und Kommunikationstechnik – Deutschland (ICT in German households), Continuous household budget surveys, online: https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/EinkommenKonsumLebensbedingungen/AusstattungGebrauchsguetern/Tabellen/Infotechnik_D.html (accessed 01/01/2013)

destatis 02; German Federal Statistical Office: Number of households in Germany, https://www.destatis.de/DE/ZahlenFakten/GesellschaftStaat/Bevoelkerung/HaushalteFamilien/Aktuell.html;jsessionid=FC932A7516B156250A5F448CD320D101.cae4 (accessed 01/01/13)

EuP Lot 3; IVF Industrial Research and Development Corporation: Preparatory studies for Eco-design Requirements of EuPs, Lot 3 – Personal Computers (desktops and laptops) and Computer Monitors, Final Report (Task 1-8); European Commission DG TREN, August 2007

Fichter 2011; Klaus Fichter, Jens Clausen, Ralph Hintemann: Roadmap: "Ressourceneffiziente Arbeitsplatz-Computerlösungen 2020" – Entwicklung eines Leitmarktes für Green Office Computing, Borderstep 2011

GeSI 2008, The Climate Group: SMART 2020: Enabling the low carbon economy in the information age, A report by on behalf of the Global eSustainability Initiative (GeSI), 2008

Hintemann 2010; Ralph Hintemann, Klaus Fichter, Lutz Stobbe: Materialbestand der Rechenzentren in Deutschland – Eine Bestandsaufnahme zur Ermittlung von Ressourcen- und Energieeinsatz (Material footprint of data centres in Germany), Im Auftrag des Umweltbundesamtes (UBA), Borderstep Institut für Innovation und Nachhaltigkeit, Berlin, 2010

Hintemann 2012; Ralph Hintemann, Klaus Fichter: Energieverbrauch und Energiekosten von Servern und Rechenzentren in Deutschland – Aktuelle Trends und Einsparpotenziale bis 2015, Borderstep Institut für Innovation und Nachhaltigkeit, Berlin, 2012

Hooghe 2011; Koen Hooghe, Mamoun Guenach: Toward Green Copper Broadband Access Networks, IEEE Communications Magazine, August 2011

Kemper 2012; Lars Kemper: Messergebnisse zum Strombedarf von IKT-Equipment in einer Cloud (Projekt GreenPad), 3. Jahrestagung des "Wissenschaftsforum Green-IT", Berlin, December 2012

Knermann 2011; Christian Knermann, Markus Hiebel, André Reinecke, Daniel Maga, Andreas Schröder: Thin Clients – Ecological and economical aspects of virtual desktops, Fraunhofer UMSICHT, Oberhausen, January 2011

Koomey 2007; Jonathan G. Koomey: Estimating total power consumption by servers in the U.S. and the world, Stanford, 2007

Koomey 2009; Jonathan G. Koomey (Stanford), Berard (Microsoft), Sanchez (Carnegie Mellon) Wong (Intel): Assessing trends in the electrical efficiency of computation over time, Stanford, 2009

Lange 2009; Christoph Lange, Andreas Gladisch: Energy Consumption of Telecommunication Networks – a network operator's view, OFC/NFOEC#09, Workshop on Energy Footprint of ICT, San Diego, CA, March 2009

Lange 2010; Christoph Lange, Dirk Kosiankowski, R. Hülsermann, Rainer Weidmann, Andreas Gladisch: Energy Footprint of Telecommunication Networks, European Conference on Optical Communication (ECOC), Torino (Italy), September 2010.

Lange 2011; Christoph Lange, Dirk Kosiankowski, Rainer Weidmann, Andreas Gladisch: Energy Consumption of Telecommunication Networks and Related Improvement Options; IEEE Journal of Selected Topics in Quantum Electronics, Vol. 17, No. 2, March/April 2011

Lehmann 2011; Heiko Lehmann, Christoph Lange, Andreas Gladisch: Energy Coupling Control of Telecommunication Network and Power Grid, Pages: 87 to 92, IARIA, Italy, May 2011

Malmodin 2012; Jens Malmodin, Dag Lundén, Mikael Nilsson, Greger Andersson: LCA of data transmission and

IP core networks, Electronics Goes Green 2012+, Berlin, 2012

Norkus 2012; Oliver Norkus: Was ist die Cloud? Wo nutzen wir die Cloud? 3. Jahrestagung des "Wissenschaftsforum Green-IT", Berlin, December 2012

Rupp 2011; Rupp K., Selberherr, S.: "The Economic Limit to Moore's Law", IEEE Transactions on Semiconductor Manufacturing, VOL. 24, NO. 1; February 2011

Stobbe 2009; Lutz Stobbe Nils F. Nissen, Marina Proske, Andreas Middendorf, Barbara Schlomann, Michael Friedewald, Peter Georgieff, Timo Leimbach: Abschätzung des Energiebedarfs der weiteren Entwicklung der Informationsgesellschaft, Fraunhofer IZM, Fraunhofer ISI for the German Federal Ministry of Economics and Technology (BMWi), 2009

UBA 2012; Umweltbundesamt: Entwicklung der spezifischen Kohlendioxid-Emissionen des deutschen Strommix 1990-2010 und erste Schätzungen 2011, Dessau-Roßlau, April 2012

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