Energy demand of workplace computer solutions

A comprehensive assessment including both end-user devices and the power consumption they induce in data centers

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***Abstract*—The number of Internet-enabled end-user devices such as personal computers, notebooks, tablets, smartphones, etc. is increasing constantly. However, since the devices themselves are becoming ever more energy-efficient, their overall energy consumption in the use phase of their life cycle seems to be increasing only marginally, or even decreasing in some areas. In contrast, the energy consumption induced in data centers by the use of end-user devices is rising. The present contribution presents the results of a Borderstep Institute study on the development of personal computers conducted within the framework of the research project AC4DC. Data was gathered on the number of workplace computer solutions in German businesses, the computers' energy consumption, as well as the energy consumption in data centers they induced. In 2014, electricity consumption in data centers induced by end-user devices amounted to between 17 and 49 kWh per end-user device and year. The contribution compares the results of this study with the data from a 2010 survey and projects the global significance of the use of Internet-enabled end-user devices on the energy consumption of data centers.**

***Keywords*—energy consumption, workplace computer solutions, data centers, virtual desktop, cloud computing, server-based computing, PC, notebook, tablet, thin client**

I. Introduction

According to current estimates, there were approx. 1.7 billion PCs and notebooks in 2014 [1] as well as approx. 500 million tablets [2]. Thus, the worldwide number of end-user devices—excluding smartphones and Internet-enabled televisions—has more than doubled since 2008 [3].

The end-user devices themselves are becoming ever more energy-efficient. One reason is technical progress pertaining to the individual system components, in particular processors, hard drives, and power supplies. Another is that growth of energy-efficient mobile end-user devices such as notebooks and tablets is greater than that of stationary personal computers. For more than five years, more mobile end-user devices have been sold globally than classical PCs [4], even excluding smartphones. The progress in efficiency has resulted in the end-user devices' energy consumption stabilizing overall, or even decreasing in some areas. For example, the energy consumption of the PCs, notebooks, and tablets in Germany dropped by 11 % to 6.8 billion kWh between 2010 and 2014 [5].

In contrast, the energy consumption of data centers worldwide has seen a marked rise [6, 7] and distinct increases in data centers' energy consumption is assumed for the future as well [8]–[10]; growth from 300 billion kWh to almost 550 billion kWh is projected for the period 2011 to 2020 [7]. A large part of this energy consumption is induced by the use of end-user devices.

This contribution presents an approach for calculating the energy consumption of data centers which is induced by the use of end-user devices. The study focuses on the use of end-user devices in business and the public sector in Germany. The contribution also goes into the situation in private homes and projects the magnitude that the energy consumption of data centers induced by all end-user devices may reach.

II. The Scope of the Study and Research Questions

This contribution presents the results of a study conducted at the Borderstep Institute within the framework of the project AC4DC (www.ac4dc.com) from June to October 2014. Data was gathered about the number of various workplace computer solutions in businesses and the public sector in Germany in 2014 as well as their energy consumption and compared with the corresponding data from 2010, differentiating between PCs, mini-PCs,[1] notebooks, tablets, and thin clients. The energy consumption of computer use at work was determined on the basis of various usage patterns and energy consumption figures of the end-user devices as well as the servers in data centers required for their use. Monitors[2] were not considered in this study, nor were smartphones.

Data transfer between the end-user device and the servers in data centers is also excluded from this study due to a lack of basic data. The authors are well aware of the fact that data transfer, especially using mobile phone networks, may account for considerable energy consumption. According to calculations by the Centre for Energy-Efficient Telecommunications (CEET) at the University of Melbourne, mobile access to cloud services is responsible for a larger share of energy consumption than data centers [12].

[1] Mini-PCs are PCs whose form factor is significantly smaller than that of classical PCs—also called compact PCs or nettops.

[2] In [11], the energy consumption of all computer monitors in German businesses in 2015 is estimated at approx. 1 billion kWh, and that of computer monitors in private households at 1.8 billion kWh.

This contribution will answer the following questions:

- How has the number of devices developed in the various classes of devices?
- How has the energy consumption of the end-user devices developed?
- How has the energy consumption in data centers induced by the end-user devices developed?
- Which conclusions can be drawn from the results regarding the global relevance of the use of Internet-enabled end-user devices on the energy consumption of data centers?

III. Methodology

The study used the methods of another study conducted in the years 2007 to 2010 [13]. That study was a joint project of the German Federal Environment Agency, the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety, and the German ICT Association BITKOM. The sales figures provided by the market research institute Techconsult [14] were used to calculate how many devices were in place in businesses in the various classes of devices (*i*). The Borderstep Institute purchased these data. Unfortunately, the contractual arrangements do not permit publication of the data, so this contribution can only provide figures derived from the original data. Additional information sources for determining the number of workplace computer solutions in Germany include publications by IDC/Bitkom about thin clients [15] as well as the results of a Delphi survey on the average amounts of time that end-user devices were in use [13], [16].

Annual energy consumption E_i for the individual classes of devices was calculated using the formula:

$$E_i = n_i * (p_{idle,i} * t_{idle,i} + p_{sb,i} * t_{sb,i} + p_{off,i} * t_{off,i}) \quad (1)$$

n_i: number of end-user devices of the class of devices *i* in place

$p_{idle,i}, p_{sb,i}, p_{off,i}$: power consumption per device in the class of devices *i* in the operating statuses *idle*, *standby* (*sb*), and *off*

$t_{idle,i}, t_{sb,i}, t_{off,i}$: annual amount of time in operation per device of the class of devices *i* in the operating statuses *idle*, *standby* (*sb*), and *off*

Since the end-user devices' average power consumption in active mode was hardly different from power consumption in idle mode, the idle mode was used for the calculations [13].

Data on the power consumption of the devices and their development over time was gathered from Energy Star program measurements [17] and validated by the above-mentioned Delphi survey [13], [16]. The annual amounts of time in operation were determined on the basis of a number of other studies ([11], [18], [19]).

The procedure described in the following was employed to calculate the energy consumption in data centers that was induced by use of the end-user devices. Four different ways of providing software were differentiated:

1. use of software installed locally on the end-user device
2. use of virtual desktops (hosted virtual desktop—HVD)
3. use of server-based computing (SBC)
4. use of software as a service (SaaS)

Each of the options 2 to 4 requires server usage. The number of clients that a server can serve (ϱ_j) differs, depending on the way in which software is provided j.

The number of servers $n_{s,i}$ used for the class of devices in question was thus calculated using the following formula:

$$n_{s,i} = n_i * \left(\frac{\alpha_{SBC,i}}{\varrho_{SBC}} + \frac{\alpha_{HVD,i}}{\varrho_{HVD}} + \frac{\alpha_{SaaS,i}}{\varrho_{SaaS}}\right) \quad (2)$$

$\alpha_{SBC,i}$, $\alpha_{HVD,i}$, $\alpha_{SaaS,i}$: *average share of each of the various ways of providing software for the classes of devices i (see Table V)*

Energy consumption induced in the data centers per class of devices i ($E_{DC,i}$) was calculated using the following formula:

$$E_{DC,i} = (p_{a,s} * t_{a,s} + p_{idle,s} * t_{idle,s} + p_{off,s} * t_{off,s}) * n_{s,i} * PUE \quad (3)$$

$p_{a,s}, p_{idle,s}, p_{off,s}$: power consumption of an average server in the operating statuses *active* (*a*), *idle*, and *off*

$t_{a,i}, t_{idle,i}, t_{off,i}$: annual amount of time in operation per device of the class of devices *i* in the operating statuses *idle*, *standby* (*sb*), and *off*

PUE: Power Usage Effectiveness[3]

IV. Computer Use in Businesses and the Public Sector

The sales figures provided by the market research company Techconsult [14] as well as additional information from the trade association BITKOM and IDC analysts about thin clients [15] provided the basis for calculating how many workplace computing solutions were in place in Germany in 2014. In accordance with [13], an operating life of 5 years was assumed for PCs and mini-PCs, 4 years for notebooks, and 8 years for thin clients. An operating life of 3 years was calculated for tablets.

TABLE I. Numbers of Different Workplace Computing Solutions in Place in Germany

	PCs	Mini-PCs	Notebooks	Thin clients	Tablets
2010	13,000,000	300,000	11,000,000	2,000,000	-
2014	11,500,000	1,200,000	13,900,000	3,200,000[b]	1,200,000

[a] Calculations: Borderstep on the basis of Techconsult, Bitkom, IDC, values for 2010 from [13], rounded

[b] 300,000 of these were software thin clients

[3] The PUE indicates the ratio of total energy consumption of a data center to the energy consumption of the IT in the data center and is a measure of the efficiency of the data center infrastructure. By definition, PUE is always greater than 1.

Businesses and the public sector in Germany used a total of approx. 31 million end-user devices in 2014, a good 15 % more than in 2010. The number of mobile devices (notebooks, tablets) increased very markedly, by almost 30 %. The number of stationary end-user devices remained constant. Although the number of PCs decreased somewhat, the number of thin clients grew to 2.9 million devices, or more than 25 %. In addition, approx. 300,000 software thin clients are in use today, which are PCs that are converted into thin clients using software. Usually, older devices that still work and have sufficient performance to function as thin clients, but would be taken out of service as PCs, are used for this purpose.

Tablets, too, are also being utilized at work. Approx. 1.2 million tablets are currently being used in businesses and the public sector in Germany. Standard work environments are still equipped with PCs or notebooks, however.

The values calculated in [13] for the power consumption of the end-user devices as well as usage patterns were used to calculate the energy consumption of the end-user devices as well as the energy consumption induced by them in data centers. Table II shows these assumptions.[4] According to these assumptions, the energy efficiency of the devices in place increased slightly from 2010 to 2014, and the usage patterns at work did not change.

TABLE II. POWER CONSUMPTION AND USAGE PATTERNS OF THE VARIOUS TYPES OF END-USER DEVICES

	2010			2014		
Power consumption of the devices in place (in watts)						
	idle	**standby**	**off**	**idle**	**standby**	**Off**
PC	65	10	2,5	62,5	8	2
Mini-PCs	30	3	1	27,5	3	1
Notebooks	30	3	0	27,5	3	0
Thin clients	12	2	1	11	2	1
Tablets[d]	-	-	-	5	0	0
Annual amount of time in operation (in hours)						
PCs	1,920	3,276	3,564	1,920	3,276	3,564
Mini-PCs	1,920	3,276	3,564	1,920	3,276	3,564
Notebooks	1,920	728	6,112	1,920	728	6,112
Thin clients	1,920	3,276	3,564	1,920	3,276	3,564
Tablets[e]				1,920	728	6,112

c. Values for PCs notebooks, thin clients from [13], rounded

d. Power consumption of tablets: Average value for current devices

e. Usage patterns in 2014 as for notebooks

The assumptions for power consumption and usage patterns of servers for external software provision, which were also taken from [13], are shown in Table III. While power consumption in active mode remained constant from 2010 to 2014, the values for idle mode and off mode decreased. Also, more servers were powered down in 2014 when not in use, so that the average time in off mode increased.

TABLE III. AVERAGE POWER CONSUMPTION AND USAGE PATTERNS OF SERVERS (IN PLACE) FOR EXTERNAL SOFTWARE PROVISION

	2010			2014		
	active	**idle**	**off**	**active**	**idle**	**off**
Annual consumption (in watts)	400	160	20	400	150	15
Annual amount of time in operation (in hours)	2,607	5,854	308	2,607	5,230	923

f. Values from [13]

Another assumption determined in [13] in Delphi surveys and used for these calculations was the efficiency improvements in data center infrastructure. An average PUE of 2.0 was calculated for 2010; for 2014, the average PUE was 1.87. The number of clients that each server can serve with the various ways of providing software can also be taken from the Delphi surveys; these values are shown in Table IV.

TABLE IV. NUMBER OF CLIENTS PER SERVER FOR THE VARIOUS FORMS OF SOFTWARE PROVISION

	2010	2014
SBC	50	90
HVD	25	35
SaaS	50	70

According to up-to-date information, the assumptions concerning the development of the use of the various ways of providing software, however, could not be used. For example, the use of virtual desktops (hosted virtual desktops) has not become as prevalent as analysts predicted some years ago [21]. According to [13], this provision model was to have reached a share of 20 % in all classes of devices as early as 2013. However, a current BITKOM survey [22] showed that this share will still be less than 20 % even in 2020 in all classes of devices except for thin clients. Still, the concept accounts for an increasing share of the software provision models [5]. The growing number of standardized cloud workspaces can be expected to continue to generate movement in this market [23]. The BITKOM survey also assumes lower market penetration rates for server based computing through 2020. In contrast, it was assumed that SaaS models will become more widespread faster. For this reason, the average shares of the various types of software provision determined in a Delphi survey [13] were corrected.

Table V shows the findings of the various studies as well as the shares of the different forms of software provision derived from them for 2014. In the case of PCs and notebooks in businesses, the use of local software still dominates (72 %), thin clients are mostly operated with server based computing concepts, and in the case of tablets, software as a service concepts are employed to a large extent even today.

4 Since tablets were not taken into account in [13], the same values for temporal use patterns were assumed as for notebooks. This results in annual energy consumption of 9 kWh (see Table VI). For comparison: A study by the Electric Power Research Institute (EPRI) calculated annual energy consumption of 12 kWh [20] for daily use of an iPad3.

TABLE V. SHARES OF THE VARIOUS FORMS OF SOFTWARE PROVISION

Year	2010	2020	2020	2014
Study	Findings Delphi in [11]	Findings Delphi in [11]	Findings BITKOM survey [19]	Assumptions for the calculation
PCs, mini-PCs, notebooks				
Local software	90 %	25 %	45 %	72 %
SBC	4 %	20 %	17 %	9 %
HVD	4 %	40 %	16 %	9 %
SaaS	2 %	15 %	22 %	10 %
Thin clients				
Local software	0 %	0 %	8 %	3%
SBC	90 %	50 %	42 %	71 %
HVD	10 %	30 %	28 %	17 %
SaaS	0 %	20 %	22 %	9 %
Tablets				
Local software	-	-	32 %	37 %
SBC	-	-	15 %	12 %
HVD	-	-	13 %	11 %
SaaS	-	-	40 %	40 %

g. rounded

The energy consumption of the various types of end-user devices in businesses and the public sector in Germany can be determined using the methodology presented above, and on the basis of the data shown in Tables I through IV (Table VI). Energy consumption of end-user devices in the work environment has declined by 14 % to just under 3 billion kWh, compared with 2010—due above all to the relatively low electricity consumption of the mobile devices and the increasing use of thin clients. However, if the electricity consumption in data centers induced by the end-user devices is taken into account, the savings amount to only just under 8 %. Overall, the end-user devices in businesses and the public sector used 3.6 billion kWh in 2014.

TABLE VI. ANNUAL ENERGY CONSUMPTION OF THE DIFFERENT TYPES OF END-USER DEVICES IN BUSINESSES AND THE PUBLIC SECTOR IN GERMANY

	2010[h]		2014	
	End-user devices	Data centers	End-user devices	Data centers
Energy consumption per end-user device (in kWh)				
PCs	200	11	164	17
Mini-PCs	74	11	69	17
Notebooks	65	11	59	17
Thin clients	43	87	34	49
Tablets[d]	-	-	9	35
Energy consumption of all end-user devices (in million kWh)				
PCs	2,610	144	1,890	197
Mini-PCs	22	3	80	20
Notebooks	713	122	817	238
Thin clients	94	192	147	154
Tablets[e]	-	-	11	42
Total	3,439	461	2,945	651

h. Values from [11], rounded

V. COMPUTER USE IN HOMES

A current Borderstep Institute study [5] is available for estimating the energy consumption of computer use in private households. The study determined the number of different end-user devices in place in homes on the basis of surveys by the Federal Statistical Office [24] and data from the Computer Electronics Markt Index Deutschland (CEMIX) [25]. In addition, the energy consumption of the end-user devices themselves as well as the energy consumption they induced in data centers was calculated using the methodology presented in this contribution. The following special features of usage in private households were taken into account:

- The energy consumption of the various types of end-user devices and the usage patterns in private households were taken from [11].
- "Local software" and "software as a service" were the only forms of software provision that were taken into account. Private usage of HVD and SBC were disregarded. It was assumed that the share of local software use is somewhat lower (58 %) in homes than in businesses, since more services such as social networks, music and video streaming, online games, etc. are used there[5].

The study produced the following findings. Computer usage in private households in Germany is clearly dominated today by the use of mobile devices. Nonetheless, approx. 26 million desktop PCs are still in place here. Most of these devices—approx. 17 million—are more than 7 years old and are hardly used any more.

Because of the relatively low electricity consumption of notebooks and tablets, the total electricity consumption of all end-user devices in homes declined by 8 % during the period studied to 3.8 billion kWh. However, the electricity consumption in data centers induced by the end-user devices increased markedly, more than tripling since 2010. Activities such as online gaming, video streaming, use of social networks, etc. are responsible for 1.8 billion kWh used in data centers. Overall, the energy consumption induced by the end-user devices increased by 20 % to 5.6 billion kWh.

VI. COMPUTER USE IN GERMANY

The results of the calculations of the use of end-user devices at work and at home in Germany are briefly summarized in the following. Figure 1 shows the development of the number of end-user devices in households and businesses in Germany overall. In 2014, there were more than 100 million Internet-enabled end-user devices in Germany.

5 The study gives a rough estimate of the number of servers required to provide these services, following the results of the Delphi survey for workplace computer solutions. Unfortunately, no robust data is available to date.

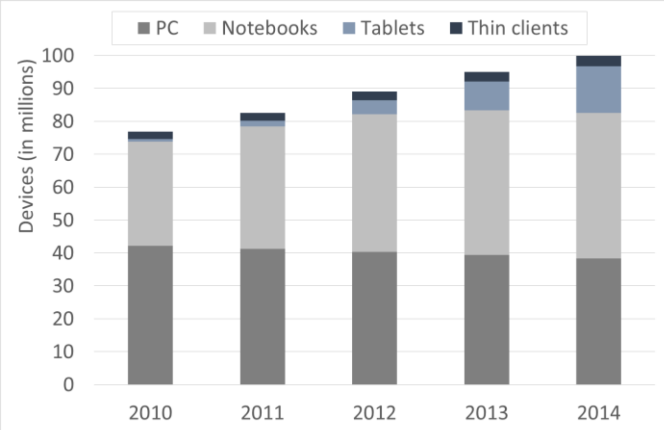

Fig. 1. End-user devices in households and businesses, 2010 to 2014 [5]

Figure 2 shows that total electricity consumption induced by the use of end-user devices in Germany increased by 8 % to 9.3 billion kWh between 2010 and 2014, even though electricity consumption of the end-user devices themselves declined, as mentioned above, by 11 % to 6.8 billion kWh.

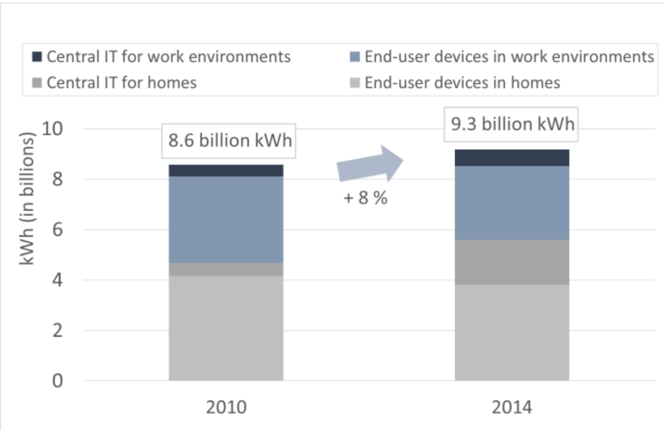

Fig. 2. Electricity consumption of end-user devices in private households and the work environment in the years 2010 and 2014 [5]

VII. Projection And discussion

The present contribution introduces an approach for determining the electricity consumption in data centers induced by computer use in the work environment. For Germany, this results in electricity consumption ranging from 17 kWh for PCs and notebooks to 35 kWh for tablets to 49 kWh for thin clients. In particular in the case of tablets and thin clients, electricity consumption in data centers is greater than that of the end-user devices themselves. An average of 26 kWh was calculated for the amount of electricity used in data centers induced by the use of end-user devices in homes.

The calculation approach described above employs a number of simplifications and generalizations. In particular, calculation of the energy consumption of data centers takes only the type of software provision into account, but not the concrete software application. Considerable further research is required here to determine whether such a simplification is defensible.

The following is to be observed when comparing the values calculated in this way with the data from other studies. Compared with the energy consumption calculated in a CEET study [12], our values appear very high. CEET assumes energy consumption in data centers of 2 kWh per user for smartphone use. Even if more intensive use of cloud services is to be assumed in the case of tablets, the difference between this figure and the data calculated here is still enormous. Taking into account that Facebook alone is responsible for energy consumption of a magnitude of 1 kWh per year per user [26] and that Google calculates energy consumption of 1 to 5 kWh for e-mail use and collaboration apps [27], however, the 2 kWh assumed by CEET seem to be very low.

A study by Masanet et al. [28] compares the energy consumption of business software in the US (e-mail, CRM, and productivity software) in the case of "classical" provision as well as cloud services. Primary energy consumption of 322 petajoules (PJ) was calculated for data center operation in the case of "classical" provision. That corresponds to electricity consumption of 23.38 TWh, assuming 13.8 megajoules primary energy/kWh (US national average grid mix). The study assumes 153.7 million end-user devices, which results in energy consumption of 152 kWh for work-related use per end-user device. If business software were provided exclusively as a cloud service, energy consumption for data center operation would drop to 6.94 PJ [28]. That would correspond to energy consumption of 3.3 kWh per end-user device. Although the study by Masanet et al. points out very large differences in energy consumption in data centers induced by workplace end-user devices depending on the type of software provision, it does confirm the magnitude of the values calculated here.

Another study, conducted by Mills, employs a different approach [29], [30], whereby the entire energy consumption of the Internet (data centers and data networks) is divided by the number of end-user devices. This is based on the notion that in the final analysis, the purpose of the Internet is only to provide applications on end-user devices. Mills calculated the annual energy consumption of an iPhone to be 400 kWh by applying this approach. The estimate derived on this basis seems to be on the high side.

Compared to this approach, the energy consumption figures calculated in the present contribution are significantly lower. If Mills's approach is applied only to the energy consumption of data centers, then energy consumption of approx. 350 TWh [7], [31] and a figure of a total of approx. 4 to 4.5 billion Internet-enabled devices[6] result in electricity consumption on the magnitude of 80 kWh per end-user device.

Cisco assumes that cloud workload currently amounts to roughly 50 % of total data center workload [33]. Assuming that the energy consumption of the cloud thus also accounts for

[6] In addition to the 1.7 billion PCs and notebooks and 500 million tablets mentioned above, there are currently still approx. 2.3 billion mobile broadband connections [32].

approx. half of the energy consumption of all data centers, this results in energy consumption for cloud services per end-user device of approx. 40 kWh. Although this value is still significantly higher than the average value ascertained in the present study, it is at least of a similar magnitude, which supports the plausibility of the results.

If the results found in this contribution for Germany are projected to all end-user devices worldwide, then a very rough estimate indicates that energy consumption induced in data centers worldwide by the use of end-user devices is approx. 50 TWh. This includes only the following classes of devices: PCs, mini-PCs, notebooks, tablets, and thin clients. The electricity consumption in data centers induced by smartphones and other Internet-enabled end-user devices could be of a similar magnitude.

The methodological contribution presented in this contribution appears to be well-suited in principle for determining the energy consumption in data centers induced by end-user devices. As this share of the total energy consumption for computer use is constantly growing, determining its amount is becoming increasingly important. In order to evaluate the data, empirical studies are necessary to verify in particular the assumptions regarding the type of software provision and the energy consumption of servers—as already mentioned above. For the case of computer use at work, the magnitude of the assumed values can be confirmed by the author on the basis of real installations in businesses. Regarding computer use in homes, the required data is still mostly lacking. Applying the methodology to smartphones is also an important task for future research.

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