Green Cloud?

The current and future development of energy consumption by data centers, networks and end-user devices

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***Abstract*— Cloud computing is an efficient way to provide IT capacity. From an ecological perspective, the use of cloud computing is usually assumed to entail lower consumption of energy and materials. However, it is difficult to assess whether this assumption is true. Cloud computing means shifting processing power from workplace computer solutions or the company server to the Internet. Yet it is comparatively difficult to determine resource consumption in the cloud. Previous studies have arrived at different results concerning the ecological benefits of cloud computing depending on the type of application. New cloud applications also cause additional resource consumption. Even today, cloud applications account for more than half of data centers' workloads. This share is expected to increase to more than four-fifths by the end of the decade. It is therefore doubtful whether IT energy and resource consumption can be reduced in the future. The present contribution considers this question and presents current research findings on the energy consumption of data centers, networks and end-user devices in Germany today and through 2025. It projects the findings from Germany to the global development and discusses the ecological effects of shifting processing power to networks and data centers through cloud computing.**

***Index Terms*—cloud computing, energy consumption, data center, networks, PC, notebook, tablet, smartphone, green IT**

I. Introduction

Cloud computing is changing the world of IT by providing a shared pool of configurable computing resources (e.g., server capacity, storage space, applications, or services) via the Internet at high speed, conveniently, and on demand [1]. Cloud computing is one of the megatrends in IT, with tremendous projected growth rates. In the current "Cisco Global Cloud Index" [2], IT manufacturer Cisco assumes that by 2019, more than four-fifths of data center workload will be handled in cloud data centers (Fig. 1). According to Cisco, cloud IT traffic will more than quadruple to 8.6 zetabytes between 2014 and 2019.

Cloud computing is generally viewed as a particularly energy- and resource-efficient form of IT resource usage ([3]-[8]). In light of these growth rates, it is at least questionable, however, whether the trend toward cloud computing can reduce energy consumption. This question is discussed in the present contribution.

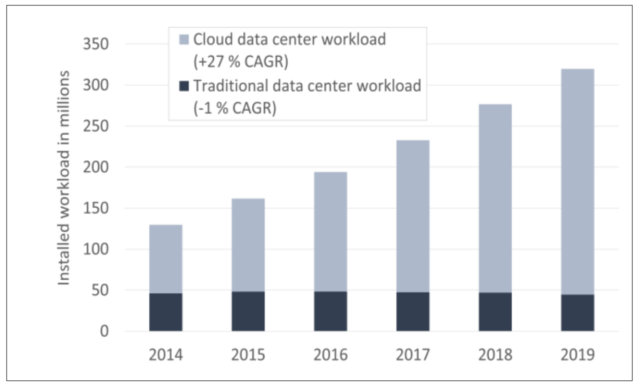

Fig. 1. Data center workload distribution [2]

The fact that the trend toward cloud computing is having an effect on IT energy consumption is obvious. In contrast, how and to what extent the use of cloud services will impact energy consumption is difficult to ascertain. The following important and partly contradictory impacts of cloud computing on IT energy consumption can be observed:

- Cloud computing makes it possible to provide IT capacity more efficiently. Special server systems for cloud services, better capacity utilization, and economies of scale because of larger and more energy-efficient data centers are reasons why as a rule, cloud solutions use less energy than classic on-premise systems. Taking the embodied energy of hardware into account, Masanet et al. estimate a technical savings potential of 87% of energy consumption if typical office applications are shifted to the cloud [6]. Consulting firms Accenture [3] and Williams et al. [8] arrive at similar results.
- Provision of processing power in the cloud enables the use of leaner end-user devices [4]. For example, thin clients, smartphones, and tablets with relatively low energy consumption can also be used for applications requiring large amounts of IT capacity. Thus, cloud computing can reduce the energy consumption of the end-user devices.
- Shifting processing power to the cloud means that greater capacity is required in the data centers and

transmission networks. This additional energy consumption is difficult to document, and it is usually not transparent to users. A Borderstep Institute study showed, for example, that a tablet used for professional purposes causes approx. five times as much energy consumption in data centers as in the device itself. Studies show that the energy consumption of data centers is increasing because of cloud services [5] [9] [10]. It is also to be expected that the above-mentioned increases in cloud traffic will result in higher energy consumption in the transmission networks [11] [12].

- Cloud computing makes IT usage simpler and more efficient. Cloud resources can be provided at very high speed and, especially for smaller businesses, at lower prices than on-premise solutions. This increase in efficiency leads to rebound effects [13], i.e., IT usage increases because of the efficiency gains made possible by cloud computing.
- Cloud computing is necessary for making it possible to use many new applications and services in the first place. Other applications and services can be significantly improved by cloud solutions. For example, small companies can use software products that they would not have purchased otherwise, e.g., for customer relationship management [14]. The use of cloud services also makes big data solutions attractive for new applications [15]. Private consumers store data in the cloud, increasingly play computer games online, or stream music and videos from the cloud. These developments give rise to additional growth in IT usage and thus also of energy consumption.

Some of the factors mentioned here cause more energy consumption, others less, and it is very difficult to determine their concrete implications for IT energy consumption overall. In the present contribution, the authors adopt the approach of determining the current and future development of total IT energy consumption and analyzing it as to which developments are due to cloud computing.[1] To this end, they draw on the findings of a comprehensive study of ICT energy consumption in Germany prepared for the German Federal Ministry of Economic Affairs in 2015 [11]. This study provides a globally unique detailed representation of the energy consumption of more than 90 different product groups. One remarkable finding of the study is the very distinct decline of the energy consumption of ICT end-user devices in Germany which in sum means that ICT energy consumption has decreased since 2010. This development contradicts most previous forecasts [17] [18]. Whether the development in Germany is an exception, globally speaking, or whether ICT energy consumption is declining worldwide cannot be determined on the basis of the available studies on global energy consumption, most of which are several years old, e.g., the SMARTer2020 report [19]. For this reason, the findings from the study for the German Federal Ministry of Economic Affairs are used to prepare an estimate of the current and future development of global IT energy consumption, utilizing current data on the development of the global stock of IT devices.

IT energy consumption between 2010 and 2015 is analyzed in terms of its development both in Germany and worldwide. In addition, the development of future energy consumption through 2025 is forecast.

The research questions studied in this contribution can be summarized as follows:[2]

- How has energy consumption due to IT usage changed in Germany and worldwide between 2010 and 2015?
- How is IT energy consumption likely to change in Germany and worldwide through 2025?
- What is the impact of cloud computing on IT energy consumption?

II. Methodology

The methodology described in the following is applied to answer these questions.

The key basis for calculating IT energy consumption is the above-mentioned study prepared for the German Federal Ministry of Economic Affairs [11] in which the energy consumption of all ICT in Germany was determined for the years 2010 and 2015 and forecast for 2020 and 2025. The detailed model used for the calculations is based on a structured quantitative survey of the stock of ICT devices in various areas of application. Energy-relevant technical and usage parameters are allocated to the various types of devices and used for calculating the resulting electric power consumption. Four basic parameters were determined for each product group included in the model:

- Type and number of devices
- Load-dependent electric power consumption
- User-specific applications and load profiles
- Dependencies on other product groups

The stock of devices is determined for each product group in the years analyzed. As a rule, the stock is determined from sales figures of previous years. Thus, the model also represents the age distribution of the devices. For each year of manufacture, electric power consumption is determined for various load statuses (e.g., off, idle, full load). The usage profiles are also determined for each product group for the years analyzed.[3] The

[1] This assumes that cloud computing has a relevant impact on the development of energy consumption. The analysis also takes other influences into account, such as the prevailing increasing digitization of the economy and society, the constantly improving energy efficiency of IT overall (Moore's Law, Koomey's Law [16]), and the increasing usage of new, energy-efficient types of end-user devices, such as smartphones or tablets.

[2] The analysis in each case refers to the energy consumption due to IT usage. Energy consumption in other phases of the product life cycle, such as manufacture and disposal, is excluded from the analysis. The values determined in this way can be used to calculate individual impacts, e.g., specific emissions factors for calculating greenhouse gas emissions.

[3] The energy needs at the various load levels and the usage profiles take the increasing use of energy management technologies in the future into account, among other things.

model is based on a database with several thousand datasets. The sources of the data for the study are publicly accessible market statistics, technical data sheets, and consumer studies. Sales figures for various product groups were obtained from market research firms to round out the data. Comprehensive assumptions resulting from an analysis of technical and usage-related trends were made for the forecasts for 2020 and 2025. The study uses a broad definition of ICT as the basis for selecting the product groups to be analyzed.

For the present contribution, only those product groups from the study are analyzed that are relevant for IT usage. This includes in particular the product groups in data centers, the various computer end-user devices, networks, and smartphones. The following, for example, were not included: landline telephones, audio devices, photo and video cameras, building automation, and the public realm with cash systems, automated teller machines, ticket machines, and advertising displays.

The development of global energy consumption can be calculated on the basis of the findings for energy consumption in Germany in 2010 and 2015. These calculations can provide only a rough estimate. A detailed calculation like the one for Germany would go beyond the scope of the present study because of the major time and effort that purchasing or gathering the necessary data would require. However, a rough extrapolation of the results for Germany to the global level is possible on the basis of the available figures for sales and stocks of servers, PCs, notebooks, tablets, smartphones, and TV sets. Here it is assumed that the types of devices, their technical characteristics, usage patterns, and dependencies between product groups vary only little in the globalized world.

The forecast of the development of global IT energy consumption in the years 2020 and 2025 is based on assumed trends derived from available data from analysts and from the comparison with the situation in Germany about the development of the stock of devices, technology, and usage patterns.

The current and future amounts of IT energy consumption calculated in this way are analyzed in terms of the degree to which they are caused by the increasing use of cloud computing. Other trends relating to the development of technology, the digitization of the economy and society, etc. are taken into account as well.

III. Development of IT energy consumption through 2015

A. Development of energy consumption in Germany

The study for the German Federal Ministry of Economic Affairs finds that ICT energy consumption in Germany dropped from 56 to 47.8 billion kWh between 2010 and 2015. For the product groups in data centers, the various computer end-user devices, networks, and smartphones, which are relevant in the present contribution, energy consumption declined by 13.2 %, from 50.8 to 44.1 billion kWh between 2010 and 2015 (Fig. 2). The reduction is due mostly to a significant decrease in the energy consumption of the end-user devices. It was brought about to a large extent by European regulation in the context of the Ecodesign Directive and by the introduction of the European energy label for television sets. Energy consumption of data centers increased by almost 15 %, from 10.5 to 12 billion kWh, during the period under consideration. The energy consumption of smartphones and tablets is very low, despite significant numbers of the devices: approx. 0.3 billion kWh in 2015 [11] (see also Table II).

The largest part of the reduction in energy consumption is due to the improvement in the case of television sets. Because of the increasing proportion of networked television sets, TV sets are considered here to be IT end-user devices. Other studies, e.g., SMARTer2020, disregard television sets. If television sets and TV cable networks that are not broadband-capable are excluded from the analysis, IT energy consumption in Germany is reduced only slightly, from 31.5 to 29.9 billion kWh, from 2010 to 2015.

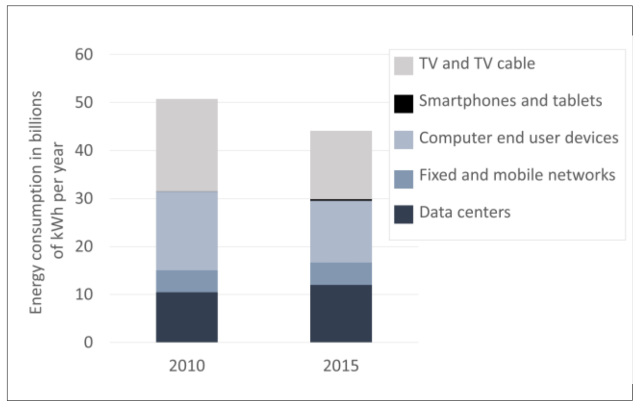

Fig. 2. Annual IT energy consumption in Germany in the years 2010 and 2015 (Source: [11], representation by authors)

B. Development of global energy consumption

Various freely available publications exist on the development of the global stock of IT devices, e.g., those by the analysts of Gartner, IDC, and IHS. Gartner and IDC regularly publish sales figures for servers, PCs, notebooks, smartphones, and tablets [20] [21]. Data on figures for sales and stock of television sets can be obtained from the publications by IHS [22] or Strategy Analysts [23].

Table I shows the figures for the stocks of the various categories of devices calculated in the study for the German Federal Ministry of Economic Affairs [11]. In addition, the figures for the global stocks estimated on the basis of the sources mentioned are indicated. If stocks were determined on the basis of sales figures, the calculation was performed with the model used in [11]. Global IT energy consumption can be estimated on the basis of the data presented in Table I. For each case, the ratio $k_{i,j}$ of the global stock of the device to its stock in Germany is calculated:

$$k_{i,j} = \frac{n_{world,i,j}}{n_{Ger,i,j}} \quad (1)$$

$n_{world,i,j}$: global stock of the device in the device class *i* in the year j

$n_{Ger,i,j}$: stock in Germany of the device in the device class *i* in the year *j*

In Table I, the calculated ratios $k_{i,j}$ for the selected device types are indicated in parentheses. Multiplication of a device class's annual energy consumption in Germany $E_{Ger,i,j}$ with the relevant ratio $k_{i,j}$ yields an estimate for its global annual energy consumption $E_{world,i,j}$.:

$$E_{world,i,j} = k_{i,j} * E_{Ger,i,j} \quad (2)$$

This type of calculation would be precise if the global stock of devices were the same as the German average in terms of structure and characteristics (e.g., sizes of the devices, electric power consumption in various modes of operation) and if the categories of devices were modeled with the same degree of detail (more than 90 product categories). Global usage patterns would also have to be identical to those in Germany.

TABLE I. STOCK OF IT DEVICES IN GERMANY AND THE WORLD IN THE YEARS 2010 AND 2015 (IN MILLIONS)

	Germany		World	
	2010	***2015***	***2010***	***2015***
	$n_{Ger,i,2010}$	$n_{Ger,i,2015}$	$n_{world,i,2010}$ ($k_{i,2015}$)	$n_{world,i,2015}$ ($k_{i,2015}$)
Servers	1.9	2.2	40.9 (21.3)	53.0 (23.9)
PCs incl. thin clients	33.2	30.3	1319.0 (39.7)	1127.5 (37.2)
Laptops	33.5	42.5	681.0 (20.3)	1126.4 (26.5)
Smartphones and tablets	14.7	93.6	419.0 (28.6)	4301.0 (46.0)
TVs	61.1	68.6	2350.0 (38.5)	2570.0 (37.5)

(Sources: Germany [11], World: calculations by authors on the basis of [20]–[23])

Since, as explained above, a survey of global data in the same degree of detail as in [11] is not possible, energy consumption is calculated in the following for a few aggregate product categories. The following procedure is applied to the product categories analyzed:

- In the area of data centers, global energy consumption in the years of analysis j is calculated by multiplying the factor $k_{Server,j}$ with the energy consumption of servers, storage, networks, and data center infrastructure in Germany.
- In the area of cellular networks, global energy consumption is calculated by multiplying factor $k_{Smartphone,j}$ with the energy consumption of the German cellular network.
- For the landline network, PC periphery, and networks in buildings, global energy consumption is calculated by multiplying factor $k_{PC,Laptop,Tablet,j}$, which is aggregated for all computer end-user devices, with the respective energy consumption in Germany.
- For PCs, laptops, smartphones, and tablets, global energy consumption is calculated by multiplying the relevant factor ki,j with the respective energy consumption of the product category in Germany.
- In the area of television (TV sets and periphery, TV cable), global energy consumption is calculated by multiplying the factor $k_{TV,j}$ with the respective energy consumption in Germany.

Table II shows the results of the rough estimate of global IT energy consumption obtained in this way. In sum, according to this calculation, global energy consumption also declined between 2010 and 2015, namely by 12.3 %, from 1622.1 to 1422.5 billion kWh. If television sets are excluded from the analysis, global IT energy consumption remained largely constant during this period under consideration, increasing slightly from 880.9 to 889.9 billion kWh. Energy consumption of data centers increased by almost 29 %, from 229.2 to 287 billion kWh. A significant increase is also to be seen in the area of landline and cellular networks. Overall, however, the significantly more efficient end-user devices compensate for these increases.

TABLE II. ANNUAL ENERGY CONSUMPTION OF VARIOUS AREAS OF IT IN GERMANY AND THE WORLD IN THE YEARS 2010 AND 2015 (IN BILLION KWH)

		Germany		World	
		2010	***2015***	***2010***	***2015***
Data centers	Servers	3.7	4.3	78.5	103.1
	Storage	1.7	2.4	37.1	56.4
	Networks in data centers	0.3	0.4	7.3	8.5
	Data center infrastructure	4.7	5.0	99.9	119.0
Net-works	Fixed networks	2.9	3.0	87.2	94.8
	Mobile networks	1.6	1.7	46.3	83.5
Computer end-user devices	PCs incl. thin clients	4.7	2.7	185.5	100.4
	Laptops	1.5	1.3	29.9	34.1
	PC periphery	5.2	4.1	155.1	126.4
	Networks in buildings	5.1	4.8	153.0	148.8
	Smartphones and tablets	0,035	0.3	1.0	14.8
TVs	TVs and TV periphery	17.3	12.9	667.2	482.6
	TV cable	1.9	1.4	74.0	51.6
Total		**50.8**	**44.1**	**1622.1**	**1422.5**
Total (without TV)		**31.5**	**29.9**	**880.9**	**889.9**

(Sources: Germany [11], World: calculations by authors)

To date, only a small amount of data on the global development of IT energy consumption is available, and it generally has a very low degree of detail. A comparison of the findings of the calculations prepared here with other available data shows that the figures appear plausible. Findings from other studies [19] [24] arrive at comparable figures for the period from 2010 to 2015 (see Discussion). IT energy consumption thus accounts for approx. 8 % of global electricity consumption.

IV. FORECAST OF THE DEVELOPMENT OF IT ENERGY CONSUMPTION THROUGH 2025

A. Forecast of the development of energy consumption in Germany

Table III shows the forecast of the future development of IT energy consumption through 2025 from the study for the

German Federal Ministry of Economic Affairs. It is assumed here that IT energy consumption will continue to decrease in the future. But this is true only if television sets are taken into account. If they are excluded, future IT energy consumption is expected to increase, from 29.9 to 33.4 billion kWh (+ 12 %). The significantly increasing energy consumption of networks by 3.9 billion kWh (+ 83 %) and that of data centers by 4.4 billion kWh (+ 36%) from 2015 to 2025 cannot be compensated for by further reductions in the energy consumption of end-user devices.

TABLE III. ANNUAL ENERGY CONSUMPTION OF VARIOUS AREAS OF IT IN GERMANY AND THE WORLD IN 2015 AND FORECAST FOR THE YEARS 2020 AND 2025 (IN BILLION KWH)

	2015	*2020*	*2025*
Servers	4.3	5.5	7.0
Storage	2.4	2.8	3.3
Networks in data centers	0.4	0.6	0.6
Data center infrastructure	5.0	5.3	5.5
Fixed networks	3.0	3.9	5.8
Mobile networks	1.7	2.4	2.8
PCs incl. thin clients	2.7	1.5	1.0
Laptops	1.3	0.9	0.8
PC periphery	4.1	3.0	2.6
Networks in buildings	4.8	4.3	3.4
Smartphones and tablets	0.3	0.5	0.7
TVs and TV periphery	12.9	9.0	7.9
TV cable*	1.4	0.8	0.0
Total	**44.1**	**40.6**	**41.3**
Total (without TV)	**29.9**	**30.8**	**33.4**

(Source: [11])

* Only cable connections that are not broadband-capable. Broadband connections are included in the fixed networks.

B. Forecast of the development of global energy consumption

A forecast of the development of the global stock of devices in the years 2020 and 2025 can be prepared on the basis of the available sources on the future development of figures for sales and stocks in the various product groups and with reference to the assumptions for future developments in the study for the German Federal Ministry for Economic Affairs (Table IV). Future global IT energy consumption can then be estimated using the procedure described in chapter 3.

TABLE IV. FORECAST OF STOCKS OF IT DEVICES IN GERMANY AND THE WORLD IN THE YEARS 2020 AND 2025 (IN MILLIONS)

	Germany		**World**	
	2020	*2025*	*2020*	*2025*
	$n_{Ger,i,2020}$	$n_{Ger,i,2025}$	$n_{world,i,2020}$ ($k_{i,2015}$)	$n_{world,i,2025}$ ($k_{i,2015}$)
Servers	2.4	2.6	64.1 (26.4)	74.2 (28.1)
PCs incl. thin clients	27.5	24.2	950.6 (34.6)	798.5 (33.0)
Laptops	45.3	49.8	1242.3 (27.4)	1410.0 (28.3)
Smartphones and tablets	117.2	130.8	5350.7 (45.7)	6010.3 (46.0)
TVs	70.9	71.9	2660.0 (37.5)	2850.0 (39.6)

(Sources: Germany [11], World: calculations by authors on the basis of [11] [20]–[23] [25])

Figure 3 shows the development of global IT energy consumption forecast with this procedure. If television are included, a global decrease is also to be expected in the future, but only in the year 2020. From 2020 to 2025, energy consumption will increase from 1310.9 to 1360.3 billion kWh. Disregarding television sets, a very significant increase from 889.9 billion kWh in 2015 to 1048.2 billion kWh in 2025 (+18%) is to be expected. In particular the energy consumption of networks will increase very significantly by 144.5 billion kWh (+81 %). The increase of energy consumption in data centers by 173.8 billion kWh (+60 %) is also very significant.

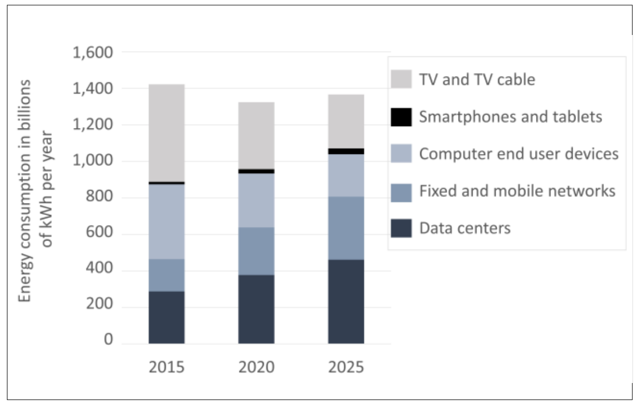

Fig. 3. Annual global IT energy consumption in 2015 and forecasts for 2020 and 2025 (Source: calculation by authors)

V. THE IMPACT OF CLOUD COMPUTING ON IT ENERGY CONSUMPTION

The findings on the development of IT energy consumption presented in the previous chapters permit some concrete insights concerning the impact of cloud computing on this energy consumption. The trend toward using resources in the cloud is responsible for a large part of the shift of energy consumption from the end-user devices to the networks and data centers presented above. The following three conclusions can be drawn.

Firstly, energy consumption by networks and data centers will presumably increase very significantly between 2010 and 2025. Energy consumption by networks in Germany is expected to increase by 89 %, that of data centers by 56 %. The extrapolated global development even yields increases of 142 % for networks and 107 % for data centers. If the above-mentioned forecasts of the development of cloud computing (Fig. 1) are correct, then a very large part of this increase in energy consumption is caused by cloud services. In the case of data centers, it can be assumed that the increase in energy consumption is caused exclusively by the cloud workload. As for networks, other developments such as sensor networks, the Internet of things, and the like may also be relevant. But a large part of the data volume will presumably be determined by the cloud [2].

Secondly, the decline in IT end-user devices' energy consumption during the period under consideration is considerable. Theoretically, cloud computing can result in lower energy consumption by end-user devices. Cloud applications make using energy-saving smartphones and tablets highly attractive in the first place and enable them to replace classical PCs or notebooks in some cases. On the other hand, this attractiveness also results in a significant increase in the number of smartphones and tablets, while the number of the other end-user devices is not decreasing overall. The reduction in the energy consumption of end-user devices is mostly caused by more energy-efficient end-user devices, which are more powerful nonetheless. The significant reduction of energy consumption in the area of television sets is not due to the IT part of the devices, but to the significantly improved energy efficiency of modern LCD displays, which are replacing the old CRT devices and energy-hungry first-generation flat-screen TVs. Overall, it should not be assumed that cloud computing has significantly reduced the energy consumption of end-user devices.

Thirdly, total IT energy consumption will increase in the future. To a large extent, this development is to be attributed to cloud computing. The hope that cloud computing can bring about an overall reduction in IT energy consumption appears illusory. Yet it should be taken into account that the enormous increase in the supply and use of cloud services that causes this increase in energy consumption entails very high positive impacts on the economy overall, with numerous new products, markets, and business models emerging. The potentials for resource conservation in other areas resulting from the use of cloud solutions (green-by-cloud) must also be taken into consideration in an overall assessment of cloud computing.

VI. Discussion

The present contribution provides some important insights into the development of IT energy consumption. In particular, it takes the currently observed significant improvement in the energy efficiency of computer end-user devices into account, which other studies to date have failed to consider to a sufficient extent.

The findings presented here provide another building block for gathering data on and evaluating IT energy consumption. Of course, these figures were also calculated on the basis of numerous assumptions, and they permit only an estimate of actual energy consumption. This applies in particular to the forecasts. Because of rapid innovation and brief product life cycles, developments in the field of information technology are so dynamic that forecasts for a period of up to 10 years are fraught with uncertainty. In the study for the German Federal Ministry of Economic Affairs, some probable partial scenarios are mentioned in which the energy consumption of individual product groups by 2025 may deviate upward or downward by 10 to 40 %.

Extrapolations of the findings for Germany to the global scale involve even greater uncertainty. The assumption that the structure and usage patterns of the stock of devices are mostly the same in Germany and the world cannot be upheld in all areas. For example, Germany has a relatively good network infrastructure for land lines and the cellular network. The structure of data centers in Germany is also significantly different from that in other countries. For instance, it was determined in a study by DCD Intelligence that German data centers are the most modern in Europe in terms of the age of the buildings, the IT equipment, and also the other equipment [26]. On the other hand, Germany has been a less attractive location for major cloud providers to date—among other things because of high electricity prices [10]. The structure of television sets in Germany is also very different from the global average in terms of the age and type of TV sets. While the share of CRT devices in Germany in 2015 had dropped to only approx. 18 % [11], their global share was still approx. 40 % [23].

Even though the results calculated for the world are imprecise, as described, they are mostly plausible. For example, the energy consumption of data centers in 2010, calculated to be 229.2 billion kWh, is between the lower and upper boundaries determined by Koomey for that year, namely 203.4 and 279.8 billion kWh [27]. The calculated rates of increase of energy consumption by data centers also concur with the values assumed in other studies [19] [28]. The forecast of the increase in energy consumption by networks is also similar, e.g., in the SMARTer2020 study [19]. Differences to other studies emerge especially concerning end-user devices. While SMARTer2020, for example, assumes that efficiency improvements and increasing numbers of end-user devices balance each other out so that overall, global energy consumption of all end-user devices will remain mostly constant between 2011 and 2020 [19], the present study calculated a decline in the energy consumption of end-user devices of more than 50 % between 2010 and 2020. Therefore, an important insight from this contribution is that the assumptions about the development of the energy consumption by end-user devices often used to date must at least be critically reassessed, if not significantly corrected.

It should nonetheless be noted that IT energy consumption will presumably continue to increase in the future. IT will thus remain a challenge for greenhouse gas reduction goals.

Acknowledgments

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