Consolidation, Colocation, Virtualization, and Cloud Computing: The Impact of the Changing Structure of Data Centers on Total Electricity Demand

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Abstract The IT industry in general and data centers in particular are subject to a very dynamic development. Within a few years, the structure and components of data centers can change completely. This applies not only to individual data centers (see [27], in this volume), but also to the structure of the data center market at the national or international level. The sizes, types, and locations of data centers are changing significantly because of trends such as the consolidation of data centers, the increasing use of colocation data centers, virtualization, and cloud computing. The construction of large cloud data centers, for example Google in Finland, Facebook in Sweden, or Microsoft in Ireland, is an example of these developments. In consequence, there is an impact on the overall energy demand of data centers. This chapter discusses these developments and the impact on the overall energy consumption of data centers using the example of Germany.

Keywords Data center · Energy consumption · Consolidation · Colocation · Hosting · Cloud computing · Virtualization · Typology

1 Introduction

Data centers account for a considerable share of electricity consumption. Koomey assumes that they consumed 1.1–1.5 % of global electricity in 2010 and estimates that the figure for the US is between 1.7 and 2.2 %. What is more, global electricity consumption increased by 56 % from 2005 to 2010 [1]. The Borderstep Institute calculated that data centers are responsible for 1.8 % of total electricity consumption in Germany [2]. In places with a very high density of data centers, such as the Frankfurt area, their share of power consumption is even on the order

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of 20 % [3]. The power consumption of major data centers, such as Facebook's in Finland or Microsoft's in Chicago, is more than 50 MW [4, 5]. These figures and examples reveal two things:

- Data centers are of high significance with regard to total electricity consumption;
- Besides total power consumption, the development of the structure of data centers is important, e.g. are more large or small data centers added, what is the purpose of the data centers, and where are they located geographically?

IT trends such as data center consolidation, virtualization, and cloud computing, as well as increasing use of colocation opportunities are giving rise to changes in the structure of data centers. This chapter deals with the impacts of these structural changes on the energy consumption of data centers overall.

Such an analysis must first confront three major challenges. Firstly, in some cases it is not quite clear how the term "data center" is defined. To date, there is no uniform definition accepted by scholars and practitioners alike [6]. Various definitions exist, depending on how data centers are used [7, pp. 5–6]. An important reason for this is that the sizes and purposes of data centers vary considerably. At one end of the scale, there are small entities with a few elements, e.g. the server room in a medium-sized engineering company with, say, twenty servers. At the other, we find factory buildings the size of a soccer field housing tens of thousands of servers, storage systems, and network devices and involving comprehensive infrastructure such as equipment for cooling and climate control, power distribution, uninterruptible power supply, emergency generators, fire safety, access control, etc.

The second challenge is the high speed of investment in ICT in general and in data centers in particular. The structure of data centers is changing very rapidly because of new hardware and software technologies, new IT concepts such as cloud computing, and new approaches with regard to infrastructure, such as direct free cooling. Studies and publications on data centers prepared 4–5 years ago [8–12] no longer reflect current reality adequately.

The third challenge when analyzing the structure of data centers is obtaining up-to-date information about them. There are no official statistics concerning data centers. The opportunities to obtain information by means of surveys are also limited because data center operators consider them to be "critical infrastructure." Failures or malfunctions would have strong economic impacts on the company which could even threaten its existence. From the perspective of data center operators, it is therefore rational to provide as little information as possible about the location, components, and structures of their data centers. A further methodological problem is the fact that data centers are not economic entities of their own. In many cases, they merely have a supporting function, for example within companies of a particular sector (engineering, finance, chemistry, etc.). What is more, the quality of the relatively small amount of information available about data centers is difficult to assess. The results of analyses are often contradictory. One reason for this is surely that there are different definitions of what constitutes a data center.

It can be said that hardly any robust data and statistics on the structure of data centers are available. Therefore, studies to date on the energy use of data centers usually focus on analyzing individual data centers (e.g. [13–16]) or determining the total electricity consumption of a country or region [1, 2, 8–10, 12, 17, 18].

Despite these challenges, I attempt to analyze and evaluate the relevance of the structure of data centers for total energy use in this chapter, using the following approach. First, the methodology will be described, followed by an introduction of a typology of data centers. This typology permits more detailed analysis of the structure of data centers as well as the determination of implications of structural changes on energy consumption. Finally, some structural changes will be presented, using the development from 2008 to 2013 as an example, and impacts on data centers' energy consumption will be discussed. In order to illustrate the data, which are valid overall, with empirical data, and to provide a foundation for the results, I have selected Germany as an example, as comprehensive data are available at the Borderstep Institute.

2 Methodology

For this chapter, a data center is defined as follows [12, pp. 13]:

> A data center is a building or space which houses the central data processing technology of one or more organizations. It must consist at least of a room of its own with a secure electricity supply as well as climate control.

Various information sources were used to obtain valid information about the current structures and components of data centers and their changes:

- A model of the structure of data centers in Germany is available at the Borderstep Institute. The model forms groups of data centers according to size and describes the average IT hardware equipment for each group as well as infrastructure elements such as climate control solutions, uninterruptible power supply, etc. The model was elaborated for the base year 2008 in a study commissioned by the German Federal Environment Agency [12] and has been developed further and updated annually in the context of the project Adaptive Computing for Green Data Centers (AC4DC, www.ac4dc.com). Above all, the model uses current sales figures for servers as well as storage and network components compiled by the market analysis firm Techconsult [19] and other available data from market studies (e.g. [20–23]). In addition, interviews with experts in the field have been conducted several times a year as well as annual surveys of data center equipment suppliers and data center operators.
- A database of the major data centers in Germany was established at the Borderstep Institute in order to test the model and develop it further. Using the model, the number of data centers with more than 500 m^2 of IT floor space was estimated at approximately 300. Internet and literature searches and especially

confidential information obtained directly from operators, planners, and equipment suppliers of data centers have made it possible to identify and describe two-thirds of them with regard to their location, operator, and purpose.

The following deliberations are based on the results of the data center model as well as the existing database on data centers.

3 Typologies of Data Centers

Before analyzing the structure of data centers, we must first clarify which types of data centers are to be differentiated. In the project AC4DC, a typology of data centers was developed which was used for this chapter as well. The typology (see Fig. 1) is oriented toward the type of IT use and includes two dimensions: the data centers' size and their purpose. The purposes of data centers include colocation data centers, cloud and hosting data centers, private data centers, and public data centers. As data centers may serve several of these purposes, they are allocated according to their main purpose. The gray areas show which sizes are typical of the various data center purposes. Data center size is differentiated between the categories "server closet," "server room," "small data center," "medium data center," and "large data center."

Data center size	No. of data centers in Germany	Colocation data center	Cloud computing and hosting data center	Private data center	Public data center
Server closet up to 10 m^2	Approx. 31,000				
Server room 11-100 m^2	Approx. 18,000				
Small data center 101-500 m^2	Approx. 2,100				
Medium sized data center 501-5,000 m^2	Approx. 300				
Large data center more than 5,000 m^2	Approx. 70				

Fig. 1 Typology of data centers (overview) (*Source* Borderstep)

Commercial providers rent out infrastructure capacity for outsourcing or situating servers in colocation data centers. The spectrum of services offered there includes providing floor space or rack space for IT hardware, electricity supply, cooling, access control, fire protection, etc. as well as connections to existing telecommunications networks. Colocation data centers' customers are companies and institutions that, for various reasons, cannot or prefer not to operate their own infrastructure.

Cloud computing and hosting data centers offer their customers services via the Internet, e.g. providing IT infrastructure (e.g. virtual or dedicated servers, storage space on the Internet), platform services, or software as a service. Many experts see a difference between cloud computing and hosting with regard to the type of customer relationship. As a rule, hosting companies have one-on-one relationships and longer-term contracts with their customers, whereas typical cloud services are offered to large numbers of customers simultaneously as standard products. Usage of cloud services can vary greatly, both in terms of time and amount [20]. There are no clear boundaries between cloud computing and hosting, and in practice, the two types of data centers are very similar. For this reason, they are considered as a single category in this chapter.

Private data centers are data centers used by companies for their own purposes. These data centers run services such as e-mail, database systems, Internet platforms, software to support business processes, e.g. bookkeeping, controlling, distribution, procurement, production, warehousing, and human resources, or software employed for research and development. The components and structures of the data centers and the types of services differ widely, depending on the company's activities. This category also includes data centers whose operators offer their customers complex services on the basis of their (the data centers') IT infrastructure.

Public data centers are data centers run by public institutions or state-owned companies. They often run services similar to those in private data centers. The public data centers also include data centers at universities and municipal or regional data centers offering services for public-sector customers. These services range from colocation to cloud and hosting to taking on entire business processes.

4 Implications of Various Types of Data Center on Electricity Demand

4.1 Colocation Providers' Data Centers

There are more than 200 providers of colocation facilities in Germany, and they are often very large—roughly 45 % of the data centers in the category "large data centers" are colocation data centers. The biggest colocation data centers in Germany have more than 50,000 m^2 of IT floor space and power consumption on the order of 50 MW. Large colocation space providers generally operate internationally and offer sizable data center capacities in practically all major German cities.

According to Borderstep Institute surveys, IT floor space in colocation data centers in Germany increased by 25 % between 2008 and 2013 and now accounts for approx. 18 %, or about 320,000 m^2, of total data center space in Germany. In the future, the space provided by colocation data centers is expected to increase significantly. The Broadgroup assumes that gross data center floor space offered by third-party data center providers will grow by 33 % between 2012 and 2016 [21].

With regard to the implications of colocation data centers as a type of data center on energy consumption, three important factors must be mentioned. First, electricity costs are a very significant factor for colocation data center providers, and for some colocation providers, they account for approx. one-third of total costs. As a result, operators of colocation data centers are highly interested in improving energy efficiency. Therefore, newly built colocation data centers are planned for high efficiency. Second, colocation providers' strong interest in energy efficiency is countered by the fact that they have no direct influence on their customers' IT usage. This largely rules out comprehensive optimization of IT hardware and data center infrastructure, for example. Third, colocation providers are not entirely free to act when implementing modernization measures for improving efficiency, since they serve several customers in a single data center and must generally guarantee continuous operation. While data centers with just a single IT user can modernize their infrastructure relatively well when replacing IT components, this is practically impossible if many customers are involved, as they will replace their IT hardware at various different times.

4.2 Data Centers Operated by Cloud Computing and Hosting Providers

There are more than 2,000 hosting providers in Germany. With few exceptions (1und1, Strato, and Hetzner), the providers whose only service is hosting are small or medium-sized companies. In addition, there are also a number of large and internationally operating providers such as IT manufacturers (HP, IBM, Fujitsu, etc.), service providers (T-Systems, Atos, Unisys, Capgenimi, etc.), and cloud providers established specifically to provide these services (Amazon, Google, Salesforce, etc.) [20]. Some cloud and hosting data centers are very large. More and more mega-data centers with tens of thousands of servers are being established around the globe, e.g. by Google, Facebook, or Microsoft. According to Borderstep surveys, roughly one-quarter of the large data centers in Germany are cloud and hosting data centers. Their IT floor space is constantly increasing. For example, Deutsche Telekom built a cloud data center in Magdeburg measuring 24,000 m^2 [24]. Overall, high growth is forecast for the market in cloud services. The Experton Group expects annual growth of 40 % from 2011 to 2015 [20].

Borderstep Institute surveys show that the IT floor space of cloud and hosting data centers in Germany increased by approx. 25 % from 2008 to 2013, and that these 250,000 m^2 account for approx. 14 % of all IT floor space in Germany. It is safe to assume that this market will continue to develop dynamically in the future, especially because of the strong growth in cloud computing.

The most important implications of this type of data center on the development of energy efficiency can be summarized as follows. Energy costs account for a high proportion of the total costs of cloud and hosting data centers, usually between 10 and 20 %. Therefore, there is a relatively strong incentive to implement energy-efficiency measures. Hosting and cloud data centers often have a relatively homogeneous IT structure. This makes more extensive efficiency measures possible, ranging from efficient cooling technologies such as direct free cooling to sourcing hardware constructed specifically for this purpose, as in the case of Google, for example [11, pp. 6]. Thus, modern cloud data centers attain power usage effectiveness (PUE) figures on the order of 1.1–1.2 [4, 25]. PUE is a measure of the efficiency of data center infrastructure, indicating the ratio between energy use of the entire data center per year and the IT hardware's energy use. The closer the PUE value is to 1, the more efficient the data center's infrastructure.

4.3 Data Centers Used by Companies Themselves ("Private Data Centers")

The category with the largest number of data centers comprises data centers used by companies for their own purposes. Almost 90 % of data centers in the categories server closet and server room fall into this category. Private data centers account for just under 60 % of total data center space in Germany. The components and structures of the data centers and the types of services provided vary greatly, depending on the company's activities.

In Germany, large data centers with power consumption in the megawatt range are operated by companies in the financial, telecommunications, or automobile sectors, for example. Approx. 20 % of the large data centers fall into this category.

When considering implications of data center type on the development of energy efficiency, it is important to note that smaller data centers often have only minor incentives to increase energy efficiency. Especially because of the higher proportion of management costs in smaller data centers, the fraction accounted for by electricity is relatively low, often on the order of 5 % or less. In relation to the total costs of a company in which operating the data center accounts for just a small share of the company's activities, the energy costs for running the data center are generally very low. In addition, the expertise and resources for introducing energy efficiency measures in a data center are often not available in the case of small locations.

4.4 Data Centers in Public Agencies and Other Public Institutions (“Public Data Centers”)

The category of public data centers also includes a large number of locations that tend to be smaller. It is reasonable to assume approx. 5,000 public data centers in Germany in 2013. They account for approx. 10 % of the total space of all data centers. The majority of public data centers is operated by municipalities. At the federal level, there are approx. 1,000 data centers.

In recent years, public data centers have seen a trend toward concentration. Public-sector service providers are now operating larger data centers in which the tasks of the various municipal and regional authorities are concentrated. They provide comprehensive IT services, but also hosting and colocation services. Universities and research institutions usually also have a high demand for computing capacity, both for research in the natural sciences and engineering and for operating their own websites as well as communication and online learning platforms. This capacity can be provided by means of high-performance computers and computer clusters in data centers.

Concerning the implications of this type of data center on energy efficiency, it can be stated that the operations of public data centers are often influenced by goals that are not purely economic in nature, for example, the requirement to store data within Germany. As increasing energy efficiency is a politically endorsed goal, politics may also directly impact data center operations. For example, public calls for tender often accord high importance to the issue of energy efficiency in the procurement of new goods. Another example of direct political influence is the goal adopted by the federal government to reduce the absolute amount of energy it uses for IT by 40 % between 2008 and 2013 [10].

5 Development of Data Center Structure and Energy Demand: The Example of Germany

What are the impacts of the structure of data centers on their energy consumption? Answering this question involves considering how the distribution of data centers by size has developed, using the example of Germany. Figure 2 shows the development of IT floor space in the various categories of data centers. Growth of data center space was relatively low through 2010, especially because of the economic crisis, and has shown significant growth only since then. The growth from 1.54 million m^2 in 2008 to 1.76 million m^2 in 2013 (annual average: approx. 2.7 %) is due almost exclusively to the increasing space provided in larger data centers. The space in small locations such as server closets and server rooms has even decreased. As mentioned above, a major part (approx. 51 %) of growth was in colocation data centers and in cloud and hosting data centers.

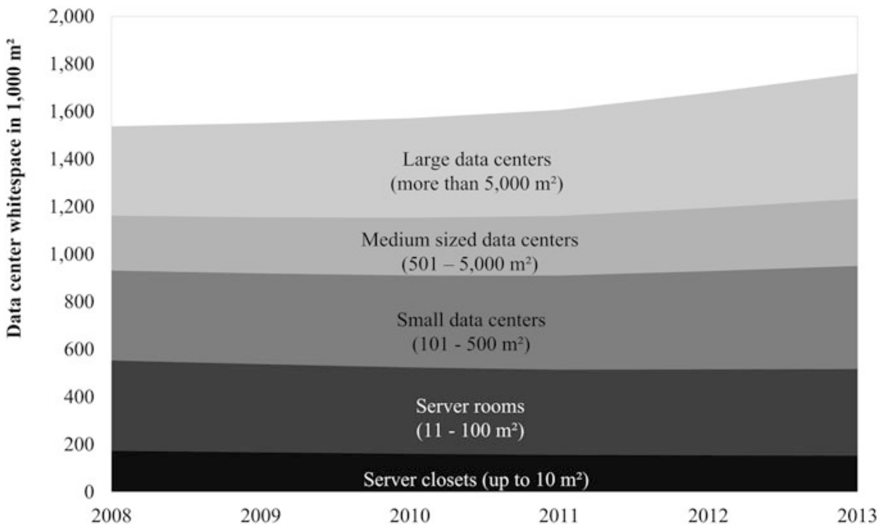

Fig. 2 Development of IT floor space in German data centers by group according to size (*Source* Borderstep)

The development of energy consumption by servers and data centers in Germany changed distinctly in 2008 (see Fig. 3). Total energy consumption declined slightly from 10.1 TWh (terawatt hours) in 2008 to approx. 9.7 TWh in 2013. There are two main reasons for this: First, the growth in data centers' energy use was slower because of the economic crisis, similar to the development in other fields of economic activity. Second, initial successes in energy efficiency have been achieved—especially as a result of the increasing discussions about data centers' energy needs [1]. In particular the newly built large data centers are distinctly more efficient than legacy data centers. According to a Borderstep survey conducted in February 2014, the PUE of good, new data centers in Germany is currently between 1.2 and 1.5. Thus, they require over 25 % less energy than a comparable legacy data center with a PUE of approx. 2, simply because of increases in infrastructure energy efficiency.

Unfortunately, the available data does not yet permit detailed analysis of the development of electricity consumption in the individual data center types broken down by size and purpose of the data center. Further research is required here. Yet there are many indications that a significant part of the efficiency gains were attained by building new, large data centers—especially in the fields of colocation as well as cloud and hosting. The federal government's Green IT Initiative is also responsible for a part of the reduction in data centers' energy use. It can be estimated on the basis of available data [26] that 25 % of the calculated absolute decline in data centers' energy use is due to the federal government's data centers alone.

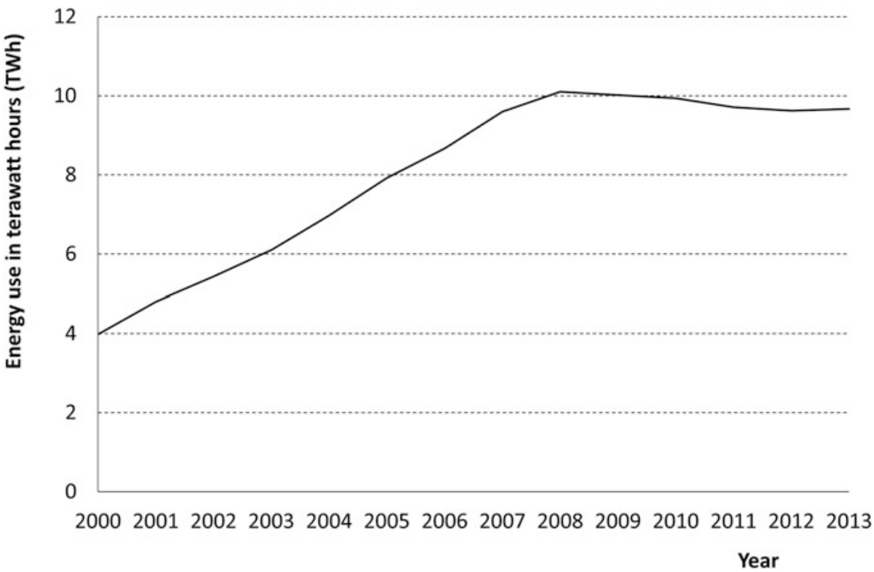

Fig. 3 Development of energy consumption by servers and data centers (*Source* based on [12], updated)

6 Summary, Discussion, and Outlook

The structure of data centers in Germany is changing, and this chapter has shown the extent of this shift. The number of small locations has clearly decreased since 2008, while the number of larger data centers is increasing. The segment of data centers with more than 5,000 m^2 IT of floor space is growing particularly rapidly. This growth is due especially to the increase in colocation as well as cloud and hosting data centers. Since the proportion of electricity costs in relation to total costs is relatively high for these two types of data centers, they have a major incentive to use efficient technologies. It can be assumed that the colocation as well as cloud and hosting market segments will continue to grow in the future. Yet is is questionable whether this will result in a decrease in data centers' total energy use. First, there are certain limits to a further increase in energy efficiency in colocation data centers, as discussed. Second, one must assume that cloud data centers in particular will grow so much that their energy use will increase overall in spite of improved efficiency. In light of the development to date, one must doubt that the computing capacity in private data centers will be reduced to the same extent as it is expanded in cloud data centers. Therefore, a significant rebound effect in cloud computing is to be expected.

The deliberations in this chapter have clearly shown that there is a substantial relationship between the structure of data centers and their energy consumption. Research in this field is still in its infancy. Above all, it is necessary to continue improving the availability and quality of data on the components and structure of data centers. Studies similar to this one for Germany must be conducted for other countries and regions as well. The international distribution of data centers in different locations is expected to be of major importance, not least because of the different climatic conditions.

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