DIGITAL INFRASTRUCTURES

WE ARE THE INTERNET

DATA CENTRES IN EUROPE – OPPORTUNITIES FOR SUSTAINABLE DIGITALISATION

Part 1

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CLASSIFICATION AND DEMARCATION OF THE PRESENT STUDY

This study deals with the sustainability effects of data centres and summarises the results of the first part of a larger investigation into this topic. The study demonstrates the importance of energy and resource demands and other sustainability effects of data centres in Europe, and calculates the development of the energy efficiency and energy consumption of data centres in Europe. In addition, the correlation between energy consumption and greenhouse gas emissions of data centres is ascertained for Europe and its regions. This study thus provides the basis for the second part of the research project, which will identify and present the potential of technologies and organisational courses of action to improve energy efficiency and reduce greenhouse gas emissions in data centres. In addition, the second part of the research project will present case studies of energy and resource-efficient data centres in Europe and discuss the opportunities and challenges of regulatory frameworks.

The research project focuses on data centres in Europe, as a component of digital infrastructure. Broadband networks are only included to the extent that their function is necessary for the operation of data centres. The term data centre is broadly defined according to the definitions of DIN EN 50600 and by the German Federal Office for Information Security. Data centres include the central spaces for IT operations within small and large organisations, as well as spaces for IT operations for the provision of services to third parties. The scope of the term thus extends from server racks or server rooms in a small or medium-sized company to colocation data centres, supercomputers for research & development, and hyperscale cloud data centres. Specially-constructed computing systems developed, for example, for crypto-mining or artificial intelligence are also understood as data centres. In terms of geographical demarcation, this study focuses on the European Union (EU 27), but also considers Great Britain, Switzerland and Norway.

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LIST OF ABBREVIATIONS

ASIC
Application Specific Integrated Circuit

BMU
Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)

CAPEX
Capital expenditures

DC
Data centre

EEcS-GoO
European Energy Certificate System – Guarantee of Origin

EU
European Union

OPEX
Operational expenditures

PPA
Power purchase agreement

RE
Renewable energies

REPA
Renewable energies power purchase agreement

SDGs
Sustainable Development Goals

UNFCC
The United Nations Framework Convention on Climate Change

WBGU
Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (German Advisory Council on Global Change)

1 INTRODUCTION

With its massive social, economic and political implications, digitalisation is changing the world. However, digital technologies also offer enormous potential for shaping our future in a sustainable manner, as demonstrated in the report "Our Common Digital Future" by the WBGU (German Advisory Council on Global Change) (WBGU, 2019). The WBGU likens the effects of digital transformation to the changes brought about by the development of human language, the emergence of production-based economies such as agriculture and livestock farming, the emergence of cities, the invention of the printing press, and the industrial revolution.

In the past, the topics of digitalisation and sustainability have often been discussed separately. This has also meant that the effects of digitalisation[1] have not always led to sustainable developments. The central task of shaping the future is therefore to place digital technologies increasingly at the service of global sustainability (WBGU, 2019, p. 27) and thus secure the future viability of our society at regional, national, European and global levels. As basic infrastructures for digitalisation, high-performance data centres, in addition to high-speed broadband infrastructure, have a considerable influence on current and future economic development and provide the basis for the anticipated additional high potential of the value-creation of digitalisation. However, data centres and broadband networks are also a central prerequisite for ecologically sustainable digitalisation in Europe. They can make a significant contribution to achieving the climate targets in Germany and Europe.

> Data centres, together with high-speed broadband infrastructure, represent a core element of digitalisation geared towards sustainability.

[1] The importance of data centres as digital infrastructures and that of a well-developed ecosystem of IT service providers, software providers, systems integrators, digital platforms, and content providers is dealt with in detail in the study "Bedeutung digitaler Infrastrukturen in Deutschland" (Hintemann & Clausen, 2018a).

This report presents the sustainability impact of data centres, and provides new findings on the development of the energy efficiency, energy consumption, and greenhouse gas emissions of data centres in Europe. The main findings of the report are summarised briefly below:

- In the public debate, the sustainability effects of data centres are often narrowed down to energy consumption and the associated greenhouse gas emissions, which can to some extent be seen as equivalent. However, data centres have a far greater influence on the achievement of sustainability goals. A high-performance, resilient and sustainable digital infrastructure promotes future-proof industrialisation and supports innovation. The current Corona situation has demonstrated the importance of digital infrastructures. The Corona pandemic also shows the extent to which traffic and physical mobility can be replaced by digital solutions in such an emergency, thus saving on greenhouse gas emissions.

- Increasing digitalisation is associated with a rise in demand for computing and storage services. Over the past decade, the global capacity of data centres has increased by a factor of ten. What is more, the amount of data transmitted worldwide has increased by a factor of almost 20. At the same time, the energy efficiency of data centres has been improved significantly. As a result, the strong growth in capacity is only associated with a moderate increase of 55% in the energy consumption of data centres in Europe.

- Conversely, greenhouse gas emissions from data centres have declined over the past decade due to efficiency improvements and the increasing use of renewable energy sources in power generation. This decline is expected to accelerate in the future. By 2030, greenhouse gas emissions are expected to reduce by 30% compared to today.

- Cloud computing represents a major trend in the provision of IT services, whether it be public cloud, private cloud, or increasingly hybrid cloud. The use of cloud-based solutions in Europe has been slow to develop compared to other markets. In 2018, 26% of European companies used paid cloud services (Eurostat, 2018). The further expansion of cloud solutions offers great potential for increasing energy efficiency and thus improving climate protection.

- With suitable framework conditions, data centres can become even more climate-friendly. Starting points are the accelerated expansion of renewable energies in power generation, e.g. through so-called Power Purchase Agreements (PPA), and the local operation of renewable-energy power plants. Heat recovery also provides a high potential for sustainable data centre operation.

- In the future, digital infrastructures in general and data centres in particular will need to be more strongly integrated into overall energy management concepts. This can create a basis for sustainable and competitive digitalisation in Europe.

The present study is structured as follows: Following on from this introduction is a presentation of the sustainability effects of data centres and the current market developments in the area of data centres, especially in the cloud computing and colocation segments. Chapter Four deals with the development of the energy efficiency and energy consumption of data centres in Europe. Chapter Five then presents the relationship between energy consumption and greenhouse gas emissions in Europe. The report concludes with an outlook on future developments and a brief summary.

2 DATA CENTRES AND SUSTAINABILITY

The impact of data centre operation on sustainability is a topic that is increasingly subject to discussion in the public sphere. The focus is usually on the energy consumption of data centres and the associated greenhouse gas emissions, which can to a certain extent be viewed as equivalent. However, a holistic view of the sustainability effects of data centres is rarely considered.

Nevertheless, data centres have many different bearings on the various facets of the topic of sustainability. Focusing solely on the energy consumption and greenhouse gas emissions of data centres does not do justice to the breadth of the often-positive sustainability effects of data centres.

In its Agenda 2030, the United Nations has adopted a total of 17 Sustainable Development Goals (SDGs), which take into account the various aspects of sustainable development. Figure 1 provides an overview of these objectives. The goals range from the fight against poverty to a clean and affordable

Figure 1: The United Nations' 17 Sustainable Development Goals
Source: United Nations

energy supply, and on to global peace. Moreover, the United Nations' target matrix makes it clear that the goals proclaimed can only be achieved through partnerships between individual states. Therefore, the formation of partnerships has also been formulated as a goal for sustainable development.

The operation of data centres and the processes upstream and downstream of these have both an indirect and a direct influence on the achievement of all sustainability goals. This report focuses on the sustainability goals that are directly affected by the operation of data centres. This selection does not represent a prioritisation. However, the indirect influences and effects are so diverse that a detailed presentation would clearly exceed the scope of this study. This applies in particular to the effects of digital services that are based on data centre services. The WBGU report "Our Common Digital Future" identifies and analyses in detail the links between digital offerings and the 17 sustainability goals (WBGU, 2019).

With regard to the climate impact of digitalisation, there is great potential for reducing greenhouse gas emissions. This potential reduction can be three to ten times higher than the greenhouse gas emissions directly caused by the operation of digital devices and infrastructures, as various studies have determined (GeSI & Accenture Strategy, 2015; GeSI & Deloitte, 2019; GeSI & The Boston Consulting Group, 2012; Hilty & Bieser, 2017; Malmodin & Bergmark, 2015). Digital technologies make it possible to implement economic processes in a more resource-efficient manner, to make traffic flows efficient and intelligent, and to make society as a whole more sustainable. Exploiting this potential is a central task of digitalisation geared towards climate protection.

Digital technologies have the potential in future to reduce greenhouse gas emissions by considerably more than their operation causes.

The current Corona pandemic illustrates the potential for climate protection that digitalisation can offer in an emergency. European air traffic and domestic German rail traffic decreased by 85% (Tagesschau, 2020). In the federal state of North-Rhine Westphalia, 70% less road traffic was measured (Dwertmann, 2020). At least in the short term, this will lead to a strong reduction in greenhouse gas emissions in Germany (Deutschlandfunk, 2020). Nevertheless, business and private communication has been maintained and new forms of communication and work, such as video-conferencing or working from home, are defining the lives of millions of employees and self-employed people. The positive climate effects may continue to exist beyond the end of the pandemic. In one survey, 71% of Germans assume that working from home will continue to establish itself even after the Corona crisis (Schuster, 2020).

Data centres also indirectly influence various sustainability goals at upstream stages of the value chain (Figure 2). Large, globally active companies in particular can exert a significant influence through their procurement.

Directly connected with data centre operation are in particular the sustainability goals **"affordable and clean energy", "climate action" and "responsible consumption and production"**. Chapters 4 and 5 of this report deal with these issues.

Data centre operations also have a major influence on the **"industry, innovation and infrastructure"** objective, which focuses on building a resilient infrastructure to promote broad-based and sustainable industrialisation and supporting innovation. In addition to broadband networks, data centres represent a basic infrastructure for many new technologies and applications. Companies need data centres in order to create their products and services in the required quality and offer them at competitive prices (Hintemann & Clausen, 2018a). In addition, data centres are an engine for innovation in many respects. On the one hand, new product developments often require powerful computing infrastructures for simulations and analyses. Artificial intelligence is being applied in more and more ways and contexts, enabling new and improved products and services that can contribute to sustainable development (Jetzke, Richter, Ferdinand & Schaat, 2019). Technologies such as autonomous driving, smart city

As a basic infrastructure, data centres support innovation and are an important prerequisite for sustainable industrialisation.

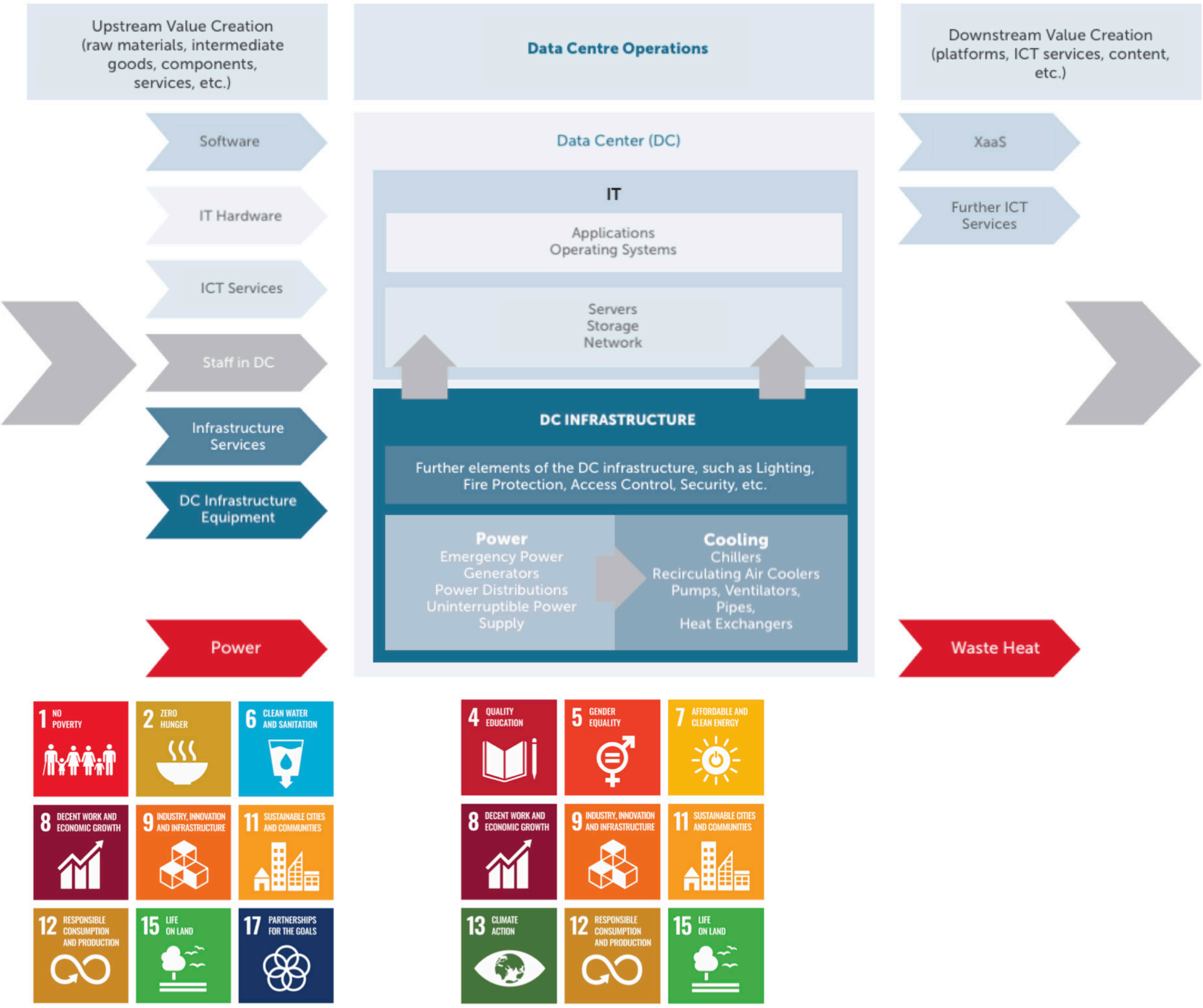

Figure 2: Sustainable Development Goals and the Value Chains of Data Centres
Figure taken from Hintemann & Clausen, 2018a with addendum

solutions, and Industry 4.0 would not be not possible without high-performance data centre infrastructures (Deloitte Consulting, 2016). Particularly for applications with high data volumes and/or requiring very low latency, it is expected that a large number of smaller, so-called edge data centres will be built in the next few years in addition to the existing data centres (Ostler, 2019a; Vertiv, 2019). In many cases, the local, application-specific provision of computing power in edge data centres brings efficiency advantages over highly centralised data processing, since large amounts of data can be (pre-)processed close to the point of origin and only distilled data need be transferred to central data centres.

High-performance and resilient digital infrastructures are also essential for economic development and human welfare. This is particularly clear in the exceptional Corona situation: Despite a significant increase in data traffic, with on average 10% more traffic and a new transmission record of 9.1 Tbit/s at DE-CIX in Frankfurt (DE-CIX, 2020a), digital infrastructures continue to function smoothly (Martin-Jung, 2020). Data centres and broadband networks make it possible to maintain private and business communication and offer alternatives for the working world and social life in many situations. But beyond this: In the Corona crisis, digital infrastructures even act as drivers of innovation, e.g. in the areas of e-health and e-education (Apobank, 2020; BR, 2020; Krahnert, 2020).

Data centres can also exert a major influence on the goals in the area of **"sustainable cities and communities"**. Data centres are often built in conurbations, as there is usually a highly-developed network infrastructure in these locations. The largest data centre locations in Europe are in Frankfurt am Main, London, Amsterdam and Paris. In these conurbations, there are often conflicts with regard to the utilisation of available infrastructure and land (Janović, 2019; Lutz & Ostler, 2020a; Ostler, 2019b; Schaefer & Ostler, 2020). However, data centres also offer great potential for sustainable cities and communities if they are intelligently integrated into spatial planning and energy systems (Lutz & Ostler, 2020b; Reveman & Ostler, 2016). The example of Stockholm shows that the waste heat from data centres can be systematically used to supply heat to cities, if appropriate framework conditions are created (Funke et al., 2019). In Germany, too, there are initial examples of waste heat recovery from data centres with the Eurotheum in Frankfurt am Main (Ladner, 2017) and with a VW Financial Services data centre in Braunschweig, which supplies a residential area with heat (Klostermeier, 2019). The topic of heat recovery from data centres is considered in detail in the second part of this study.

Data centres can also directly influence the sustainability goal of **"life on land"**, which aims to protect and restore terrestrial ecosystems and promote their sustainable use. In rural areas, too, an expanded data centre infrastructure is of great importance for the regional economy (Hintemann & Clausen, 2018a). Very large hyperscale cloud data centres are sometimes deliberately built away from large metropolitan areas. Such investments have tangible positive effects on the development of the regional economy and society. With investments in a sustainable energy supply, such projects often also promote the further development of renewable energies (Basalisco, 2018; Dose, 2018). Since the demand for data centre capacities will continue to grow with increasing digitalisation, an intelligent and sustainable combination of urban and regional planning along with energy and data networks offers great sustainability potential both in cities and in rural areas. With the expected roll-out of edge data centres, the possibilities will increase even further.

In their function as employers, data centre operators also have a direct influence on the sustainability goals in the areas of **"quality education", "gender equality" and "decent work and economic growth"**. The operation of data centres creates and secures high-quality jobs. In Germany alone, data centres secure more than 200,000 jobs (Hintemann & Clausen, 2018a).

In summary, reliable digital infrastructures are a prerequisite for a sustainable economy and society. In public discussions, the sustainability assessment of data centres focuses mainly on energy consumption and climate impact. However, data centres have many other sustainability effects that make direct and indirect contributions to all 17 sustainability goals of the United Nations and thus offer great opportunities for a sustainable transformation of the economy and society.

3 CLOUD COMPUTING AND COLOCATION DATA CENTRES IN EUROPE

The data centre industry is in a continuous state of flux. While in the 2000s the operation of one's own IT hardware and software (on-premise) was still the rule for companies and other organisations, data centre services today are increasingly being sourced from service providers. This is achieved through using the services of colocation data centres, IT service providers, and hosting and cloud companies.

Cloud computing is becoming the dominant form for the use of IT (Eurostat, 2018; IDC, 2015). Advantages such as flexibility, scalability, low administration effort, and no investment costs are leading more and more organisations to make the move to cloud technologies. Different models are being used, including public clouds, private clouds, and hybrid clouds.

Cloud services – often in the form of free offers or as a flat rate service – are also becoming increasingly popular in the private sphere. The regions within Europe vary, in some cases considerably, in their usage of cloud services.

Compared to other parts of the world, Europe lags behind in the use of cloud services in enterprises (Lorica & Nathan, 2019). On average, 26% of EU companies used paid cloud services in 2018. In recent years, cloud use by companies has increased significantly – in 2014 only 19% of companies used cloud services. The Scandinavian countries in particular are in the lead, with over 50% cloud use, while over half of the other European member states have relatively low cloud services usage, at under 30%

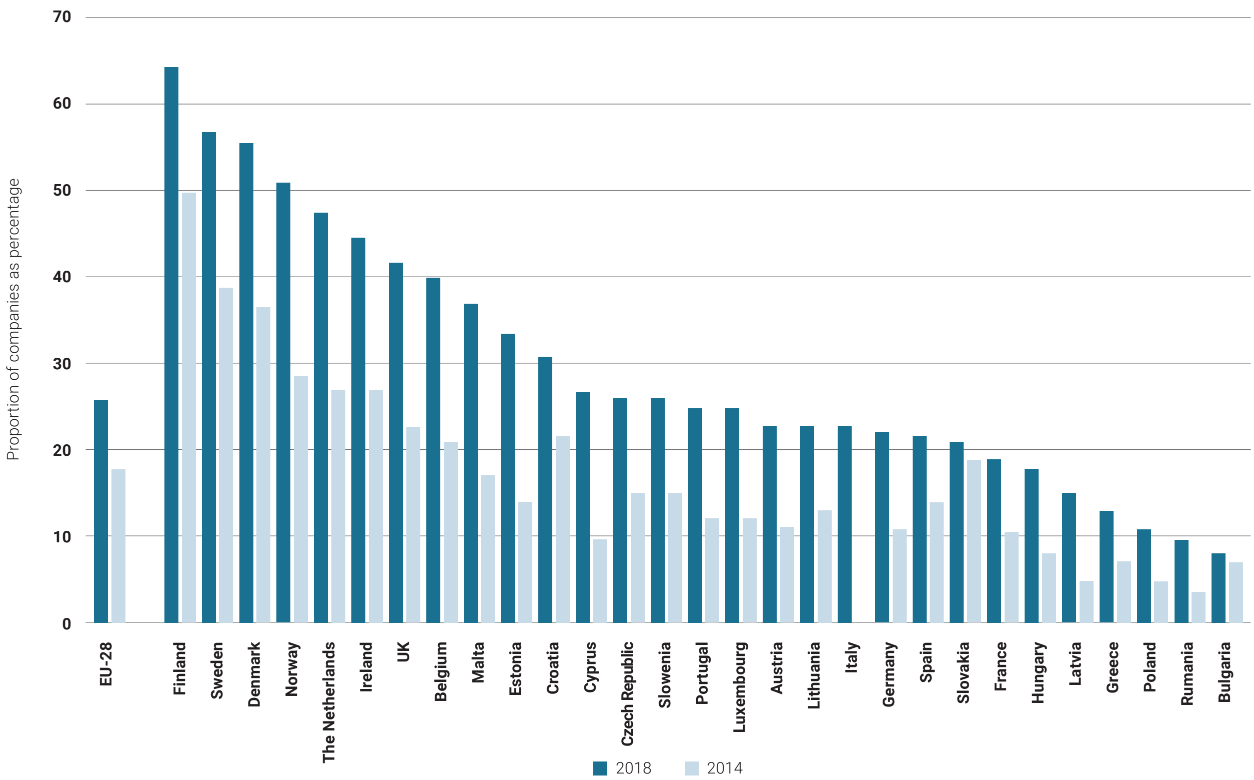

Figure 3: Usage of Paid Cloud Services in Companies with More than 10 Staff (EU28+Norway)
Source: (Eurostat, 2018)

(Fig. 3). In Germany, concerns about data security in particular are seen as an obstacle to the prevalence of cloud service usage, followed by fear of data loss and uncertainties about the legal situation (KPMG & Bitkom, 2019).

Some studies (CIF, 2017; IDC, 2015; KPMG & Bitkom, 2018) identify a significantly higher cloud usage in companies than the Eurostat survey. How the deviations in the results can be explained can only be surmised. The Eurostat survey – with 158,000 companies surveyed in all EU28 countries (Eurostat, 2018) – is by far the most valid from a statistical perspective. It can therefore be considered that these results are representative. The fact that other studies come up with different results may be due to the specific question posed. It could also be that proportionately more large companies were surveyed in these investigations. According to the Eurostat survey, 56% of large companies use cloud services, while only 25% of small and medium-sized companies do. Furthermore, it is possible that IT analysts' surveys have increasingly reached ICT-affine companies that use more cloud services than the average company. Regardless of the current percentage of cloud users, however, all studies conclude that the use of cloud services in companies is increasing significantly and that cloud usage is becoming mainstream (CIF, 2017; Cisco, 2018; Dutch Data Center Association, 2017; eco & Arthur D. Little, 2015; Eurostat, 2018; IDC, 2015; KPMG & Bitkom, 2018).

The use of cloud services is also increasing in the private sphere. In Germany, people under 40 spend almost 75 hours a week online (Postbank, 2020). This development is documented, for example, through the use of social networks. In the EU, 54% of people aged 16-74 used the Internet for social networking in 2019. In 2011, the figure was still 36% (Eurostat, 2020). It can also be seen that private Internet usage is particularly high in Northern Europe, generally at 70% or more. In contrast, the use of social media in France and Italy is only at 40%. According to Cisco, consumer applications are currently

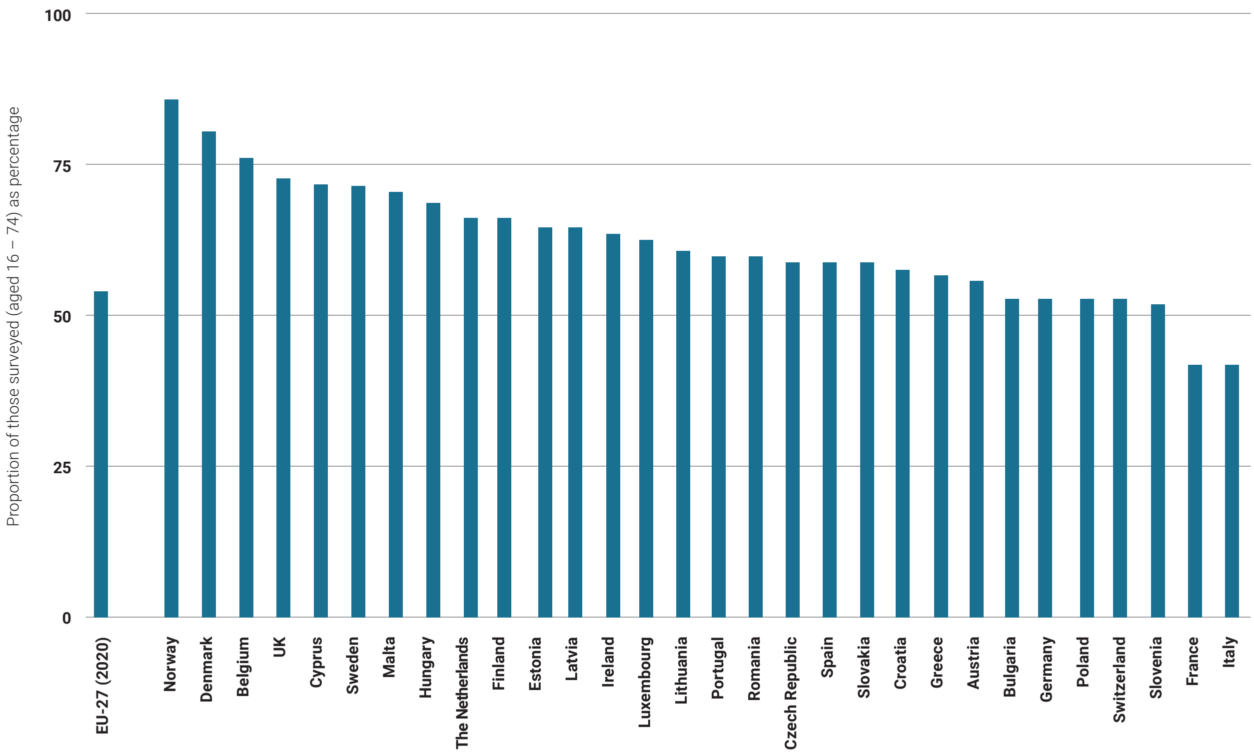

Figure 4: Individuals Using the Internet in the Last 3 Months for Social Networking (2019)
Source: (Eurostat, 2018)

responsible for approximately 25% of the workloads and compute instances[2] in data centres worldwide. The use of cloud applications such as video streaming and social networks is growing the fastest, and Cisco forecasts that by 2021 these applications will account for almost 60% of consumer workloads (Cisco, 2018).

Cloud technologies and cloud data centres offer considerable potential for increasing economic performance and improving cost and energy efficiency. Cloud services are highly scalable and can be adapted to performance requirements. In many cases, they offer the possibility of utilising existing IT capacities in a much better manner than traditional IT concepts do. Cloud offerings are often provided in large, very efficient, and process-optimised data centres. The United States Data Center Energy Usage Report estimates that hyperscale cloud data centres require up to 80% less energy for infrastructure such as cooling and power supply than traditional data centres (Shehabi et al., 2016).

> Cloud computing represents a significant trend in the delivery of IT services. However, the use of cloud-based solutions in Europe has so far been slow to take off in comparison to other markets. The further development of cloud solutions offers high potential for efficiency.

The trend towards more cloud computing is resulting in a positive overall economic effect. A study by IDC on behalf of the European Commission forecasts an increase in the EU's gross domestic product of €103 billion in 2020 as a result of cloud computing. That would equate to 0.71% of GDP. This cloud-driven economic growth would be associated with over 300,000 new companies and nearly 1.6 million new jobs in the EU (IDC, 2015).

According to Cisco, cloud technologies are already the dominant data centre delivery model and are responsible for the majority of data processing, storage and transmission. According to Cisco, in Western Europe in 2020 less than 10% of workloads in data centres are forecast to be so-called traditional workloads, with more than 90% cloud workloads. Measured according to the number of physical servers, this means that 75% of servers in Western Europe are operated as cloud servers (Cisco, 2018). When classifying the content of these analyses by Cisco, it must be taken into account that many companies also use cloud technologies in their own data centres, or on their own IT hardware in colocation data centres.

Over the past decade, the capacities of colocation data centres in Europe in particular have been significantly expanded. At the major data centre locations London, Frankfurt am Main, Paris and Amsterdam alone, the offering in colocation data centres increased by a factor of four between 2010 and 2020 (CBRE, 2017a, 2020). Broadgroup assumes that the percentage of users of colocation data centres will increase significantly compared to the number of users of in-house data centres. While 78% of data centres in Europe were still being operated by the company itself in 2015, a share of only 54% is forecast for 2020 (Howard-Healy, 2018). In the German federal state of Hesse, with the Frankfurt Rhine-Main conurbation, colocation data centres make up 50% of the total capacity of data centres (Hintemann & Clausen, 2018b). In the market for colocation services, a clear concentration on a few large providers has been observed in recent years (Ostler, 2018). However, there are still a large number of small suppliers with market shares of less than one percent (Hintemann & Clausen, 2018b).

[2] The performance of data centres is difficult to measure. One approach is to take the number of workloads and compute instances running in data centres as a measure of performance. Cisco defines Workload and Compute Instances as follows: "A server workload and compute instance is defined as a set of virtual or physical computer resources that is assigned to run a specific application or provide computing services for one or many users." (Cisco, 2018). For language reasons, only the term "workloads" will be used in the following sections instead of "workloads and compute instances".

4 THE DEVELOPMENT OF THE ENERGY EFFICIENCY AND ENERGY CONSUMPTION OF DATA CENTRES IN EUROPE

Increasing digitalisation requires powerful data centres. Worldwide, the range of computing, storage and data transmission services has increased massively over the past decade. According to analyses by Cisco, the number of workloads installed on servers will have increased by a factor of ten between 2010 and 2021. The IP data traffic of data centres is expected to increase by a factor of 19 during this period (Cisco, 2011, 2018). The impact of this strong growth in data centre capacity on the energy consumption of data centres is assessed in a variety of ways in the scientific literature.

While optimistic studies assume that the worldwide energy consumption of data centres has only increased slightly over the last decade (GeSI & Deloitte, 2019; Malmodin & Lundén, 2018; Masanet, Shehabi, Lei, Smith & Koomey, 2020), pessimistic analyses assume that the energy consumption of data centres worldwide has multiplied many times over (Andrae & Edler, 2015; Belkhir & Elmeligi, 2018; The Shift Project, 2019). The Shift Project assumes an increase by more than a factor of four (The Shift Project, 2019).

One of the main reasons for the existing uncertainty regarding the development of the energy consumption of data centres is that there is little data available for data centres. In particular, there is hardly any data available on data centres used by companies for their own purposes (on premise) (Hintemann, 2014). Even the data from various sources on server sales figures vary by up to a factor of almost two (Bio by Deloitte & Fraunhofer IZM, 2016).

From the point of view of the authors of the present report, it is neither likely that the energy consumption of data centres worldwide has remained constant in recent years, nor that the energy consumption has increased by a factor of three or four. What speaks against an extreme increase is that the available figures on sales of IT hardware and infrastructure solutions are not compatible with such a significant increase in energy consumption. Energy consumption that has remained largely constant over the past decade is also hardly compatible with the available market data (Hintemann, 2020). Worldwide, data centre capacities have been massively expanded over the past decade (CBRE, 2017b, 2017c, 2020; Cook & Jardim, 2019; Greenpeace & North China Electric Power University, 2019; Howard-Healy, 2018; Technavio, 2015, 2020). Moreover, the optimistic analyses obviously do not take into account new applications and IT infrastructures such as those being built for crypto-mining or artificial intelligence. For example, a number of studies (CBECI, 2019; Digiconomist, 2019; Kamiya, 2019; Rauchs et al., 2018) show that in 2019 alone around 60 to 70 TWh of electrical energy was required for the mining of Bitcoins. That alone would equate to around 1/3 of the worldwide energy consumption of data centres in the optimistic analyses.

The various studies dealing with the development of the energy consumption of data centres in Europe also come to different results (Fig. 5). In a study for the EU Commission, the Borderstep Institute calculated an increase in energy consumption in the EU28 of around 50% between 2010 and 2020 (EU Cloud Study in Fig. 4).

The Borderstep calculations are based on a detailed model of the data centre landscape, with which the energy consumption of data centres can be calculated based on the inventory of individual components (various types of servers, storage systems, network components, cooling/air conditioning, power supply, etc.). This model has been continuously developed over more than ten years (Fichter & Hintemann, 2014; Hintemann & Clausen, 2018a; Hintemann, Fichter & Stobbe, 2010; Hintemann & Hinterholzer,

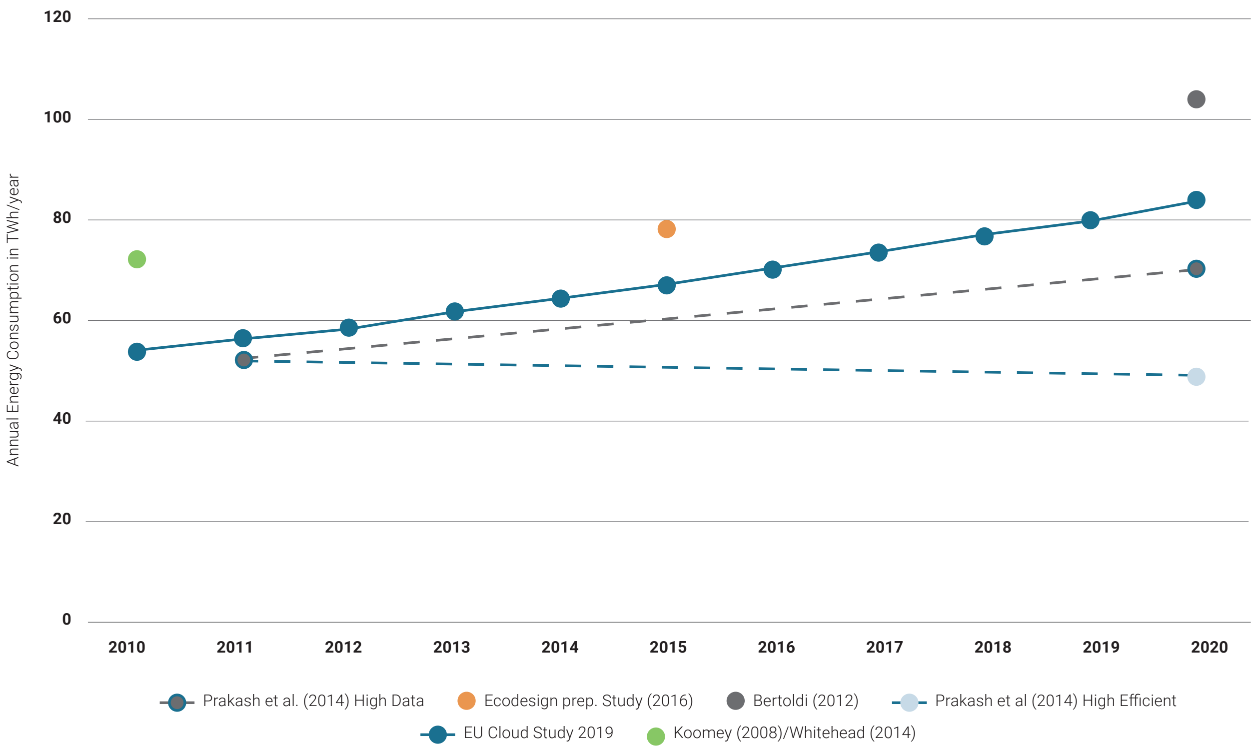

Figure 5: Overview of Studies into the Development of Energy Consumption of Data Centres in Europe from 2010 to 2020
Sources: (Bertoldi, Hirl & Labanca, 2012; Bio by Deloitte & Fraunhofer IZM, 2016; Hintemann, 2019; Prakash, Baron, Ran, Proske & Schlösser, 2014)

2019; Stobbe et al., 2015) and in its current version contains more than 10,000 individual data sets. For the present study, the model was updated with sales figures for server hardware (status 2020) and expanded to include Switzerland and Norway.

Figure 5 shows the results of the calculations carried out for this report. According to these, the energy consumption of data centres in Europe rose from 56 TWh/year to 87 TWh/year between 2010 and 2020 (+ 55%). This means that data centres currently require approx. 2.7% of the electricity consumed in Europe. A moderate further increase in energy consumption is forecast for the future, to 98 TWh/year by 2030. The analyses show that investments in energy-efficient data centre infrastructures over the past decade have led to a significant decline in the proportion of technical building equipment – for cooling, power supply, fire protection, etc. – in the energy consumption of data centres. This is a sustainable and positive effect.

While in 2010, technical building equipment was still responsible for an average of about 50% of the energy consumption of data centres in Europe, this share sank to 40% by 2020. In efficient newly-built data centres, the technical building equipment already accounts for 25% or less of total energy consumption.

Due to the relatively long service life of data centre infrastructures, often more than 15 years, the efficiency investments in the inventory will pay off especially in the next decade. It can be assumed that the share of technical building equipment in the inventory of all data centres will decline to an average of 25% by 2030.

In the past, very high efficiency gains were also achieved in the IT equipment of data centres. If we relate the development of energy consumption to the installed workloads in data centres, energy consumption per workload has reduced by around a factor of six since 2010. What is more, the energy consumption per transmitted GB of data in the data centre has

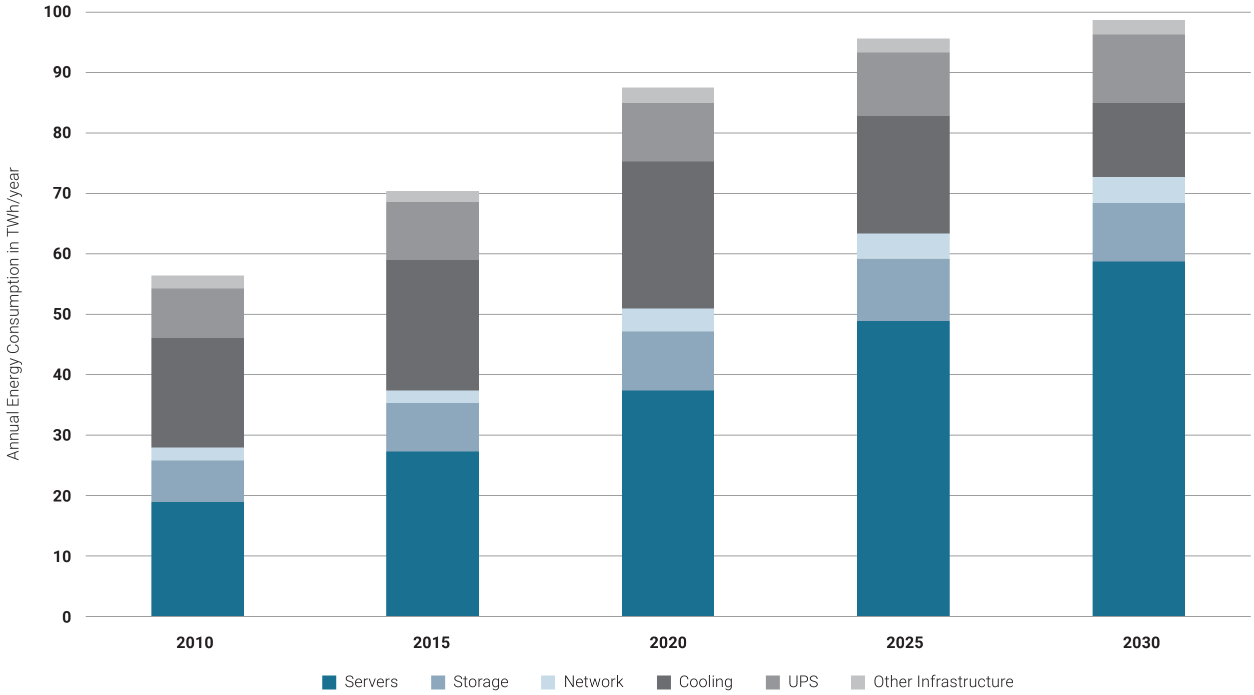

Figure 6: Energy Consumption of Data Centres in Europe (from 2020: Forecast)

been reduced by almost a factor of 12.

In view of the development of IT provisioning models towards cloud computing, it can also be assumed that the energy consumption of cloud data centres will increase. In practice, it is often difficult to distinguish between cloud data centres and traditional data centres, as cloud technologies are increasingly being used in traditional data centres as well. More and more companies today are working with hybrid multi-cloud solutions (Equinix, 2020; Flexera, 2020; VansonBourne, 2019). For applications in the private end-consumer sector, it can be assumed that these are predominantly offered from cloud data centres. For enterprise applications, based on the trends outlined above, it is assumed in this report that around 30% of workloads in Europe are currently delivered from cloud data centres. This means that the share of cloud data centres in the workloads in Europe is just over 50%.

Data centres have been able to achieve high gains in efficiency in the last decade. Power demand for computing and storage capacity has reduced by a factor of six to twelve.

Fig. 7 shows the development of the energy consumption of data centres in Europe as a function of the type of data centre. Despite the efficiency advantages (Masanet et al., 2020; Shehabi, Smith, Masanet & Koomey, 2018), the energy consumption of cloud data centres has risen continuously in the past. This can be explained by the fact that cloud computing is becoming the dominant delivery model, as shown above. The share of cloud data centres in the total workloads of data centres and, thus also in the energy consumption, will continue to increase in the future. Fig. 7 also presents a forecast for the energy consumption of edge data centres in Europe. From today's perspective, the development of the market for edge data centres can only be provided as a rough estimation. The forecast is based on the assumption that the market volume of edge data centres will increase by approximately 20% annually, as predicted by market analysts (SBWire, 2018). If this development continues, edge data centres could be responsible for around 20% of the energy consumption of data centres in Europe by 2030.

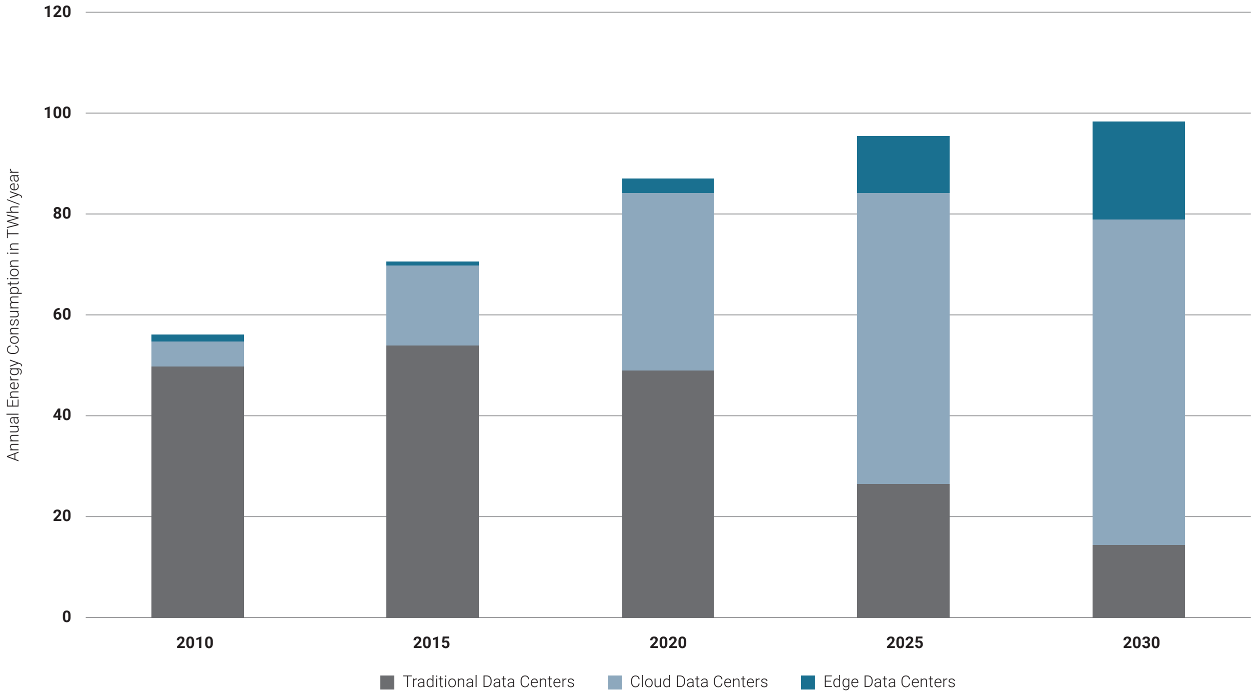

Figure 7: Development of Energy Consumption of Data Centres in Europe According to Type of Data Centre (from 2020: Forecast)

Over the last decade, the data centre industry has seen strong growth, particularly in Western Europe, Northern Europe, and Scandinavia. In Western Europe, growth has mainly been driven by the strong economic power and the good existing network infrastructure. Northern Europe and Scandinavia offer advantages for a cost-effective and, due to climatic conditions, energy-efficient operation of data centres.

> Digitalisation is driving the expansion of data centre infrastructures, especially in Western and Northern Europe.

In addition, a large proportion of the electricity there can be generated from renewable energy sources. The Scandinavian countries – like other countries in Europe – are pursuing an active settlement policy for data centres, with low electricity prices, tax breaks, and other incentives (Hintemann & Clausen, 2018a). As digitalisation progresses, further growth of data centres in Western Europe and Scandinavia can be expected in the future, combined with a further moderate increase in the energy consumption of data centres (Fig. 8).

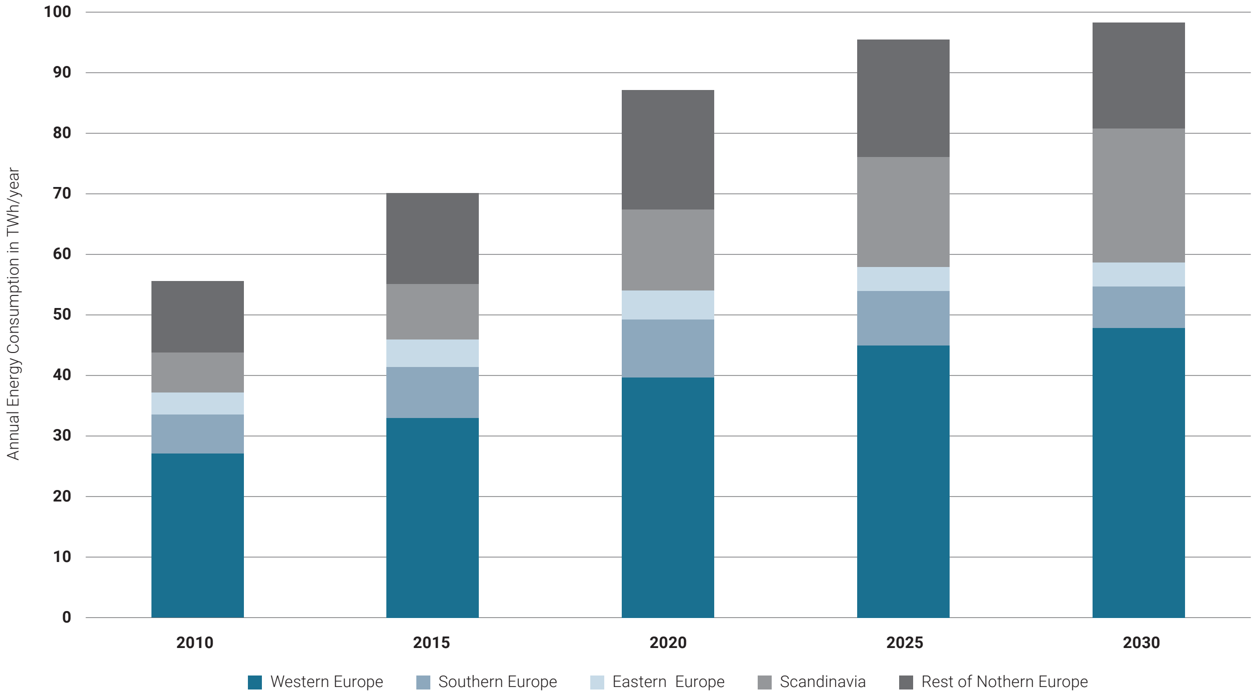

Figure 8: Development of Energy Consumption of Data Centres in Europe According to Region (from 2020: Forecast)
(**Western Europe**: Belgium, Germany, France, Luxembourg, The Netherlands, Austria, Switzerland; **Southern Europe**: Greece, Italy, Croatia, Portugal, Slovenia, Spain; **Eastern Europe**: Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia; **Scandinavia**: Denmark, Finland, Norway, Sweden; **Rest of Nothern Europe**: Latvia, United Kingdom, Ireland, Estonia, Lithuania)

5 GREENHOUSE GAS EMISSIONS FROM DATA CENTRES

The environmental impact of data centres is highly dependent on the electrical energy required for operation and the carbon dioxide (CO_2) emissions potentially caused by this.[3] Accordingly, in addition to the level of energy consumption during operation, the type of power generation is also highly relevant for assessing the impact on climate change.

Many data centre operators are already improving their CO_2 balance today by increasing power generation with renewable energies (RE). In a survey of data centre operators in Germany in 2017, 30% of those surveyed stated that they exclusively use power from renewable energies for their data centres (Hintemann, 2017). This can be done by purchasing power directly from RE plant operators under a Power Purchase Agreement (PPA), by purchasing green power from an electricity supplier or through the (local) operation of one's own RE power plants.

PPAs between electricity customers like data centres and the operators of renewable energy generators – so-called corporate PPAs – ensure the refinancing of renewable-energy power plants through the guaranteed purchase of electricity. Especially for the investment decision for plants with high capital expenditure (CAPEX) and low operating expenditure (OPEX), as is usual for photovoltaic and wind energy, this security is a relevant factor for the long amortisation period.

PPAs for renewable energies (REPAs) are used significantly less in Europe, with a total of 9.8 GW, than in the USA, where over 40 GW of plant capacity has already been marketed through PPAs (BloombergNEF, 2020). This can be attributed above all to different market structures, regulatory frameworks, and support mechanisms. Although renewable energy projects are already being financed through PPAs in individual European countries such as Sweden, Norway and the Netherlands, PPAs have not been able to establish themselves in other large markets such as Germany, or have done so only to a very limited extent, due to the support regime in place there (e.g. in Germany the Renewable Energies Act (EEG) with its pay-as-you-go financing) (K2 Management, 2019). A recent study assumes that the existing support regime with feed-in tariffs cannot be completely replaced by PPAs (Ryszka, 2020).

Among the largest buyers of renewable PPAs, both in the USA and in Europe, are IT companies, which often operate large data centres themselves (BNEF, 2020b). PPAs are often unattractive for smaller companies or individual data centre locations to procure electricity, as their purchase volumes are too small to even be able to procure PPAs – which are usually offered in the two to three-digit MW range – or to obtain attractive terms. Moreover, previous practical application of PPAs demonstrate that the associated contractual complexity is usually difficult or impossible for small electricity consumers to manage. An alternative could be a supply contract with a green power provider. There are different options for such contracts. In some variants, the revenues from the contracts are used to promote new RE installations, in other variants RE power is used from older existing plants.

The following regional analysis of CO_2 emissions from data centres in Europe is based on the CO_2 emissions of the respective national power generation infrastructures.[4] The range of emissions specific to the power generation mix in different European countries is very wide (Fig. 9). With this balancing method, the local generation mix of the respective countries has a correspondingly significant effect on the calculated CO_2 emissions of data centres. In

[3] Due to the intensive use of IT in data centres in continuous operation (24 hours a day, 365 days a year), greenhouse gas emissions caused by operations account for the vast majority of the total emissions of data centres. The manufacture, transport and disposal of equipment and facilities in data centres are responsible for only around 10% of the total greenhouse gas emissions caused. This is shown in the analysis of the results of various studies (Andrae & Edler, 2015; Belkhir & Elmeligi, 2018; Malmodin & Lundén, 2018) on this topic.

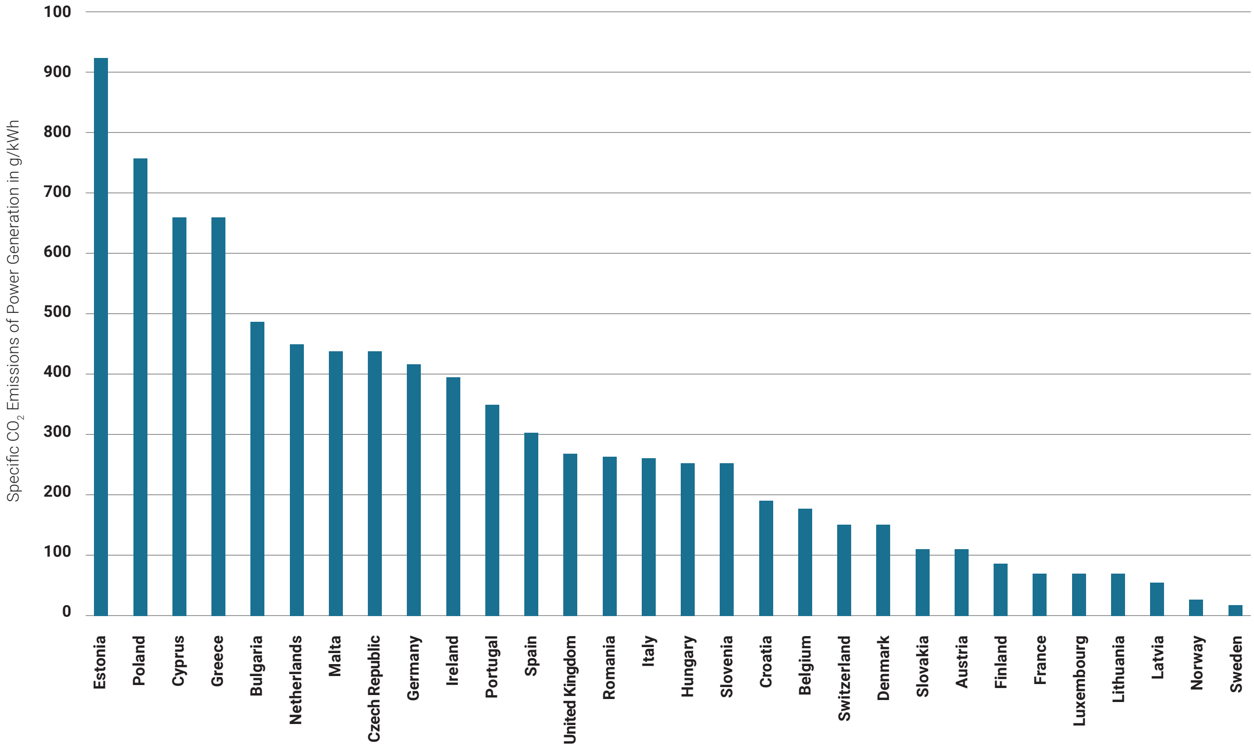

Figure 9: Specific CO_2 Emissions of National Power Generation in European States in the Year 2017 (CO_2 Intensity)
Source of data: (EEA, 2020), values for Switzerland calculated with EEA methods on the basis of the UNFCCC Report 2019 – reference year 2017

the countries of today's EU28, the emission factor in 1990 was still 539 g/kWh, and in 2017 still 297 g/kWh. For the EU28, the framework scenario EUCO 3232.5 forecasts further reductions in the CO_2 intensity of power generation to 150 g/kWh by 2030 (EU, 2019). Individual measures by individual data centre operators are not taken into account in this type of consideration.

Figure 10 shows the CO_2 emissions of data centres in Europe (EU28 + Switzerland + Norway) from 2010 to 2030 in the different regions. Compared to 2015, the CO_2 emissions of data centres in Europe have decreased by 8%. In the coming decade a further significant reduction of 30% in emissions is expected. This decrease is due to the efforts in the individual countries to reduce CO_2 emissions in power generation. The reduction targets are documented in the Climate&Energy Framework of the European Union. The aim is to achieve a 32% share of renewable energies by 2030 (European Commission, 2020).

As Fig. 10 shows, the CO_2 emissions of Western Europe remain at a relatively high level. This is due to the high shares of Germany and France in the Western European data centre market. In both countries, CO_2 emissions from power generation are

Data centres are becoming more environmentally friendly – on average, the greenhouse gas emissions of data centres in Europe even today are sinking appreciably.

[4] In this report, the specific CO_2 emissions of power generation at the level of the individual countries were taken as a basis. Non-energy-related greenhouse gas emissions from data centres, e.g. from refrigerants, are not considered. Neither the pure trade of guarantees of origin (EECS-GO) nor actual physical energy flows between countries (import/export) are taken into account in this method. The emission factors are based on the European Union's current reference scenario EUCO 3232.5, which is used to classify national energy and climate targets at EU level. For Switzerland and Norway, current emission factors were calculated based on UNFCCC reporting.

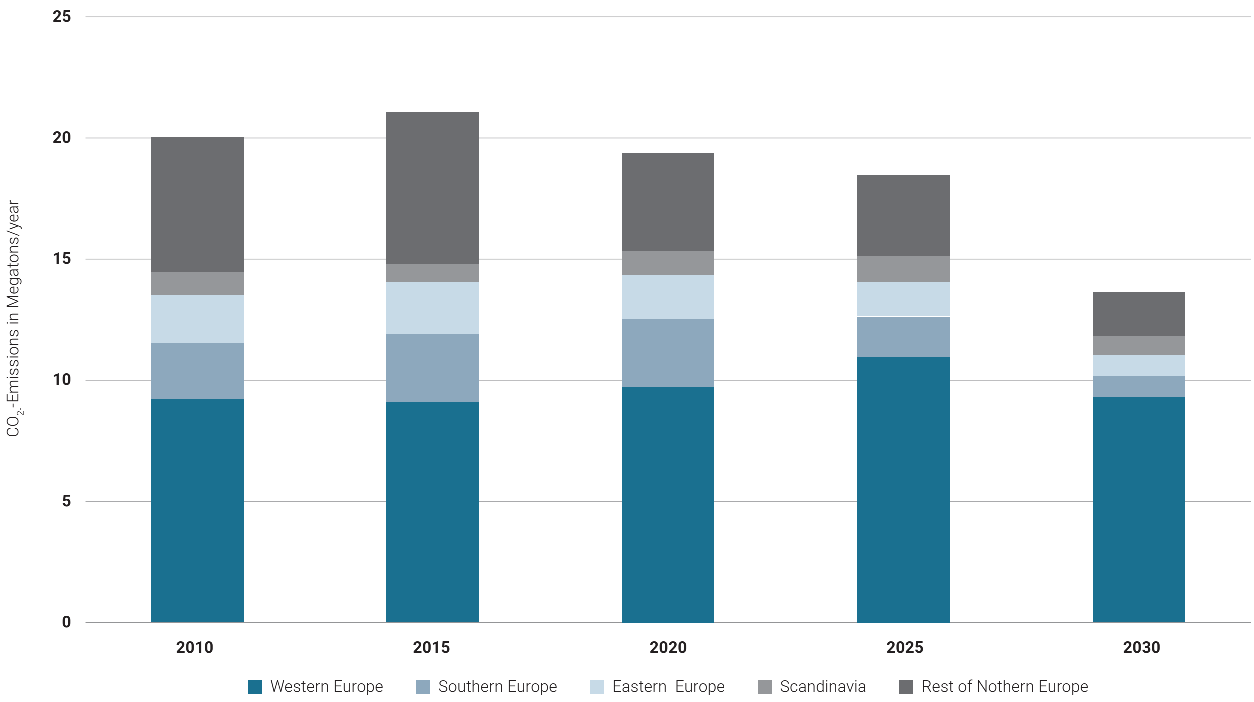

Figure 10: CO_2 Emissions Through the Energy Consumption of Data Centres in Europe
(For a breakdown of regions, see Fig. 8)

expected to decrease relatively little in the future. In France, this is due to the fact that electricity generation is already associated with very low CO_2 emissions (approx. 40 g/kWh) due to the high proportion of nuclear energy. A further reduction is therefore hardly possible.

For Germany, the forecasts assume that CO_2 emissions from power generation will only fall slowly, from 400 g/kWh in 2020 to 300 g/kWh in 2030. This is mainly due to the fact that, under current legislation, the phase-out of coal-fired power generation will continue until 2035, or 2038 at the latest. In 2019, the share of lignite and hard coal in the German power generation mix was around 33%. However, a faster, politically-controlled coal phase-out in Germany could lead to a much greater reduction in CO_2 emissions resulting from the energy consumption of data centres in Western Europe. Concerted efforts on the part of companies with regard to energy efficiency or green power procurement thus have a particularly strong impact on reducing CO_2 emissions in Germany.

While the increasing commitment of data centre operators, through green power and REPAs, is an important support for the construction of new renewable-energy power plants, there are still major challenges for the complete decarbonisation of the electrical power system and data centre operations.

On the one hand, there are large regional differences in Europe in the potentials for hydropower, wind power, and photovoltaics, while at the same time there are multiple location factors for data centres, which is why generation and consumption often take place far away from each other. On the other hand, the availability of wind power and photovoltaics is not constant over time, which is why, in addition to the spatial transmission of energy, the temporal distribution with the help of storage and flexible load is becoming increasingly important. Here too, there are several ways in which data centres can support the transformation to a sustainable supply of electrical power. For example, there are already initial projects in which data centre workloads are to be aligned with the hours of sunshine (Ostler, 2020).

6 OUTLOOK AND CONCLUSION

This report provides an overview of the sustainability effects of data centres in Europe. In addition to a qualitative description of the manifold effects, it assesses the development of energy consumption and CO_2 emissions caused by data centres in the past with the help of a model of the data centre landscape available at the Borderstep Institute, and makes a forecast for the future. The future forecast is based on the assumption that there will be no fundamental trend reversals and that the markets and technologies will continue to develop in the future as anticipated from today's perspective.

Especially in the highly dynamic and innovative environment of digitalisation, such future projections are subject to great uncertainty. New applications, new technologies, or changed market conditions and structures can lead to significant changes in the paths of development. The second part of the present investigation will deal with such possible developments and influences. At this point, a number of factors are briefly outlined that can have a significant impact on the energy consumption and CO_2 emissions of data centres in Europe.

The **technical development** in the area of IT in data centres is only to a certain extent predictable. The limits of miniaturisation in particular can cause trend reversals. For more than fifty years, the semiconductor industry has repeatedly succeeded in doubling the number of transistors per chip every 18 months to two years (Moore's Law). This has also led to corresponding progress in the energy efficiency of computers, which has improved at a relatively constant growth rate: According to 'Koomey's Law', the number of calculation steps per kilowatt hour doubles every 1.57 years. For the next decade, many experts assume that these increases in performance and efficiency can no longer be realised with current technology, since miniaturisation has advanced to such an extent that chip structures are already being produced today in the range of only a few atomic layers (Andrae & Edler, 2015; Li, Su, Wong & Li, 2019; Peckham, 2012; Waldrop, 2016). It is unclear whether a change in technology or other materials will make it possible to continue in the future to achieve high performance increases in processors with significantly improved energy efficiency.

However, the possibilities offered by digitalisation constantly create opportunities for completely **new applications**. In the past, this has meant that the potential offered by improvements in technical performance and efficiency has always been fully exploited. The increase in efficiency in data centres has not led to an overall reduction in the number of data centres, but on the contrary, has led to an ever-increasing demand for computing power. More and larger data centres have been built and the overall energy consumption has increased. However, this has also enabled new services and products to be offered and economic output to be increased (Hintemann & Clausen, 2018a). This correlation is sometimes referred to as the rebound effect. It is difficult to predict what new applications will be developed in the future and what take-up they will have in the market. From today's perspective, the use especially of artificial intelligence will increase strongly in many areas of application (eco & Arthur D. Little, 2019). Deep Learning algorithms, in particular, can require very high computing power, and therefore also entail a high energy consumption. The training of a single AI application for speech recognition generates five times as much CO_2 as a car over its entire lifetime, as researchers at MIT have calculated (Hao, 2019; Strubell, Ganesh & McCallum, 2019). Also in the areas of autonomous driving, Industry 4.0 and smart cities, a large number of new applications are anticipated that require high levels of performance from data centres. The example of crypto-mining shows how quickly new applications can lead to the construction of additional and sometimes even new types of data centre infrastructure. Within a few years, very extensive new IT capacities have been built up on the basis of application-specific integrated circuits (ASICs), with individual crypto-mining data centres requiring more than 200 MW of power (Rauchs et al., 2018).

Combined with the high dynamics in the field of digitalisation and the changing applications, **market shifts and market concentrations** are emerging in the field of digital infrastructures (eco & Arthur D. Little, 2015). Particularly in the area of cloud computing and colocation data centres, a market concentration can be observed (eco & Arthur D. Little, 2015; Hintemann & Clausen, 2018a; Wilmer-Goßner, 2019), which also has an impact on the structure of data centres. Currently, analyses show that the number of hyperscale data centres in Europe and Asia is increasing at the highest growth rates (Sverdlik, 2019). Of the more than 500 hyperscale data centres, the majority – at just under 40% – are located in the USA; however, the USA's share is currently declining (Miller, 2017; Sverdlik, 2019; Synergy-Research, 2019a). It is difficult to predict how the European data centre market will develop in the future and what effects national and European policy, regulation and funding initiatives will have. Support strategies by individual states for the settlement of data centres, such as those pursued in Scandinavia and the Netherlands (Hintemann & Clausen, 2018a), certainly have an influence on the sustainability of data centre infrastructures in Europe. The GAIA-X initiative (BMWi, 2019) to establish an efficient and competitive, secure and trustworthy data infrastructure may also have a significant impact on the market. In particular, increasing investment in digital infrastructures and a strengthening of European operators can be expected in this context. If energy efficiency and climate targets for data infrastructures are also defined within the framework of GAIA-X, this could lead to a further reduction in greenhouse gas emissions from data centres in Europe.

Public discussions and regulatory **measures for climate protection** could also have a significant impact on the future development of digital infrastructures in Europe. The increased expansion of renewable energies in the power supply can help to reduce CO_2 emissions even more significantly. Coordinated CO_2 pricing at the European level and a reduction in special regulations in individual EU states would also have a significant impact. The European Commission's objective of operating data centres and telecommunications networks in a climate-neutral way by 2030 (EU Commission, 2020) could – depending on how it is translated into concrete measures – have a significant impact.

Last but not least, **unforeseeable events** can have a massive impact on the future development of digital infrastructures. This is very clearly demonstrated, as shown above, by the current Corona crisis, which has had a significant impact on the Internet industry (Arthur D. Little & eco, 2020). Despite – or perhaps even because of – the severe limitation of economic output in Germany, data throughput at the Frankfurt Internet Exchange DE-CIX increased by 10% to 20% within one month (DE-CIX, 2020b; Peterelt, 2020).

The brief description of the factors influencing the future development of data centres in Europe and their energy consumption shows that future developments may also differ significantly from those predicted at the outset. In order to illustrate the range, two further scenarios for the future development of the energy consumption of data centres are presented below, an efficiency scenario and a worst-case scenario.

In the efficiency scenario, it is assumed that the existing technological potential for saving energy in data centres is exploited exhaustively. New applications are implemented in a resource-saving manner with the help of efficient technologies. The efficiency advantages of cloud computing can be exploited and the utilisation of IT hardware is significantly increased compared to the trend scenario. Moore's Law can be maintained through new technologies.

In the worst-case scenario, however, not all efficiency potentials can be exploited. Market conditions and regulations evolve in such a way that insufficient investments are made in energy efficiency. The limits of miniaturisation mean that Moore's Law no longer applies and therefore massive increases are no longer possible in the energy efficiency of computing power.

Based on the scenarios described above, Fig. 11 shows the span of the potential future development of the energy consumption of data centres in Europe. While in the efficiency scenario, the energy consumption of data centres shows the potential for a significant reduction down to 54 TWh/year by 2030, an increase to 158 TWh/year is also conceivable in the worst-case scenario.

Fig. 12 presents how the CO_2 emissions of data centres could develop in the various scenarios. To illustrate the influence of power generation, the effects of

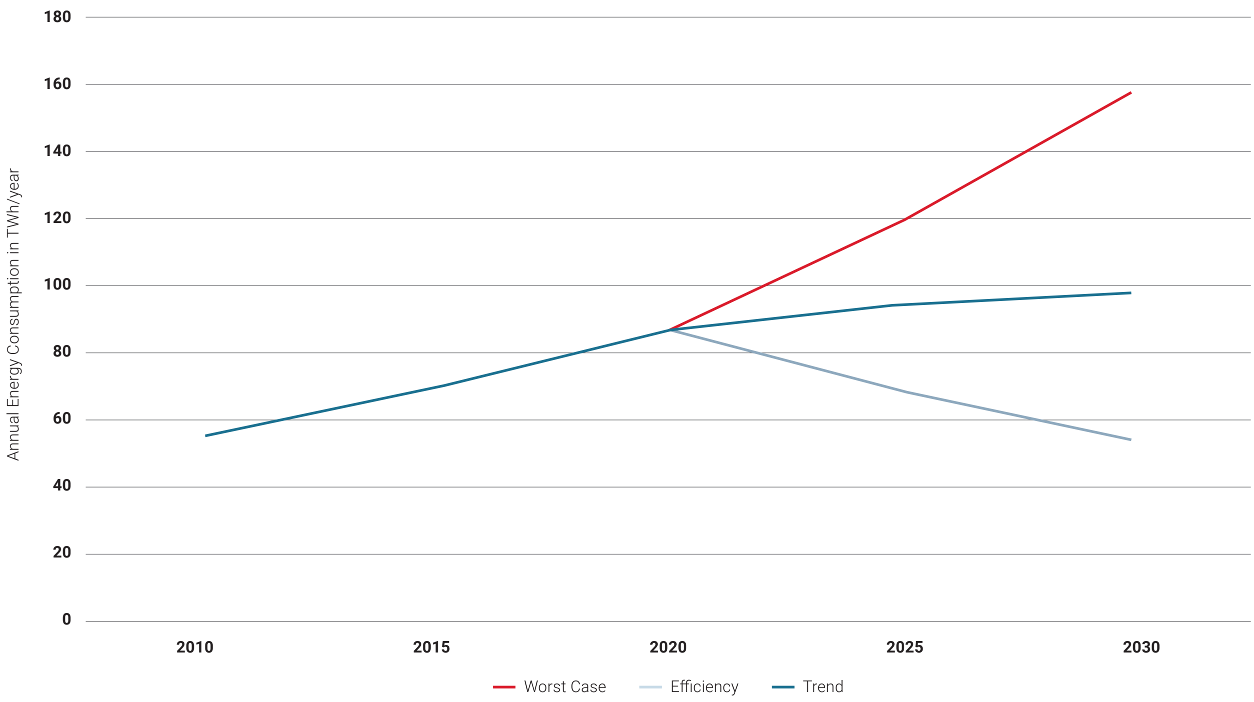

Figure 11: Development of the Energy Consumption of Data Centres in Europe to the Year 2030 in 3 Scenarios

an expansion of renewable energies were also calculated. Here, it was assumed that specific CO_2 emissions from power generation can be reduced by 30% by 2030 compared to the reference scenario of the European Union. The analysis shows that in almost all cases there can be a reduction in CO_2 emissions in data centres in Europe. Only in the worst-case scenario do CO_2 emissions increase slightly compared to the current level. With an expansion of renewable energies in power generation, CO_2 emissions can, by 2030, be reduced by more than half compared to 2020, even with the continuation of current trends. In the efficiency scenario, it is possible to reduce this to less than a third if renewable energies are expanded.

The scenarios presented show in particular the wide range of possible future developments in energy consumption and CO_2 emissions of data centres in the dynamic environment of digitalisation. The actual development will result from an interplay of the further digitalisation of the economy and society with technical developments, changes in market structures, and the influence of politics and regulation. The potentials of new technologies and the opportunities and challenges of regulatory frameworks will be dealt with in the second part of the study.

As an interim conclusion, however, it can already be stated that data centres not only have a significant influence on the future development of digitalisation, but can also make a significant contribution to greater sustainability. Without well-developed data centre infrastructures, sustainable digitalisation will hardly be possible. The direct impacts of data centres on energy consumption and CO_2 emissions are considerable. However, it can be assumed that CO_2 emissions, in particular, will decrease significantly in the future. In addition to the efforts of European countries to reduce CO_2 emissions from power generation, the initiatives of individual data centre operators to expand the use of renewable energies also contribute to reducing CO_2 emissions.

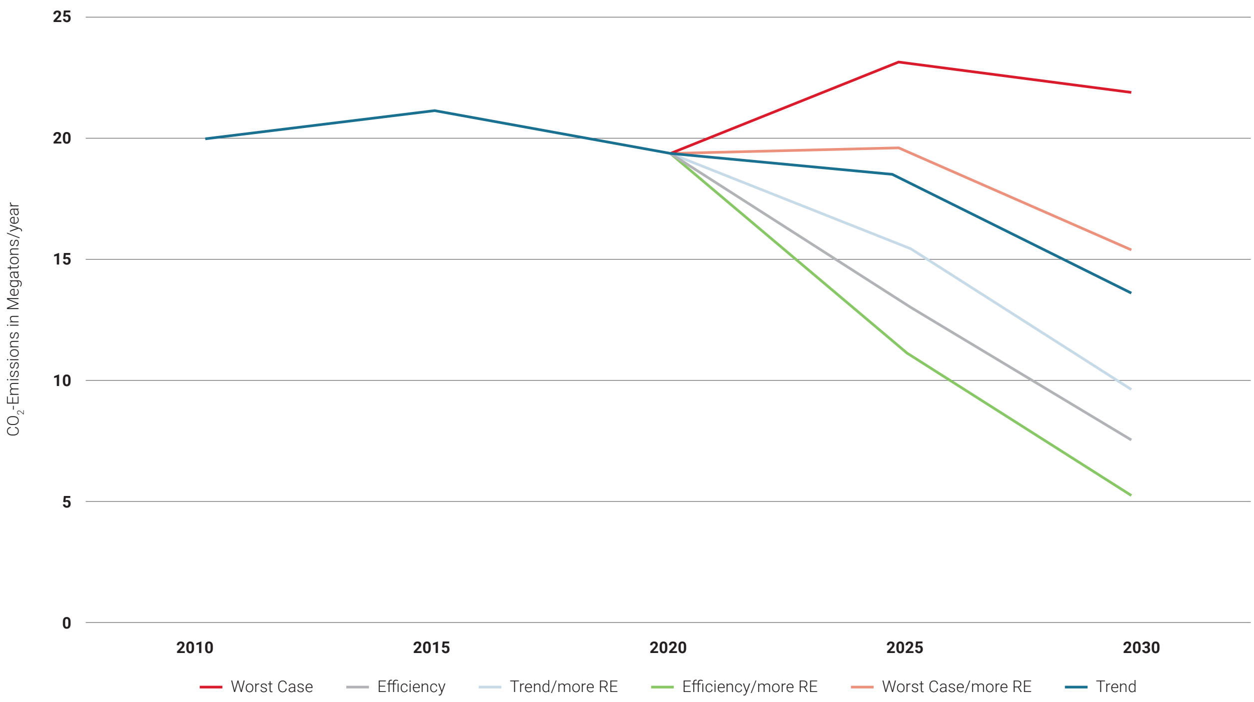

Figure 12: Development of the CO_2 Emissions of Data Centres in Europe to the Year 2030 in Varying Scenarios

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ABOUT THE ALLIANCE FOR THE STRENGTHENING OF DIGITAL INFRASTRUCTURES IN GERMANY

The Internet industry is a key sector and growth engine of our time: Its proportion of the entire economy has been growing continuously for years. And yet, while operators and large providers of social media platforms are often in the focus of politics and in the public eye, companies located at the beginning of the Internet value chain – namely operators of digital infrastructures such as data centres or colocation providers – remain largely unknown. Nevertheless, this sector is of outstanding importance for successful digital transformation in Germany. The Alliance for the Strengthening of Digital Infrastructures in Germany brings together leading companies from different branches of digital infrastructures, such as data centre operators, colocation providers, Internet service providers, carriers, cloud providers, software vendors and representatives from the user industry, under the auspices of eco – Association of the Internet Industry. Its members want to raise awareness for the importance of their sector for Germany as a digital location, and engage in constructive dialogue with politics and the public.

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