DIGITAL
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DATA CENTRES IN EUROPE – OPPORTUNITIES FOR SUSTAINABLE DIGITALISATION

Part 2
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CLASSIFICATION AND DEMARCATION OF THE PRESENT STUDY

This report is the second part of a Borderstep Institute study commissioned by eco – Association of the Internet Industry, which deals with the sustainability effects of data centres. The first part of the study presented the significance of the energy and resource consumption and other sustainability effects of data centres in Europe, and determined the development of the energy efficiency, energy consumption, and greenhouse gas emissions of data centres in Europe. As such, the first part of the study provided the basis for the present report, which identifies and presents the potential of technologies and options for action at the organisational level for improving energy efficiency and reducing greenhouse gas emissions in data centres. For the present report, in addition to extensive desk research, a Delphi survey of European data centre experts was conducted. In two rounds of interviews, 70 experts from industry, public administration, science and politics were interviewed. In addition, detailed interviews were conducted with ten selected experts. In order to illustrate the identified potentials and options for action for sustainable data centre operation, the report presents six best practice examples. Due to the large number of technological approaches considered for increasing the sustainability of data centres, an extensive glossary is included in the report.

LIST OF FIGURES

1 INTRODUCTION

High-performance and efficient data centres are the ultimate prerequisite for digitalisation geared towards sustainability. This is a key finding of the first part of this study on the sustainability effects of data centres, which was published in May 2020. Part 1 of the study provides an overview of the current and expected future sustainability effects of data centres. Part 2 of the study examines starting points and possible courses of action for how data centres can become even more sustainable in the future. The results of this second part are presented in this document.

> Data centres offer a wide range of opportunities for greater levels of sustainability – as the basic infrastructure for digitalisation, high-performance and sustainable data centres are necessary to achieve greater climate protection and sustainability in the future.

Increasing digitalisation is leading to a significant rise in the demand for processing and storage power, and thus to an increased expansion of data centre infrastructure. This expansion is occurring both in large centralised cloud and colocation data centres, as well as in a decentralised manner in hybrid data centres and edge data centres (Hintemann & Hinterholzer, 2020; Mordor Intelligence, 2020). For digitalisation to be sustainable, it is essential to expand digital infrastructures. It is only with the help of digitalisation that industrial processes can be made more efficient and resource-saving, that traffic flows can be reduced, and that energy systems can be restructured in a climate-neutral way. Digital infrastructures are the backbone of digitalisation, and at the heart of this are the operators of data centres in their various forms.

As the first part of the study has shown, despite a further significant increase in energy efficiency, the growing demand for processing and storage capacity in data centres associated with advancing digitalisation is likely to lead to a moderate increase in energy consumption. Due to the increasing use of renewable energies in power generation, the CO_2 emissions of data centres in Europe overall are decreasing. Already today, individual operators of data centres can make the power supply of their data centres climate-neutral, e.g. via Power Purchase Agreements (PPAs).

The question of how to assess the different regional conditions (e.g. nuclear power in France, hydroelectric power in Northern Europe) in an overall appraisal of the CO_2 emissions of the data centres presents a significant challenge. This applies in particular with regard to the goals of the EU Commission to operate data centres and telecommunications networks in a climate-neutral manner by 2030 (see Chapter 3).

Despite the successes already achieved in increasing energy efficiency and reducing CO_2 emissions from data centres, efforts to reduce the ecological impact of digitalisation must be stepped up in the future. As Chapter 2 of this report shows, a variety of technological and organisational approaches are available for this purpose. In most cases, these approaches are, in their own interest, rapidly implemented in the data centre industry. On the one hand, energy savings mean at the same time cost reductions, and on the other hand many companies in the digital economy have concrete goals to reduce their greenhouse gas emissions very significantly in the next few years, and therefore usually implement the corresponding measures rapidly.

In the course of this study, however, technologies and fields of action were also identified in which the implementation of new solutions is not occurring to the extent desirable from a sustainability perspective, owing to economic, organisational or regulatory conditions. These are the starting points for government action. Chapter 3 of this report deals with this issue. In particular, technologies from the field of renewable energy use and sector coupling are often unable to establish themselves in data centres due to the existing framework conditions. Other obstacles to the use of new technologies are often related to the modernisation of data centres or contradictory customer requirements.

Special attention is paid in the full report to the potentials of waste heat recovery from data centres. Since this area is seen to offer great potential for increasing the sustainability of data centres, this topic is increasingly becoming a focus for politics and the public. Even though a number of practical examples prove the applicability of this approach in data centres in principle, there are still a number of challenges that need to be met, especially in Germany. This topic area is dealt with in Chapter 4. Chapter 5 summarises the findings and arrives at a final conclusion.

2 TECHNOLOGICAL POTENTIALS FOR REDUCING THE ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS OF DATA CENTRES

Development of technology

Chapter 2 deals with the technological potential for reducing the energy consumption of data centres. The energy supply of data centres is based almost exclusively on electricity. This means that the greenhouse gas emissions from the operation of data centres are clearly dependent on the type of power generation. The specific CO_2 emissions per kWh of electricity generated vary greatly throughout Europe. While they are currently below 20 grams/kWh in Norway, they are around 420 grams/kWh in Germany and about 600 grams/kWh in Poland (EEA, 2020).

In the past, IT hardware has become more and more efficient as a result of the progressive development of microelectronics, without increasing the energy consumption. Part 1 of the study showed that the energy consumption in relation to processing and storage power have been reduced by a factor of six to twelve over the past decade (Hintemann & Hinterholzer, 2020). According to the law of Robert H. Dennard (Dennard scaling[1]), this trend is mainly due to increasing miniaturisation, in line with the law of Gorden E.

[1] Robert H. Dennard, in a paper published in 1974, already predicted that with increasing miniaturisation, the thermal power dissipation of electronic chips per surface area would remain more or less constant, even if the number of components per surface area were to increase sharply (Dennard et al., 1974).

How do you estimate the future development of IT energy efficiency until 2030?

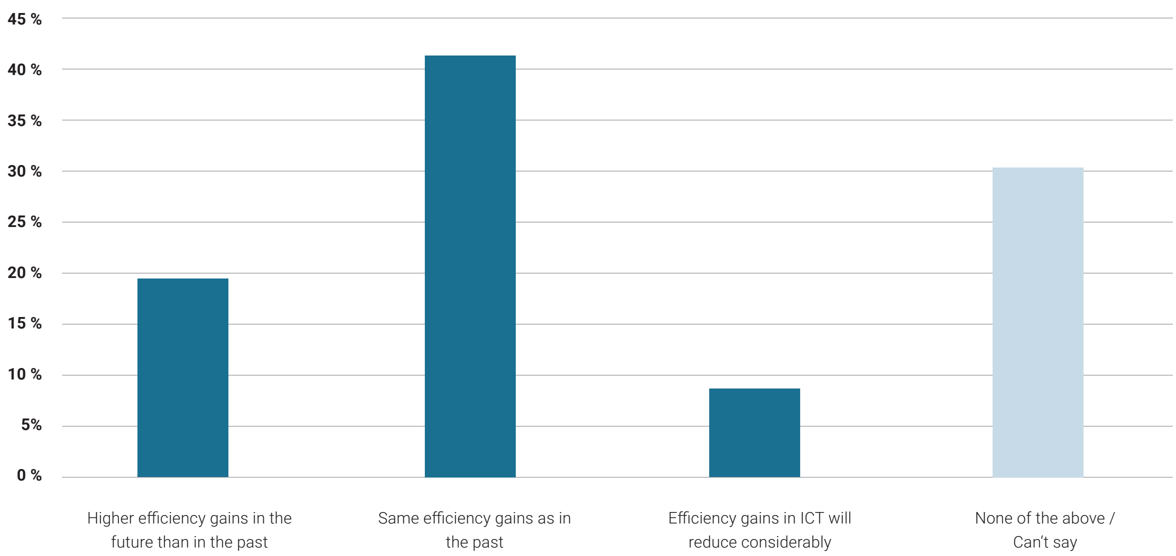


Figure 1: Expert Survey – Development of the Efficiency of IT in the Future

Moore (Moore's Law[2]), and the decreasing power consumption of the individual elements (transistors) during this miniaturisation.

Due to physical limitations of miniaturisation, many experts assume that it will no longer be possible to realise performance and efficiency gains in line with Moore's Law at the same speed in the future (Li, Su, Wong & Li, 2019; Peckham, 2012; Waldrop, 2016). It is therefore questionable whether in the future energy efficiency progress can be achieved as it has been in the past through other mechanisms and technology changes in microelectronics.

For this reason, international experts and data centres operators were asked, within the framework of a Delphi survey in the context of this study, what future developments they expect regarding energy efficiency in IT up to the year 2030 (see Figure 1). At around 42%, the largest share of respondents indicated that they predicted future efficiency gains to be comparable to those of the past, while just under 20% of respondents actually expect efficiency gains to be even higher. Only around 8% of respondents indicated that they expect efficiency gains to decrease significantly. Approximately one third of the respondents were unable to or chose not to make a statement on this.

While enormous increases have been achieved in efficiency in the IT sector over recent decades, the demand for processing and storage capacity has increased even more. This leads to the fact that – as shown at the beginning of this report – despite the efficiency gains, the total energy consumption of data centres have increased in the past (Hintemann & Hinterholzer, 2020). Against this background, the expert survey also sought to assess the future development of the energy consumption of data centres. The majority of the experts surveyed – more than 60% – assume that energy consumption will continue to rise. 26.1% of respondents take the position that the energy consumption of data centres will increase moderately until 2030, while 34.8% predict that they will increase significantly. Only around 10.9% of the experts interviewed assume that energy consumption will remain more or less the same. A moderate decline in energy consumption is anticipated by 13.0% of the respondents, while only 2.2% (one respondent) expect a sharp decline. Around 13% of

[2] Published in a paper in 1965, "Moore's Law" foresees the annual doubling of components on silicon chips (Moore, 1965). In 1975, the forecast was reduced to a doubling every two years (Moore, 1975), a forecast which remained valid until the mid-2010s.

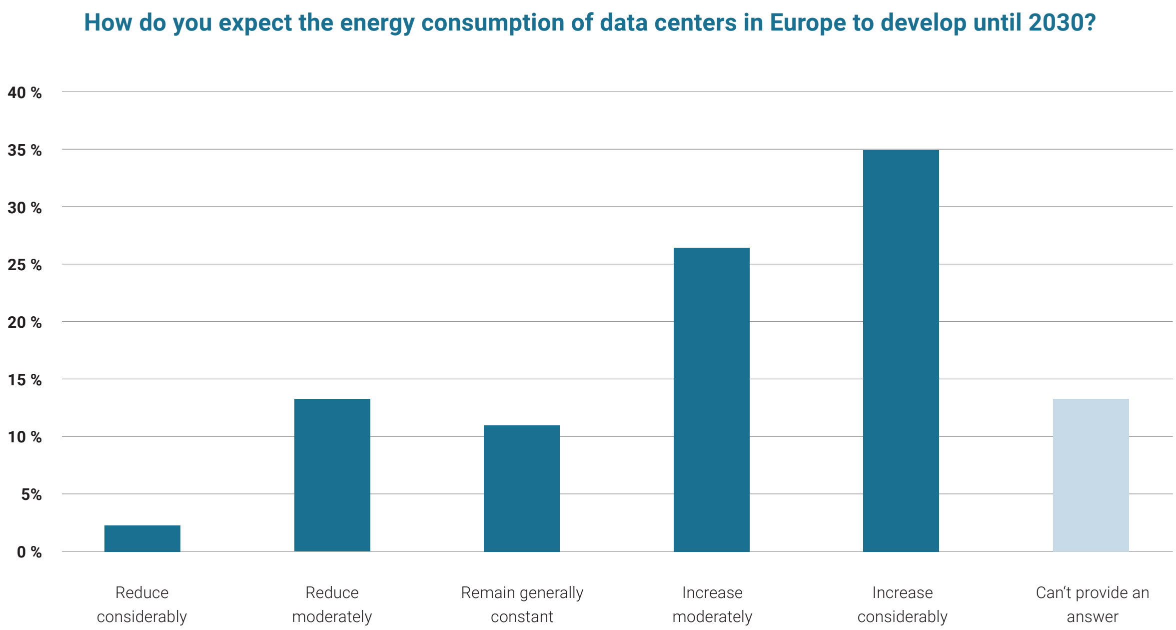


Figure 2: Delphi Survey – Future Development of the Energy Consumption of Data Centres in Europe

the respondents stated that they could not give an answer to this question. One reason for the variation in the experts' assessments is probably the lack of clarity regarding what further performance demands will be placed on data centres resulting from advances in digitalisation.

The survey shows that there is no uniform opinion among experts as to how the energy consumption of data centres will develop in the future. Nonetheless, the general view among a clear majority of experts is the assumption that energy consumption will rise – as is also forecast for the scenario based on the continuation of current trends in Part 1 of the study. The scenarios developed in the first part of the study show that it is also possible for this to proceed along a significantly different line of development. The forecast of the future development of the energy consumption of data centres in Europe until 2030 ranges from 54 TWh/a in the efficiency scenario to up to 158 TWh/a in the worst-case scenario. Which development path will actually occur depends on future technological developments. In the following, technologies are presented that could have a significant impact on the future sustainability of data centres.

Four technology areas and particularly promising technologies

A whole range of technologies are relevant for data centre processes, and the technological options for increasing sustainability are correspondingly diverse. Looking at the physical elements in the data centre, the main distinction is between infrastructure (power supply, cooling and ventilation, etc.) and ICT hardware. However, software – including virtualisation, architectures and management – also has a significant impact on the performance and efficiency of data centres (see Figure 3).

In the following, therefore, the technologies with which the sustainability of data centres can be increased in the future are presented on the basis of the following four fields:

- Cooling and Ventilation
- Architecture, Management and Software
- ICT Hardware
- Power Supply

Figure 3: Delivery Model for Data Centre and Cloud Services

There is very high potential for improving the energy efficiency of data centres in the fields of climate control and IT management.

In the expert survey, a ranking was carried out for these technology fields with regard to the potential for saving energy. The experts saw the greatest potential for savings in the field of Cooling and Ventilation (see Figure 4). This assessment was again confirmed in the second round of the Delphi survey. In a direct comparison with the field of Architecture, Management and Software, 63.8% of the respondents (n=69) saw the highest energy saving potential in the field of Cooling and Ventilation.

In each of the four technology fields, there is a wide range of technologies that can contribute to reducing energy consumption and thus to lowering the greenhouse gas emissions of data centres. The influence of reductions in energy consumption on greenhouse gas emissions is particularly strong in countries with relatively high CO_2 emissions in power generation, such as Germany.

Within the scope of this study, 70 promising technologies can be single-handedly presented and classified – from free cooling of data centres to load-adaptive data centres – in which the computing load is shifted temporally so that it can be adapted to the power supply.[3]

These technologies are presented with the help of Borderstep technology radars. This instrument was developed at the Borderstep Institute in 2016 for the presentation of energy- efficient technologies for data centres, and has been continuously refined since then. The potentials of the various technologies have been analysed and evaluated in recent years in a large number of expert workshops and surveys (Hintemann & Hinterholzer, 2018a, 2018b). The Delphi survey also asked for specific assessments of the technologies.

There are a multitude of technological potentials to realise even greater sustainability in the operation of data centres in the future.

In the field of **Cooling and Ventilation**, four technologies were identified which offer particularly high

[3] A brief description of the 70 technologies can be found in the Appendix (Glossary) of the full study.

In which of the following technology fields do you anticipate the highest potential for energy savings?

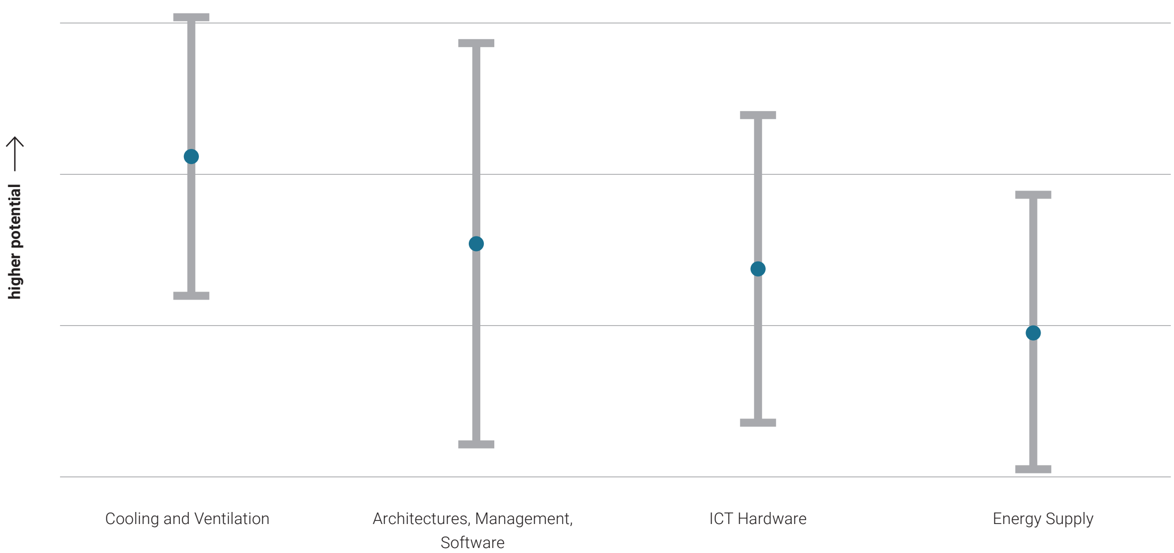


Figure 4: Delphi Survey – Assessment of the Potential for Reducing Greenhouse Gases in the Technology Fields

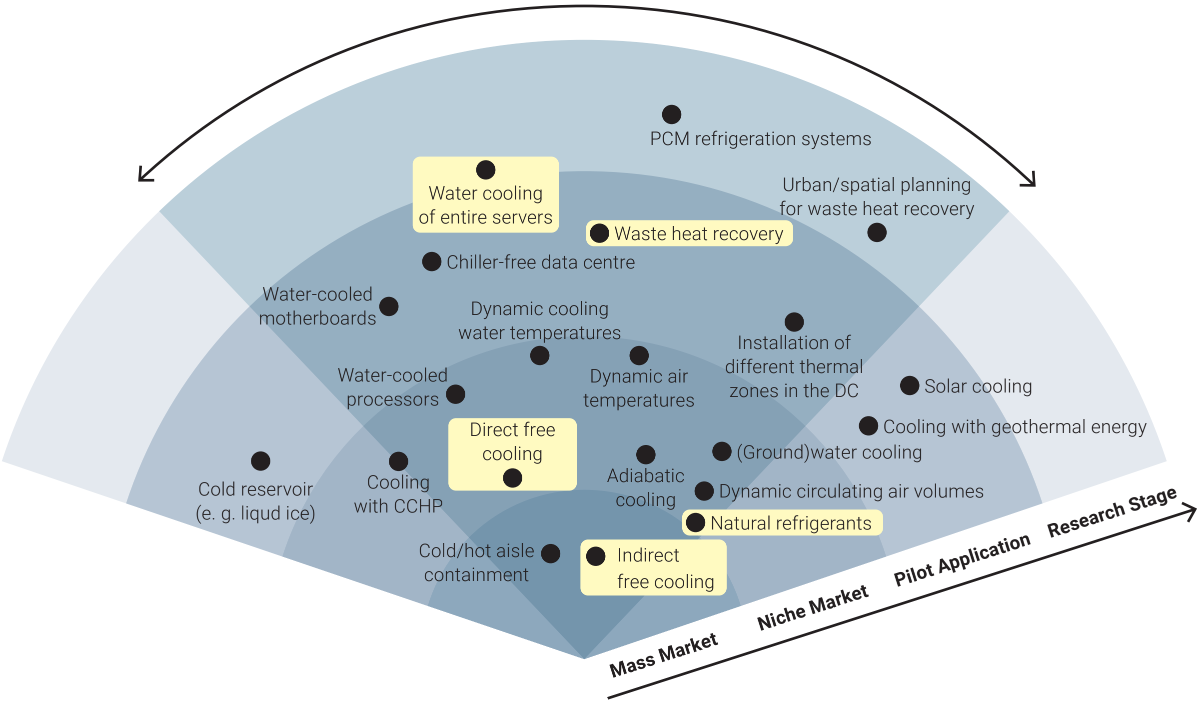


Figure 5: Borderstep Technology Radar Cooling and Ventilation

potentials for energy savings, and thus also for reducing greenhouse gases. These technologies are highlighted in yellow in Figure 5.

In this area, **waste heat recovery** is of particular importance, as the heat generated in many data centres in Germany and throughout Europe is still today usually discharged untapped into the environment. This subject is therefore dealt with independently in a separate chapter (Chapter 4).

The **water cooling of entire servers** is directly related to waste heat recovery. All heat from all server components is extracted via water. This technological approach has two main advantages. On the one hand, water enables very energy-efficient cooling of the components at low flow-rates, in comparison to large volumes of circulating air. Due to the higher heat capacity and density of water, much smaller volumes need to be moved for cooling, and the energy required for heat transport is orders of magnitude lower. As a result, energy savings for cooling are possible in the order of 70%. On the other hand, water as a medium also enables higher waste heat temperatures, making heat recovery particularly attractive (Cloud&Heat, 2019).

Similarly, in the area of cooling, the already extensively implemented **direct free cooling** and **indirect free cooling** have already been identified as efficiency technologies that can be used to further improve the energy efficiency of data centres in the future. In this case, cooling takes place either via cleaned outside air (direct free cooling) or indirectly with an intermediate medium that releases the heat from the data centre to the outside air, either in liquid form (e.g. water) or through motion (e.g. Kyoto wheel). These technologies make it possible to either completely or partially dispense with energy-intensive cooling using compression chillers in the data centre. Compared to year-round cooling of a data centre with compression chillers, free cooling technologies enable energy savings for cooling in the range of 40 to 90% – depending on climatic and technical conditions.

In the area of **Power Supply,** high potentials are anticipated for two technologies in particular for saving energy and CO_2 in data centres (Figure 6).

On the one hand, **fuel cells** represent an interesting possibility to replace diesel generators – which have so far been used for uninterruptible power supply (UPS) – with a low-emission or, in the case of

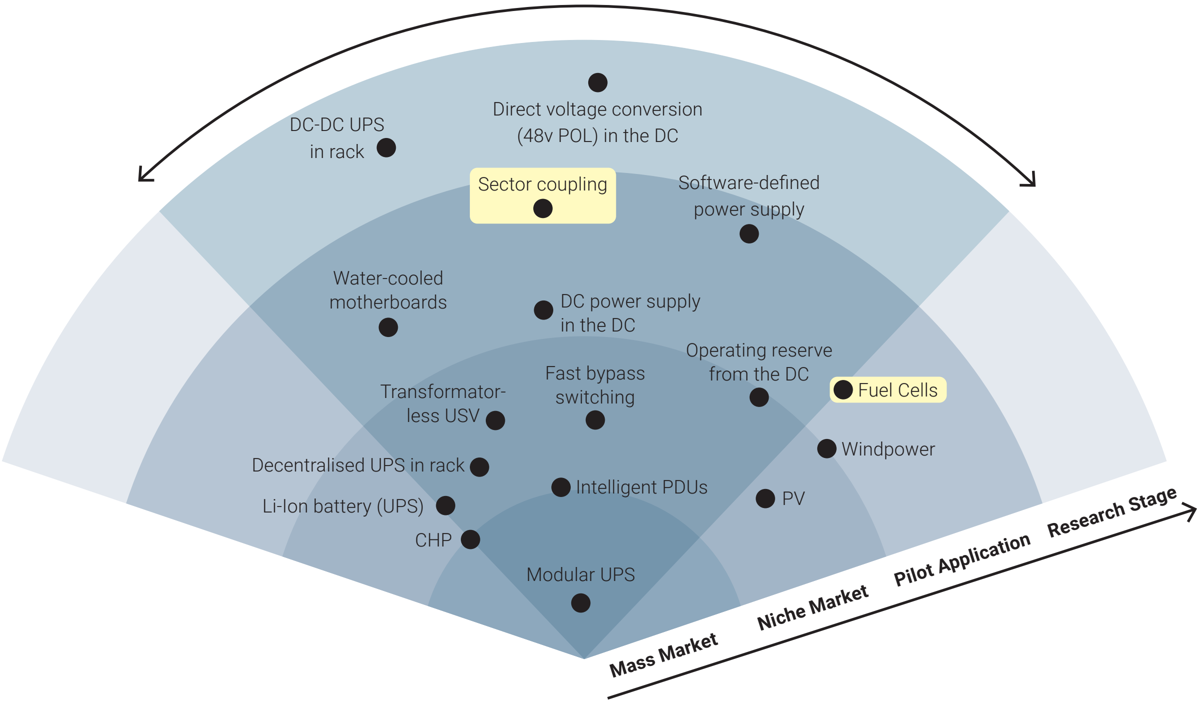


Figure 6: Borderstep Technology Radar Power Supply

hydrogen, an emission-free power generator. Even in regions such as Germany with very stable electricity grids, test runs of the emergency power supply are carried out as a standard procedure to test and ensure functionality. This involves the combustion of considerable amounts of diesel and the generation of noise emissions, which is why a fuel cell can represent a clean and quiet alternative in this context.

With the help of **sector coupling** technologies and the holistic integration of data centres in the various energy sectors, an assortment of synergies can be developed for the decarbonisation of the power supply. In the power sector, load adaptivity in particular, as well as operating reserves – e.g. from existing emergency power generators or UPS batteries – can be utilised. In Germany, for example, a total of more than 700 MW of power generation capacity is available in data centres, which could be used to stabilise the electricity grid (Hintemann & Clausen, 2018a). Data centres are also a possible energy source for the heating sector (see Chapter 4).

HOT WATER COOLING IN THE EUROTHEUM FRANKFURT

Hot water cooling makes waste heat recovery economically feasible

Sustainability Aspects

- Efficient direct cooling with hot water
- Reduction of server power consumption by approx. 10% by eliminating the need for server fans
- Utilisation of the waste heat from the data centre to heat the building complex
- Demand-oriented and energy-efficient data processing through software-supported control
- Reactivation and modernisation of the existing data centre infrastructure

In 2018, the Dresden-based company Cloud&Heat Technologies took a cloud data centre into operation in the Eurotheum building complex, on the premises of the former ECB data centre in Frankfurt/Main. The existing data centre infrastructure was retrofitted in just six months. This involved switching from air-cooled server systems to hot water direct cooling. This makes it possible to utilise the waste heat of the data centre in an ecologically and economically attractive way, even under the difficult framework conditions in Germany. While classical air-cooled systems usually only provide a temperature level of 30°C to 35°C, the Cloud&Heat solution delivers hot water at the server outlet of 60°C.

Thanks to a water-based direct cooling system, approx. 70% of the waste heat can be utilised directly on site to heat the resident office and conference rooms, hotels and restaurants. CTO Dr. Jens Struckmeier explains the economic advantages of the solution: "By using sustainable Cloud&Heat technology, we at the Eurotheum can save 40% of our energy costs annually". The very efficient hot water direct cooling of the data centre saves around €190,000 per year in cooling costs compared to conventional air cooling. In addition, the waste heat recovery enables savings of €65,000 per year in heating costs.

With the open source software KRAKE, Cloud&Heat also provides a software solution that allows data in distributed infrastructures to be processed at the exact location where processing is either most energy-efficient – for example, because the electricity is drawn from wind turbines and there is a particularly strong local wind – or where the demand for (waste) heat is highest.

"With our data centre at the Eurotheum, we save over 700 tons of CO_2 per year."
Dr. Jens Struckmeier
CTO & Founder Cloud & Heat Technologies GmbH

Facts & Figures

- Type of data centre: Cloud data centre
- IT space: 50m2 plus 25m^2 (expansion stage)
- Year of construction: 1999, modernisation: 2017/18
- PUE: 1.27 (old PUE: 1.92)
- Power per rack: 6 to 100 kW

Further information:
White Paper: https://www.cloudandheat.com/wp-content/uploads/2020/02/2019-12-16_Whitepaper-Einsparpotenzial.pdf
Photos: Cloud&Heat Technologies

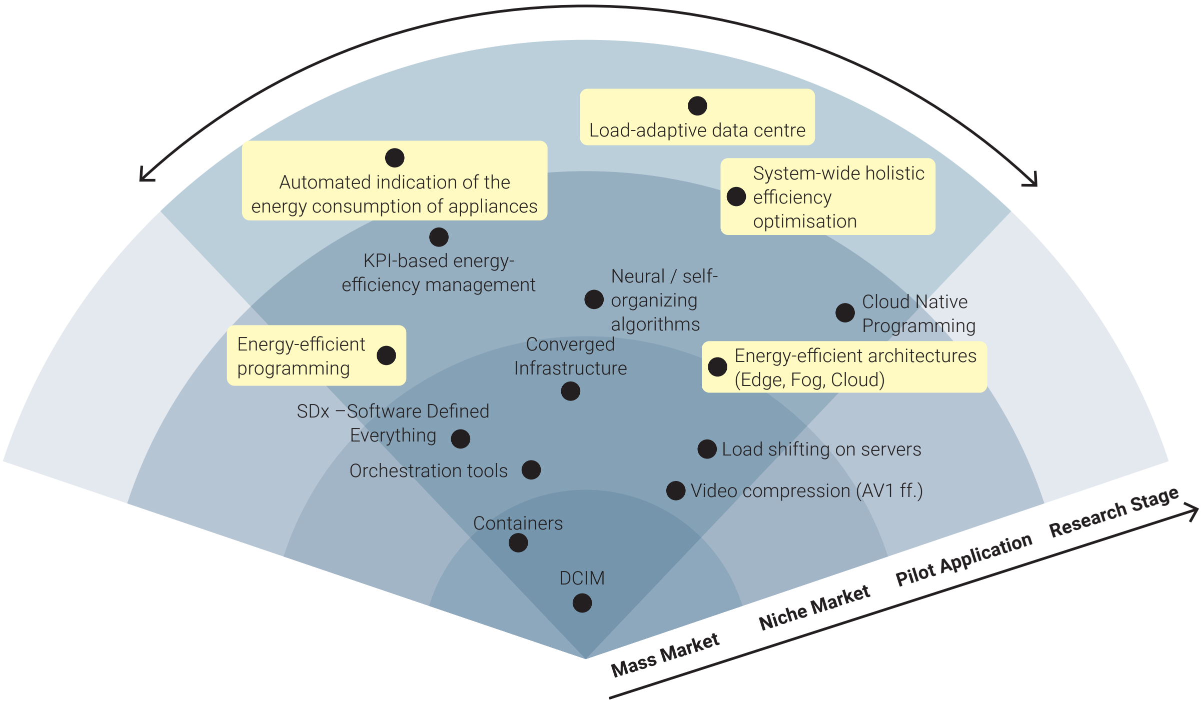


Figure 7: Borderstep Technology Radar Architecture and Management

In the field of **Architecture and Management**, five technologies have been identified with particularly high potential for reducing energy consumption, and thus CO2 emissions (Figure 7).

Load-adaptive data centres can time-shift portions of their processing load or move virtualized workloads to other data centres. This is particularly useful in view of the increasing generation of electricity from wind power and photovoltaics, as these energy sources are only available in temporal correspondence to the hours of sunlight or wind strength, and the storage of electricity is only possible at high costs. A shifting of loads is already possible today, but until now has only made limited technical or economic sense (Hanstein, 2014). With the expansion of telecommunications networks and the widespread introduction of edge data centres, it is expected that, in 10 years time, a variable shift of cloud workloads to locations with fossil-free energy will be possible (Minde & Ostler, 2020).

The **automated indication of the energy consumption of appliances** can be used to more effectively record and monitor the energy consumption of individual components in the data centre. It thus represents the basis for eliminating unnecessary consumption within the data centre.

Fundamental to the demands placed on IT resources is the **programming of software**. Depending on how efficiently a piece of code executes the requirements, the demand placed on the hardware needed to run it will be lower. Particularly in the area of applications on mobile devices, software products are often already programmed to be highly energy-efficient. However, great potential for improving energy efficiency is still seen in the area of application software in data centres. Energy saving potentials from 10% to more than 30% are expected through efficient algorithms, as well as demand-oriented programming of the software optimised for the existing hardware (Hilty et al., 2015; Pinto & Castor, 2017).

Energy-efficient architectures are one way to optimise the provision and distribution of data or services in distributed IT structures. With the increasing demands on the latency of applications, e.g. in the area of Industry 4.0, Smart City or autonomous driving, distributed data centre structures (edge computing or fog computing) are becoming increasingly important. In this context, larger portions of the data

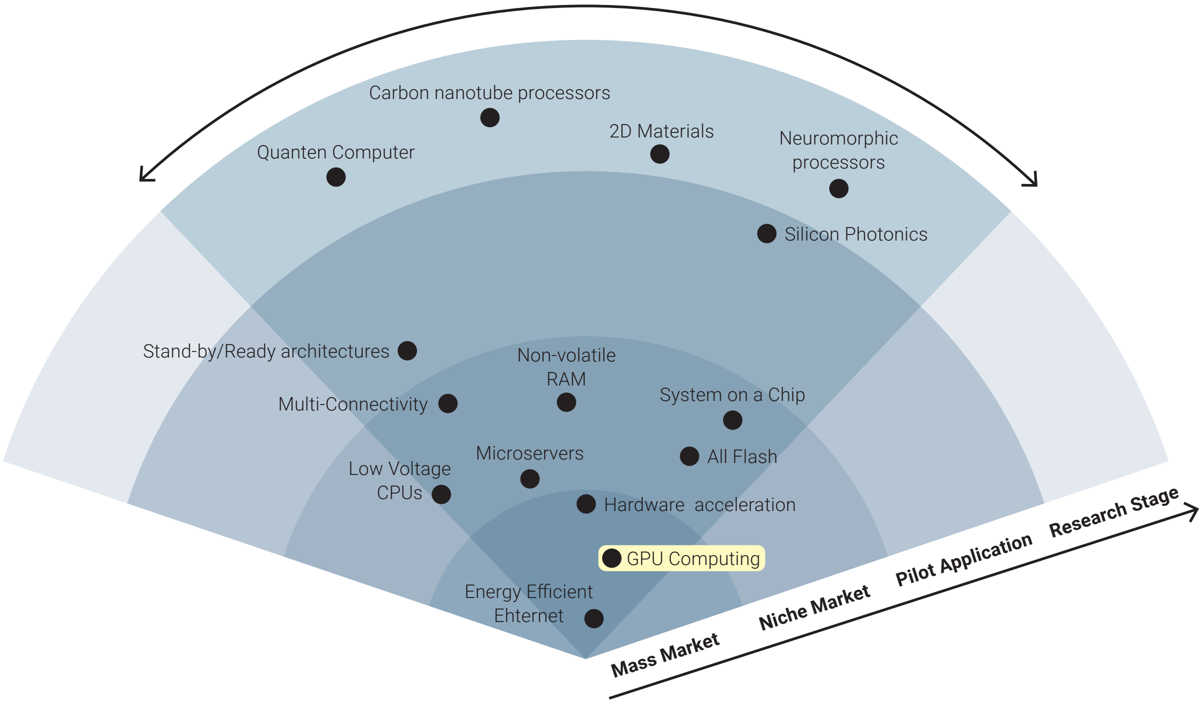


Figure 8: Borderstep Technology Radar ICT Hardware

processing take place at the edge of the network (Luber & Karlstetter, 2018). To optimise the distribution of data and services across these distributed structures, not only can latency criteria be taken into account, but also energy efficiency criteria (Jalali et al., 2016). Optimised architectures and management solutions make it possible to align the decision on where to carry out which processes with the necessary energy consumption of data processing, transmission and storage. This approach also allows data and services to be distributed depending on the supply of renewable energy in the grid or the demand for heat recovery (see best practice example "Hot Water Cooling in the Eurotheum, Frankfurt").

In **system-wide holistic efficiency optimisation**, an approach comparable to Enterprise Resource Planning (ERP) is pursued, in which the resources used are usually analysed and controlled in real time in relation to the business process. The use of ERP in ICT infrastructure can ensure a high utilisation of ICT.

In the area of **ICT hardware**, GPU computing in particular has been identified as a technology with great efficiency potential. For particular applications, such as in the field of artificial intelligence, the special architectures offer considerable advantages in terms of processing speed. Compared to classical CPUs, performance increases by a factor of 30 and more are indicated (IBM, 2019; Martins & Kobylinska, 2018).

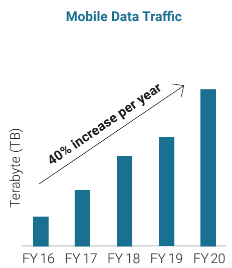
In summary, a key takeaway is that a large number of innovative technologies are available or are being developed to increase the sustainability of data centres. It can be assumed that it will be possible to continue to increase energy efficiency in data centres significantly in the future. However, when it comes to realising the efficiency potentials, a distinction must be made between new and legacy data centres.

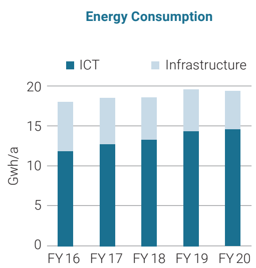
Many of the innovative technologies available on the market are already being used in **new data centres** (see also best practices examples), so that very high levels of energy efficiency can be achieved. With a view to the long service life of the building and the building services infrastructure (>10 years), the technological course in this area should be set for sustainable operation in the long-term. This applies to almost all the infrastructure technologies mentioned above in the field of Cooling and Ventilation and Power Supply.

There are greater challenges for **already existing and operating legacy data centres** to enable energy-efficient operation of the infrastructure with the help of new technologies. The replacement of existing solutions is often not possible during operation without difficulty, and is also often not desirable for sustainability reasons. Nevertheless, a great deal of attention should be paid to achieving the highest possible efficiency, especially when replacing IT hardware and introducing management tools. Every kilowatt hour that the IT does not need also does not have to be secured in the power supply and extracted in the form of heat by cooling.

ENERGY OPTIMISATION BY VODAFONE PORTUGAL

Energy efficiency of telecommunications sites





Sustainability Aspects

- Efficient ICT hardware and virtualisation
- Efficient uninterruptible power supply (UPS)
- Modernisation of existing sites
- Increased transparency through monitoring and building management systems
- Operation of sites using renewable energy

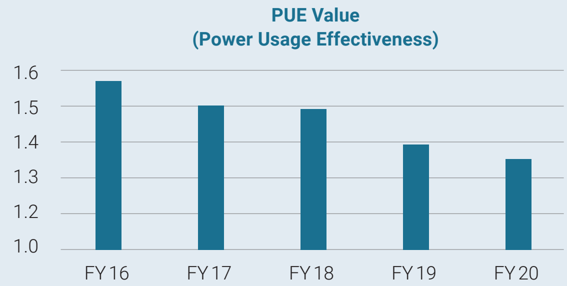
Vodafone operates mobile and fixed networks in several EU countries. Operations depend on data centres and telecommunications centres that are distributed regionally to ensure the necessary area coverage and redundancy (e.g. in the event of earthquakes). It is a great challenge to optimise these established sites from an energy perspective, because the structural conditions of these buildings differ significantly from those of modern data centres. At the same time, the significant increase in data traffic of around 40% per year requires capacity adjustments, which are provided by new high-performance hardware.

Since closing such sites and relocating the hardware to modern, efficient data centres is only justifiable – both technically and economically – in a few cases, a multi-year optimisation program was launched in the fiscal year (FY) 2015/16 (April 2015 to March 2016). With the following measures, the PUE value was reduced from 1.57 to the current 1.36:

- Monitoring of energy data and the PUE according to Green Grid and EN 50600 standards.
- Modernisation of the cooling systems with direct and indirect free cooling and highly efficient chillers, as well as optimisation of the data centre layout and air flows.
- Installation of building management and modern control systems, optimisation of the temperature profile and settings.
- Use of highly efficient modular UPS systems and removal of -48V DC rectifiers.

Despite mobile data traffic increasing by a factor of 5.1, energy consumption remained almost unchanged, at just under 20 GWh/year. The achieved PUE value of 1.36 is an excellent result for sites of this age, the type of building, and the relatively high outside air temperatures in Portugal.

Vodafone is using the knowledge gained for further optimisation projects in Portugal and also in other markets. From July 2021, electricity for all European sites will be supplied using renewable energy. Vodafone's aim is to optimise the energy efficiency of all its sites worldwide, and to minimise CO_2 emissions by using renewable energy sources.



Facts & Figures

- Type of data centre: Telecommunications sites
- 12 sites, 30 to 500 kW power consumption
- Year of construction: before 2010, modernisation starting in 2015
- PUE: Ø 1.36, before 2015: Ø 1.57

Further information:
https://www.vodafone.com/our-purpose/planet/reducing-emissions-in-our-operations

3 FRAMEWORK CONDITIONS FOR DATA CENTRES IN GERMANY AND EUROPE

Chapter 3 deals with the political, regulatory and other framework conditions that have an influence on the sustainability of data centres. To this end, the study examines, in the first instance, where government action can lead to the promotion of the use of new technologies. In the second instance, analysis is undertaken of regulatory and other framework conditions where industry representatives see a need for action at European and German level.

As Chapter 2 has shown, there is a wide range of technologies with which data centres can be operated with even greater energy efficiency and sustainability in the future. The majority of these solutions contribute to increasing not only energy efficiency, but also the cost-effectiveness of data centre operations. From research into the spread of innovations (diffusion research), it is known that, in the area of capital assets, efficiency-enhancing innovations brought to market by established suppliers develop a high diffusion dynamic and rapidly achieve high market shares (Fichter & Clausen, 2013). Most of the newly-developed solutions in the data centre environment count as this type of innovation. Support for the diffusion of such innovations through state measures is therefore rarely necessary. Financial grants for these technologies can therefore usually focus on the general promotion of research and development to increase energy and resource efficiency. For individual innovative technologies, support for pilot and demonstration projects can facilitate market entry; for the broad application of technologies within the industry, the focus should mainly be on reducing bureaucratic hurdles.

However, as the Delphi survey shows, there are still certain technology areas in which concrete government action is considered necessary (Figure 9). In addition, there are diffusion barriers in the data centre industry that counteract an increase in energy and resource efficiency (Hintemann & Clausen, 2018a, 2018b). On the one hand, the modernisation of existing data centres (retrofitting) poses great challenges. Modernisation measures that are not absolutely necessary are often not taken, in order to avoid jeopardising the trouble-free operation and availability (“Never touch a running system”). However, especially in existing data centres, high optimisation potentials are often still seen, with energy savings of up to 50% considered realistic (Gröger & Köhn, 2016).

> The energy-related modernisation of existing data centres confronts operators with major financial and organisational challenges.

In some cases, the energy-related modernisation of data centres is also made more difficult by customer requirements. For example, the energy-related modernisation of data centres during operation is considered an avoidable risk, which is why corresponding measures are assessed critically. Customer requirements with regard to low temperatures in data centres also often impede the energy-efficient operation of data centres. In the case of colocation data centres, it is quite common for customers to require contractual guarantees for very high-capacity power and cooling, but only partial use is made of these (Hintemann & Clausen, 2018b). In this way, customers want to have the flexibility to rapidly expand their IT hardware if necessary. This flexibility was advantageous during the Corona lockdown, for example.

However, the normally low levels of utilisation results, on the one hand, in the situation that existing infrastructures cannot be operated efficiently in partial load operation. On the other hand, unrequired resources must be kept ready in the data centre and in the power grids.

WINDCORES

Data Centres in Existing Wind Turbines

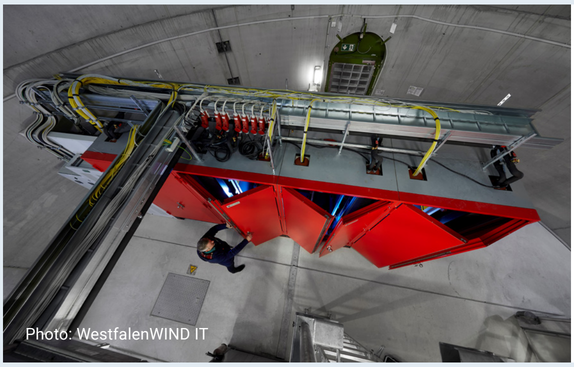


Photo: WestfalenWIND IT

Sustainability Aspects

- Use of existing wind turbines as data centre buildings
- Supply of electricity to the data centres directly from wind power
- Reduction of electricity feed-in can reduce grid bottlenecks
- Scalable, redundant and distributed data centre architecture

In 2017, under the brand name of “windCORES”, WestfalenWIND IT GmbH & Co KG started to use wind turbines as data centre buildings. In this way, the already existing secure-access rooms can be put to a sustainable secondary use.

The windCORES concept allows the use of wind power directly where it is produced. This not only provides the data centres with regenerative power, but also avoids the need to curtail wind turbines. In 2019 in Germany, as a result of curtailment to avoid overloading the electricity grid, a total of 5.4 TWh of electricity generated from renewable sources could not be used. This amount of unused energy corresponds to approximately one third of the energy consumed by data centres annually in Germany.

“We strengthen the sustainable supply of energy for digitalisation. To this end, we recombine wind turbines with data centres in an innovative and economic model.”
Dr. Gunnar Schomaker
Creator and Initiator of windCORES

The windCORES are used both as colocation spaces and within the scope of managed services. Power consumption of up to 90 kW per rack can be realised. Therefore, the concept is particularly suitable for applications in the field of high-performance computing, such as climate simulations or aerodynamic flow calculations. The sites are directly connected to the Internet Exchange DE-CIX in Frankfurt. Due to the large number of already existing buildings, windCORES enables the fast commissioning of new data centres and a decentralised distribution of computing load. The direct supply of electricity has the added advantage that WestfalenWIND IT can offer its customers low-cost electricity. windCORES currently offers rackspace for systems integrators, managed service providers and an internationally active streaming service provider. The wide range of customer applications highlights the flexibility of the infrastructure.

Facts & Figures

- Types of data centres: Managed services and colocation data centres
- IT area: 100m² per wind turbine (a total of 100 wind turbines)
- Max. power output: 600 kW per wind turbine
- Year of construction: from 2017
- PUE: < 1.3

Further information: https://www.windcores.de/

The following section presents how and in which areas technology promotion would further increase the sustainability of data centres. In addition, selected regulatory and other framework conditions in Europe and Germany are discussed.

For **technology promotion**, differentiation can be made between the promotion of research on the one hand, and the promotion of the use of energy and resource-saving technologies on the other. In the area of research, it would be worth undertaking a further general promotion of new energy and resource-saving technologies in the field of information technology and the operation of data centres. In particular, due to the limits of miniaturisation and the expected end of Moore's Law, there is a considerable need for research. It is necessary to research and develop alternative options that will enable us to continue to achieve the efficiency gains of the past. Possible technological solutions may lie in the fields of 2D materials, carbon-based microelectronics, quantum computers, silicon photonics, or neuromorphic processors. In these technological areas, European research institutions and companies are internationally competitive (Hintemann & Clausen, 2018a). It is still unclear which solutions will contribute to further increases in the sustainability of data centres in the future. There is also a need for research in this area. General research promotion should be open to new technologies and also support completely new and alternative lines of development.

Within the Delphi study, a concrete need for the promotion of technologies was identified, especially in energy-related solutions such as waste heat recovery from data centres, sector coupling, renewable energy supply of data centres, use of data centres as flexible elements in the energy system, and in the field of fuel cells. In addition, the need for governmental action in the development and use of natural, largely climate-neutral refrigerants for data centres was seen. These questions are all of great importance if the operation of data centres is to be climate-friendly in the future. There is a wide range of approaches to make the energy consumption of data centres climate-neutral. Today's common practice of establishing climate neutrality through contracts with electricity suppliers or the purchase of CO_2 certificates

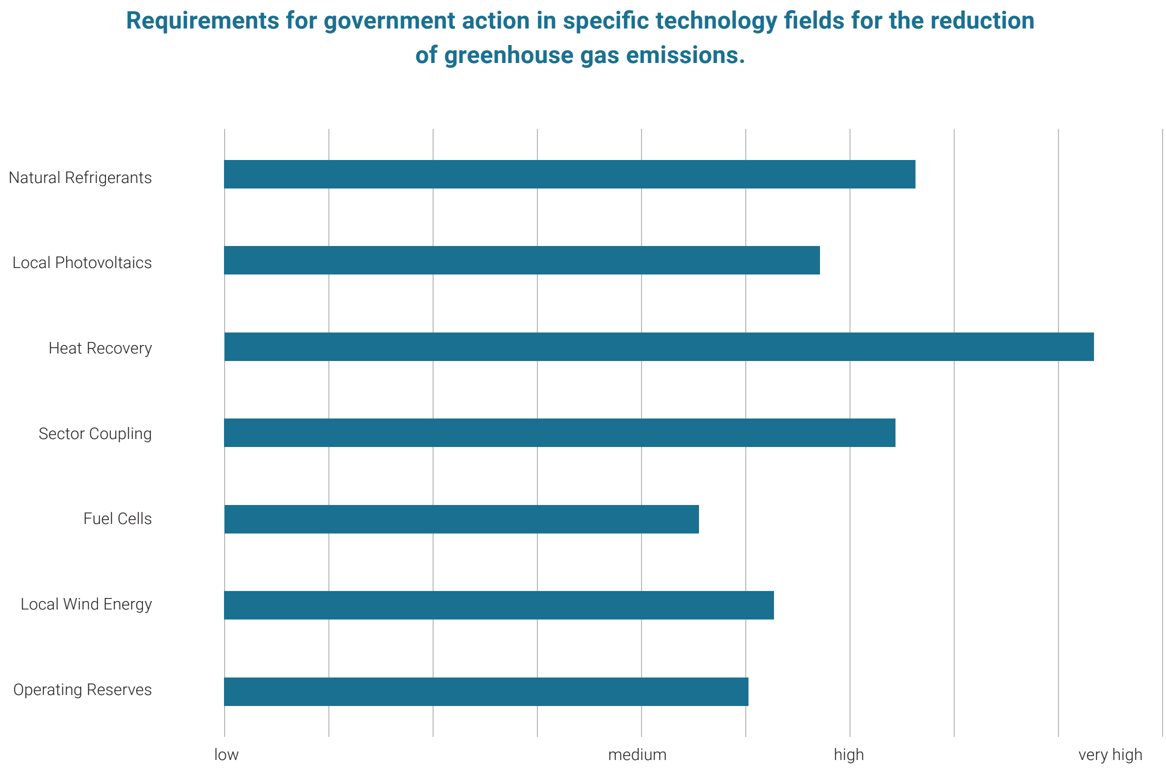


Figure 9: Fields of Technology for Which Government Action is Considered Necessary

is sometimes criticised as insufficient (Reveman & Ostler, 2019, 2020). Actual operation of data centres with renewable energy would at least have to ensure that the power generation facilities were set up specifically for the data centres, and also that the energy is generated at the same time as it is consumed or that corresponding storage capacities are available. Research has already been underway for some time to find appropriate solutions (Hintemann, Fichter & Schlitt, 2014; Ostler, 2020a). Google, for example, has made the commitment to cover its energy consumption around the clock (24/7) by 2030 with CO_2-free electricity (Google, 2020). However, such solutions are usually technically very complex and difficult to implement across the breadth of all data centres and their locations.[5] Therefore, as a result of the increasing energy consumption of data centres and their high importance for a sustainable economy and society, targeted promotion of research for the 24/7 supply of data centres with CO_2-free electricity is desirable.

In addition to the promotion of research, it is also important to promote the use of energy and resource-efficient technologies. This is particularly true for the modernisation of existing data centres. State support would be possible here through appropriate criteria in public procurement, in addition to the existing programmes for energy efficiency consulting and investment incentives. State institutions at the federal, state and local levels are responsible for more than 10% of the total demand for data centre services in Germany (Hintemann, 2014). In this way, state institutions can assume a clearly visible function in acting as a role model as well as steering the formulation of sustainability goals.[6] Data centre-specific pilot and flagship projects and field testing can also promote the implementation of new sustainable technological approaches in data centres.

With regard to the framework conditions for sustainable data centre operation at European level, the interviews conducted in the context of the study discussed in particular the topics of the Green Deal/ Digital Strategy, Ecodesign, GAIA-X, and the Energy Tax Directive. The main results of the interviews are briefly presented below.

The European Union's **Green Deal** addresses the issues of climate change and environmental degradation, which represent an existential threat to Europe and the world. A new growth strategy is to be developed for Europe to facilitate the transition to a modern, resource-efficient and competitive economy. By 2050, no net greenhouse gas emissions should be released, and economic growth should be decoupled from resource use. The European Green Deal provides the roadmap for such a sustainable EU economy (European Commission, 2019). According to an EU Commission communication on shaping Europe's digital future (EU Commission, 2020), it is planned that data centres and telecommunications networks will become climate-neutral by 2030.

> The targeted consideration of ecological aspects in public tenders represents powerful leverage for the diffusion of new efficiency technologies.

In the interviews with representatives of the data centre industry, there was support for the objectives of the Green Deal. The need to make digital infrastructures climate-friendly in the future was also emphasised. How exactly the "climate neutrality" of digital infrastructures is to be defined and how the path to achieving this is to be mapped out, however, is not yet known. According to current plans, Germany will not have phased out coal until 2038 at the latest. This raises the questions as to how climate-neutral operation of digital infrastructures can be realised in Germany, and how a possible special regulatory treatment of digital infrastructures could affect their development, as well as that of the energy markets.

The interviewees stressed that the increasing attention paid to the sector and its importance was generally very much appreciated. However, it was seen as urgently necessary to ensure close cooperation with

[5] At locations with large amounts of hydropower or nuclear energy, 24/7 operation of data centres with CO2-free electricity is already possible today. At many other locations, such as in Germany, this will hardly be feasible within the next ten years, especially for smaller and local data centres.

[6] The German Environment Agency (Gröger & Köhn, 2016) and the European Commission offer support in the environmentally-friendly public procurement of data centre services (European Commission, 2020).

the industry in discussions relating to the design of possible regulations and support measures.

In 2019, the EU Regulation (2019/424) establishing **ecodesign requirements for servers and data storage products** was published in the Official Journal of the EU. The regulation defines requirements regarding the energy and resource consumption of servers and data storage products. The initial requirements apply as of 1 March 2020. In detail, the regulation regulates the efficiency of power supply units, the power in idle state, the efficiency in active state, the capacity to replace components, and data erasure, as well as the information obligations of the manufacturers. Even though industry representatives are of the opinion that the specific design of individual requirements could be improved, the regulation is welcomed in principle. It supports the operators of data centres in the procurement of server and storage systems. However, the interviews emphasised that the current discussions on extending the ecodesign requirements for data centres or data centre components must be conducted jointly with the industry. The Ecodesign Directive applies to energy-related products. The data centre, as a generic term for a multitude of different concepts and business models, should not be subject to blanket regulation. Which products used in digital infrastructures require a concrete need for action with regard to further ecodesign requirements, and how these can be designed, should be worked out together with industry.

"In recent years, data centres have received much more attention from the public and politicians. However, concrete political support is often still lacking to further promote the sustainability of data centres."
Dr. Béla Waldhauser
Spokesperson, Alliance for the Strengthening of Digital Infrastructures in Germany

The **GAIA-X** project was presented to the public for the first time at the 2019 German Digital Summit. The initiative, which is supported by a broad circle of representatives from industry, politics and science, aims to develop an efficient, competitive, secure and trustworthy data infrastructure for Europe. This is intended to preserve European "data sovereignty". GAIA-X is to interconnect central and decentralised digital infrastructures to form a homogeneous and user-friendly system, and to define European requirements for digital infrastructures (BMWi & BMBF, 2019). The GAIA-X project is also supported by a wide range of companies that operate and use data centres. Currently, more than 300 user companies and providers of digital infrastructures are already working together within the initiative. In the interviews conducted, the project was positively assessed and the chances of using GAIA-X to formulate and establish European standards with regard to the sustainability of data centres were particularly emphasised. In view of the goal of a European Digital Single Market, there should be no more unilateral national efforts in this future-oriented field.

One topic that was raised very frequently in the interviews conducted is the European **Energy Tax Directive** (2003/96/EC). The current regulations mean that taxes and levies on electricity vary significantly throughout Europe. As a result, electricity prices for data centre operations vary widely in Europe. Figure 10 shows the typical annual electricity costs for a data centre with an average power consumption of 5 megawatts (MW) for the year 2019 in various European countries. It becomes clear that data centre operators in Germany bear the burden of significantly higher electricity costs compared to other locations. The differences range to up to 5 million Euro per year. The high electricity prices for data centres in Germany are due in particular to the renewable energy levy (EEG), which was 6.405 ct/kWh in 2019, rising to 6.756 ct/kWh in 2020. In addition to the EEG levy, data centre operators in Germany have to pay the full electricity tax of 2.05 ct/kWh, as this industry does not receive any reduction or refund of electricity tax under the German Electricity Tax Act.

In contrast to many other energy-intensive companies – e.g. in the steel or chemical industries – operators of data centres in Germany are not exempt from the EEG levy. While in Germany an additional price

"The Internet industry welcomes the Environmental Digital Agenda as a successful start for further discussions in the interplay between sustainability and digitalisation."
Alexander Rabe
Managing Director, eco – Association of the Internet Industry

component increases electricity costs, other countries such as Norway and Sweden reduce taxes and charges for operators of large data centres in order to specifically promote the establishment of data centres (Hintemann & Clausen, 2018a; Ostler, 2018a). In the interviews it was stressed that a harmonisation of electricity prices within Europe would be welcomed in order to create comparable competitive conditions.

With regard to the framework conditions at national level, the Delphi survey found that in Germany, especially for hyperscale data centres, conditions are significantly worse than in Scandinavia. While 75% of the respondents stated that Scandinavia is a top location for hyperscale data centres, only 13% thought that this also applies to Germany. For small and medium-sized data centres, however, the attractiveness of Germany and Scandinavia was rated equally. The electricity prices for data centres in Germany, which are comparatively very high, were discussed in the interviews as the main reason for this assessment. A reduction or abolition of the EEG levy was considered by industry representatives to be important for Germany as a business location. A possible reduction of the EEG levy in the context of the introduction of the CO_2 tax has been welcomed (Huesmann, 2019). Other important topics in the interviews were, in particular, the digital strategy of the German federal government in connection with the Environmental Digital Agenda and the activities for voluntary ecological labels such as the Blue Angel for data centres.

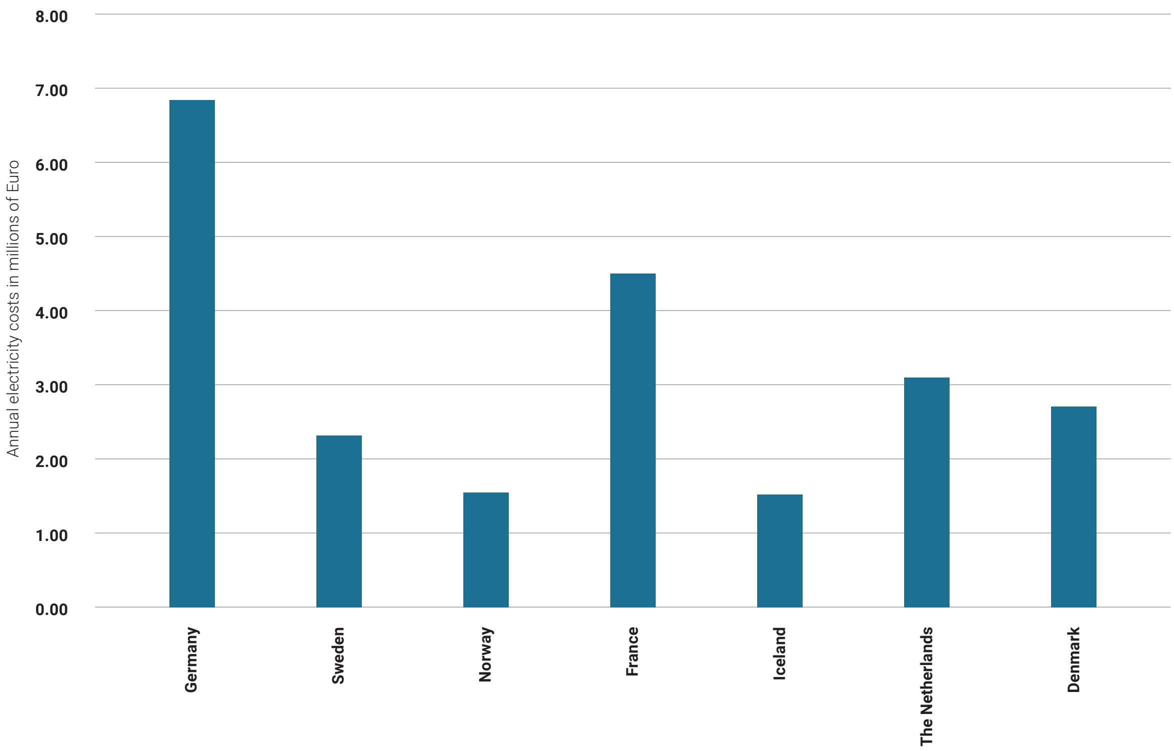
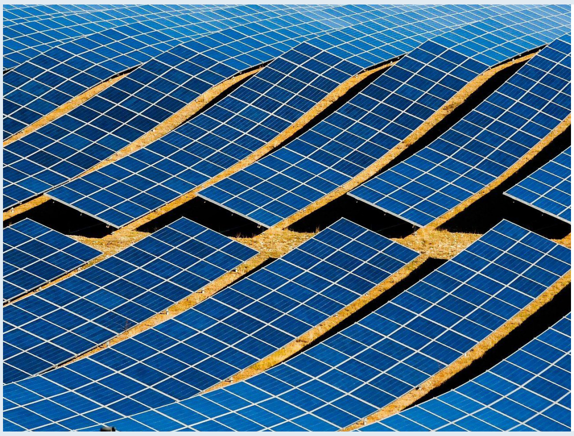


Figure 10: Energy Costs for a Data Centre with an Average Annual Output of 5 MW in Europe

PPA FROM AWS MAKES PV PLANT IN SEVILLE POSSIBLE

IT industry is a major purchaser of renewable electricity



Sustainability Aspects
- Direct promotion of new renewable energy generation plants
- Annual generation of 300,000 MWh of renewable energy
- Planning and financial security through power purchase supports the investor
- The PV modules are uniaxially tracked to increase the yield
- Due to its high levels of solar irradiation, Spain is ideally suited for PV

In its "Climate Pledge", Amazon Web Services (AWS) has set itself the goal of becoming climate-neutral by 2040, and of transitioning its energy supply to 80% renewable energy by 2024. In this context, a long-term electricity supply contract was also concluded with Encavis AG for a photovoltaic (PV) system with a capacity of 149 megawatts.

As of June 2020, Amazon operates a total of 91 projects with renewable energy generation. In total, this corresponds to a generation capacity of 2,900 megawatts and power generation of 7.6 TWh per year. The total investment amounts to €158 million. The implementation is being realised without any state support.

Renewable Power Purchase Agreements (REPAs) are contracts between an electricity producer and a buyer that regulate the long-term purchase of electricity from renewable energy sources. These contracts, known from conventional power plant operation, are particularly effective instruments for providing purchase and price security for new plants and their investments. They are therefore attracting a great deal of interest from investors and operators of renewable energy plants, as well as their (industrial) customers, and represent a promising perspective for further development in the field of renewable energy. Due to the increasing willingness of companies to act in a climate-friendly manner, the demand for renewable energy is increasing.

In Germany, plant operators consider that marketing electricity under the feed-in tariff is more attractive than under a PPA. However, since the feed-in tariffs are constantly falling and older systems are no longer eligible under the EEG due to the maximum subsidy period, the marketing of electricity via PPAs in Germany could become much more important in the coming years.

Facts & Figures
- Cloud provider AWS
- 149 MW PV plant capacity under PPA contract
- Operator is the Encavis AG from Hamburg
- Total volume: 3,000 GWh over 10 years
- Planned commissioning Q3 2020
- Mediation of the PPA by Pexapark

Further information:
https://www.encavis.com/en/news/press-releases/press-release/encavis-ag-signs-power-contract-with-amazon/
Photo: Grégory ROOSE auf Pixabay

With its **Digitalisation Implementation Strategy**, the German federal government intends to shape digital transformation and prepare Germany for the future. The aim is also to allow the ecological potential of digitalisation to unfold. The strategy therefore increasingly includes initiatives relating to the sustainability of digital infrastructures (Die Bundesregierung, 2020). The German Federal Ministry for the Environment presented its **Environmental Digital Agenda** in March 2020. As part of this agenda, particular announcements were for made for the establishment of a data centre cadastre and the promotion of the energy and resource efficiency of data centres in the municipal environment. In addition, framework conditions and incentives are to be set to limit the ecological footprint of digitalisation. The Blue Angel ecological label is seen by the Ministry as a key instrument for this purpose.[7]

The industry representatives interviewed generally welcomed the German federal government's initiatives described above, but in some points they saw a need for further discussion and coordination between the federal government and the data centre industry. eco – Association of the Internet Industry has produced a position paper on the Environmental Digital Agenda (eco, 2020).

In principle, from the perspective of the industry representatives, greater transparency would be desirable with regard to the respective German federal government departments responsible and uniform coordination of the activities in the field of the sustainability of data centres. Due to the large number of departments involved in digitalisation and energy efficiency within the German federal government, there is a need for action in this area. At present, the activities of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) on the Environmental Digital Agenda and the dialogue process "Roadmap Energy Efficiency 2050" – under the auspices of the German Federal Ministry for Economic Affairs and Energy (BMWi) – are not yet perceived as coordinated.

Although the interviewees welcomed in principle the establishment of the data centre cadastre, some fears were expressed that this would involve the querying and recording of the operating data, intellectual property and business secrets of the operators, which could possibly lead to problems under competition law. As such, the concrete design of the cadastre and its creation was regarded to be of great importance. Of particular note was a rejection of the recommendation from the German Environment Agency's Green Cloud Computing project for a mandatory energy certificate for data centres (Umweltbundesamt, 2020). According to the interviewees, the development and establishment of the cadastre would have to be carried out in close cooperation with the industry. What was regarded as a particular opportunity was the improvement to be enabled by the cadastre in the coordination of waste heat sources in data centres with heat requirements in the surrounding area.

The strong focus of the Environmental Digital Agenda on the Blue Angel ecological label with regard to possible efficiency parameters of data centres was seen as questionable in the interviews. The Blue Angel can be awarded to particularly environmentally-friendly products and services. In the field of data centres, the **Blue Angel** can be awarded for "Energy-efficient data centre operation" (DE-UZ 161) and, since January 2020, also for "Climate-friendly colocation data centres" (DE-UZ 214). Although the Blue Angel has been awarded to data centres since 2012, the ecological label has not been able to establish itself in the industry. Only three data centres have been awarded the Blue Angel for energy-efficient data centre operation; so far, no colocation data centres have been awarded the Blue Angel.

> Industry representatives support the efforts to establish uniform efficiency standards for data centres, but a focus on the Blue Angel ecological label is viewed rather critically.

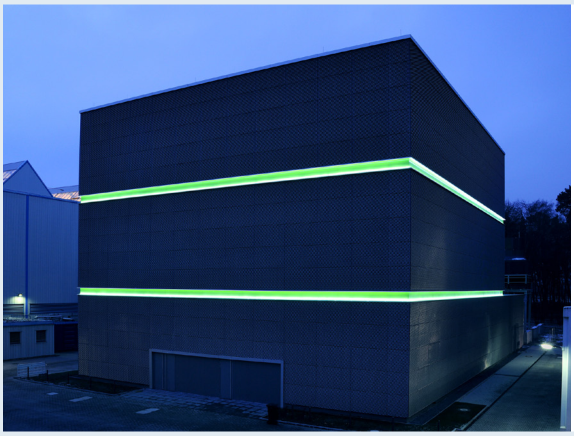
The general criticism levelled at the focus on the Blue Angel was that it is a national label which does not take sufficient account of the strongly international business environment in the field of digital

[7] This has also been called for in the recommendations for policy action of the German Federal Environment Agency's "Green Cloud Computing" project. Further recommendations in the project include a mandatory energy certificate for data centres, the binding requirement to take waste heat recovery into account, and the continued use of still-functional technology in data centres (Umweltbundesamt, 2020).

infrastructures. Fulfilment of the specific requirements of this ecological label is hardly feasible for data centres in the free economy, as is demonstrated by the number of existing label holders. In particular, the required use of halogen-free refrigerants for data centres that were commissioned from 2013 onwards has so far been virtually impossible to implement in commercial data centres. Even the very high demands on the efficiency of the cooling systems – in addition to the overall efficiency of the data centre infrastructures – would not be achievable in many data centres. As an alternative to the Blue Angel, an energy-efficiency label for data centres in Europe should be developed together with the industry. This would be possible, for example, within the framework of the German federal government's dialogue process "Roadmap Energy Efficiency 2050", under the auspices of the German Federal Ministry for Economic Affairs and Energy (BMWi). It would be conceivable that the cross-sectoral working group on digitalisation could consult on the development of such energy-efficiency labels for the various types of infrastructure. Another platform mentioned where the energy-efficiency requirements for data centres could be discussed and developed was the European cloud initiative GAIA-X, in which users and providers of digital infrastructure services are working together to make Europe a sustainable and competitive digital location.

GREEN IT CUBE

Energy and Resource-Efficient Supercomputer



Sustainability Aspects

- Very high energy efficiency of data centre infrastructure and IT systems
- Savings of 30% in the floorspace and 50% in the construction volume compared to conventional data centres
- Water-cooled racks with year-round free cooling as a system solution for an entire data centre
- Refraining from use of a UPS solution
- Annual savings of 15,000 tons of CO_2 emissions compared to conventional supercomputers

The Green IT Cube is the data centre operated by the international accelerator facility FAIR at the GSI Helmholtz Centre for Heavy Ion Research in Darmstadt.

A total of around 800 water-cooled computer cabinets on steel girders on six levels, in a structure similar to high-rise warehouse shelving, are accommodated in the Green IT Cube. This design is considerably more compact than conventional construction. The data centre is dimensioned for 12 MW and can accommodate 40,000 servers. The construction costs for the full construction amount to €16 million.

The technology of the Green IT Cube is suitable for efficiently extracting large amounts of heat. The fans in all servers move the warm air through a heat exchanger door at the back of the racks, through which cooling water flows. This can cool up to 35 kW. Due to the low air resistance of the heat exchangers, these impose no extra power demands on the servers than in standard operation. Due to the minimal temperature difference between the supply temperature of the cooling water and the air temperature in the IT room, free cooling can be carried out all year round. The recooling is achieved through the simple evaporation of water.

The Frankfurt Goethe University and the GSI Helmholtz Centre for Heavy Ion Research have been granted a European patent for the energy-saving cooling structure.

The Green IT Cube is currently (as of October 2020) one of three data centres in Germany that have been awarded the Blue Angel for energy-efficient data centre operation (DE-UZ 161).

"We have already received enquiries from various regions of the world for our data centre concept."
Prof. Volker Lindenstruth
Professor of High Performance Computer Architecture, Goethe University Frankfurt a.M.

Facts & Figures

- Type of data centre: Research data centre
- Size: up to 40,000 servers, approx. 800 computer cabinets, 12 MW cooling capacity
- Date of construction: 12/2014 to 07/2015

Further information:
https://ttsp-hwp.de/de/projects/green-it-cube/
https://www.gsi.de/start/aktuelles/detailseite/2020/02/12/erfolgreiche_patentierung_und_vermarktung_fuer_gruenen_supercomputer.htm
Photos: G. Otto, GSI Helmholtzzentrum für Schwerionenforschung

4 WASTE HEAT RECOVERY FROM DATA CENTRES

Despite approximately half of the overall energy consumption in Germany being used for heat generation (Wilke, 2020), this topic is often only recognised and discussed as a field of potential which merely bears secondary importance (Witsch, 2020). To achieve a largely climate-neutral way of life and work, however, it is imperative that the heat energy system also be remodelled in a sustainable and climate-friendly manner. The recovery and utilisation of waste heat from data centres could make an important contribution in this context. There are several reasons for this. On the one hand, electricity is converted into heat in data centres, especially in the IT components. This heat could be reused for various purposes. So far, however, this has been the exception rather than the rule. Currently, the heat generated in data centres is released into the environment in a manner that involves considerable additional energy expenditure. On the other hand, it can be assumed that the energy consumption of IT components in data centres will continue to increase in the coming years. Part 1 of this study forecasts that the energy consumption of the IT in data centres in Europe may increase by 40% to over 70 TWh/year between 2020 and 2030. This energy consumption will take place to a very large extent in large data centres, so that large amounts of waste heat will be available (Hintemann & Hinterholzer, 2020). In particular, waste heat recovery in urban areas opens up a wide range of possibilities (see best practice examples). The German City of Frankfurt, for example, has set itself the goal of becoming 100% climate neutral by 2050. This means that, in 2050, a quantity of heat ranging between 5.2 TWh/year and 8.8 TWh/year must be produced and provided in a climate-neutral manner (Schumacher et al., 2016). Due to the already very high density of data centres in the Frankfurt area and its ever-increasing expansion as a data centre location (CBRE, 2020; Liggitt, 2020), it can be assumed that by 2050 a large proportion of this heat could be provided by data centres. Currently, more than 10% of the heat requirements of the City of Frankfurt could theoretically be provided by data centres (Clausen et al., 2020).

How much of this waste heat can be used in practice depends on the technologies used and the existing possibilities for the purchase of waste heat (Funke et al., 2019). As examples from Sweden show, systematic waste heat recovery from data centres is already technically very feasible today (see best practice example "Stockholm Data Parks").

In Germany, too, waste heat from some data centres is already being utilised – however, in general, only a very small proportion of the technically available heat is being availed of. In surveys conducted by the Borderstep Institute, approximately one third of the data centre operators questioned stated that they utilise at least a portion of the waste heat for adjacent office space or for the hot water supply. Currently, around another third of respondents are planning to implement waste heat recovery in the next major modernisation or new construction project. According to the data centre operators, there are two main reasons why a greater amount waste heat is not being utilised: the lack of economic feasibility and the absence of a user of the waste heat in the vicinity of the data centre (Hintemann, 2017).

The **lack of economic feasibility** of waste heat recovery in Germany is due to the considerable investment costs – as well as the power costs – for the often necessary operation of a heat pump to raise the temperature level. The feeding-in of waste heat from a data centre to a heating network is generally not economically feasible in Germany due to the high electricity prices (Clausen et al., 2020). As example calculations show, an increase in waste heat temperature from 25°C to 70°C at an electricity price of approx. 16 cents/kWh would mean electricity costs of 5 cents/kWh of heat. In many cases, refinancing an investment in the technology required would clearly be too expensive. In contrast, a data centre in Sweden can calculate with an electricity price of less than 4 cents/kWh (Hintemann & Clausen, 2018a, p. 40), so that the electricity costs only amount to approx. 1.3 cents/kWh of heat. In Germany, an abolition of the renewable energy (EEG) levy on the use of electricity for heat pumps in data centres and a realisable electricity price of around 10 cents/kWh could significantly increase the economic feasibility of waste heat recovery. The temperature level of the waste heat can then be raised to 70°C with acceptable electricity costs of approximately 3 cents/kWh of heat (Clausen et al., 2020). This temperature level is sufficient to feed the heat into low-temperature heating networks. In Stockholm, for example, the waste heat from the data centres is raised to a temperature level of 68°C using heat pumps, before it is fed into the heating network (Open District Heating & Stockholm Exergi, 2020).

"The example of Sweden shows very well that waste heat recovery from data centres is possible on a large scale. In Germany, the necessary framework conditions for this are lacking. Those who produce heat and those who consume heat should be able to work together without bureaucratic hurdles and unnecessary requirements."
Staffan Reveman
Managing Director/Owner of Reveman Energy Academy

If the servers in the data centres are cooled directly with hot water, no heat pump is required for many uses of the waste heat. This increases the economic feasibility considerably. With this technology, it is already possible to use 70% of the waste heat generated (see best practice example "Hot Water Cooling in the Eurotheum, Frankfurt"). With the temperature level achievable with hot water cooling, it is possible to feed heat into low-temperature heating networks without needing a heat pump. Waste heat at this level is also potentially suitable for generating cooling capacity with the help of an adsorption chiller. Such a solution is being pursued at the Leibniz Data Centre in Munich (Häuslein, 2019) and is also being tested in the HotFlAd project at the TU Berlin, as well as by Noris Networks (Hintemann, 2019a). However, water-cooled server systems have so far been used more in niche applications – especially in the field of high-performance computing. Due to the increasing share of high-performance applications (Hintemann, 2019b; Market Research Future, 2018), it can be assumed that the proportion of water-cooled systems will continue to increase. This trend could intensify with increasing numbers of applications in the field of artificial intelligence, since the hardware used for this purpose is often directly cooled with hot water (Bayer, 2017; Ostler, 2018b). Increasingly, there are now also water-cooled systems in the area of standard servers (Müller & Schmitz, 2018; Ostler, 2019b, 2020b). If the use of directly water-cooled servers can be successfully transferred from niche applications to a broad range of applications in the coming years, waste heat recovery from data centres will become much more attractive economically.

In principle, economically feasible waste heat recovery is conceivable almost exclusively in newly-built data centres or where considerable modernisation is being carried out for other reasons. For legacy data centres, the necessary retrofitting is as a rule so expensive that refinancing the investment through the provision of heat is not possible.

The actual **existence of a user for waste heat** represents another significant challenge for waste heat recovery. If there is no local heat demand, and such a demand cannot be generated, external use of the waste heat is also not particularly expedient. The waste heat can be utilised for a range of purposes. Of particular interest is its utilisation for space heating or hot water preparation via local and district heating networks (Hintemann, 2019c). Since in most cases an increase in the temperature of the waste heat by means of a heat pump is necessary for this purpose, the economic challenges already mentioned above often exist here. For the connection to existing heating networks, there is the additional challenge that the existing heating networks in Germany to date generally operate at a very high temperature level of around 100 to 120°C. Only with modern heating networks of the 4th generation does the temperature level drop below 70°C, which would make the feeding-in of waste heat from data centres more attractive. A connection to existing heating networks is often prevented by the fact that the heating network infrastructure does not run in the direct vicinity of existing data centres.

In view of the challenges described above, it is hardly surprising that hardly any projects exist in Germany to date in which data centres feed their waste heat into heating networks. Despite this, there are some examples to be highlighted, such as the Technical University of Darmstadt's project "Rechenzentren als Baustein der Energiewende auf Quartiersebene" ("Data centres as a building block of the energy transition at neighbourhood level") relies on waste heat from water-cooled processors. The project aims at coupling a high-performance computer with return temperatures of 60°C with the district heating network of the university. A heat pump is to be used to raise the temperature level by 10°C to 70°C. The small temperature difference enables a coefficient well above 10. In parallel, the heat pump cools the return flow of water from 60°C to 50°C for server cooling (Weis, 2017). The waste heat of the new data centre at the University of Greifswald is also utilised on the campus (Oberdörfer, 2017). The Volkswagen Financial Services data centre in Braunschweig contributes to the heat supply of a new area of building development with around 400 residential units and an adjacent commercial area in the south of Braunschweig (Müller & Ostler, 2019). The heat network created here is designed for a supply temperature of 70°C. The heat pump raises the return temperature of the data centre from 25°C to the supply temperature of the heating network of 70°C (Müller & Ostler, 2019). A further project in which the waste heat of a data centre is to be made available for residential units is planned by Telehouse/KDDI in Kleyerstrasse in Frankfurt. Promising negotiations are already underway here. According to a representative of the City of Frankfurt, the main challenge still lies in the economic feasibility of the planned concept (Lutz & Ostler, 2020a).

It is clear from the above that a significantly increased feed-in of waste heat from data centres into heating networks only appears possible under changed framework conditions. From a technical perspective, it makes sense to achieve the highest possible temperature level for waste heat from data centres. In air-cooled data centres, this can be done by further raising the room temperature in the data centre. The use in data centres of servers cooled using hot water offers significantly higher potential. At the level of local and district heating networks, a further reduction in operating temperature would be very beneficial. These technical measures would make the economically-feasible provision of waste heat from data centres much more realistic. A reduction in the price of electricity for the operation of heat pumps would significantly increase the economic feasibility of waste heat recovery in Germany. If, at the same time, the use of fossil-fuel energy sources becomes more expensive, there will be an additional incentive for waste heat recovery. The introduction of the CO_2 tax in Germany could accelerate these two developments. On the one hand, the CO_2 tax makes the use of gas or oil for heat generation more expensive and, on the other hand, the financing of the expansion of renewable energies in Germany in future is planned on a pro rata basis from the CO_2 tax. With the increase of the CO_2 tax to €55 per ton by 2025, the EEG levy could decrease significantly in the long run (Huesmann, 2019).

In addition to the necessary changes in the technical and economic framework conditions, it is essential that future urban and regional planning develops integrated concepts in which the locations of data centres are combined or synchronised with the expansion of heating networks and the spatial presence of heat users. To this end, it is necessary to bring together the various players, in particular those responsible for urban and regional planning, the operators of data centres, energy network operators, and potential users of waste heat. The best practice example of the Data Parks from Sweden shows one possible approach. In Germany, too, there are already approaches involving similar cluster concepts for data centres (Lutz & Ostler, 2020c).

> In order to promote waste heat recovery from data centres in Germany in the short and medium term, targeted government support is needed.

Even though the current framework conditions, especially in Germany, mean that projects for waste heat recovery from data centres can rarely be implemented on a large scale, it can be assumed that this field of application will become significantly more important in the long term. On the one hand, the need for the climate-friendly re-design of the heat supply system already described above will lead to a significant increase in demand for these solutions. Particularly in conurbations, the further expansion of data centre infrastructure can be expected to result in corresponding requirements from the local authorities (Lutz & Ostler, 2020b; Ostler, 2019a). With increased temperature levels of waste heat, the expansion of low-temperature heat networks, and possibly falling electricity prices, the solutions are becoming more economically attractive, while fossil-fuel heat generation is likely to become less and less attractive. However, from today's perspective, these developments will not have a significant impact for at least five to ten years. Therefore, without adjusting the framework conditions for waste heat recovery, it cannot be assumed that the large new data centres that will be built in Germany in the next few years will be able to cover their costs in the provision of waste heat on a larger scale. To accelerate this development, government action would be necessary in addition to initiatives from the data centre industry. This is also shown by the expert survey, in which 85% of those questioned stated that government action would be necessary when it came to the topic of waste heat recovery from data centres. Initial declarations of intent to improve the framework conditions for waste heat recovery from data centres have already been made within the framework of the EU strategy for the integration of the energy system (European Commission, 2020) and in the Environmental Digital Agenda.

Four general government options for action are currently available to improve the framework conditions for waste heat recovery from data centres: technology promotion, the implementation of integrated urban and regional planning concepts, the reduction or abolition of the EEG levy in Germany, and promotion through public procurement. These options are briefly described below.

STOCKHOLM DATA PARKS

Promoting collaborative waste heat recovery


Photo: Staffan Reveman

Sustainability Aspects
- Use of waste heat from data centres in the Data Parks to supply the Stockholm heating network
- Expansion of renewable energy capacities offered by the energy supplier Stockholm Exergi to the extent necessary to meet the energy consumption of the Data Parks
- Possibility of closure of the last remaining coal-fired heat production in Sweden, inter alia by introducing open district heating in the Data Parks

The supply of local and district heating based on coal, natural gas or heating oil is not very sustainable and is to be replaced increasingly in the future by climate-friendly alternatives. Besides solar thermal or geothermal heat, the use of waste heat is an important option. In Stockholm, waste heat from data centres is already being systematically recovered. So far, more than 30 data centres have already been connected to the district heating network (Ostler, 2017). By 2035, it is planned that data centres will cover one-tenth of Stockholm's heating needs (GTAI, 2018).

The expansion of waste heat recovery from data centres in Stockholm is supported by the Data Parks concept. Urban planning identifies construction areas for data centres where it is possible to feed waste heat into the heating network. The spaces are marketed through Stockholm Data Parks. Stockholm Data Parks offers data centres an integrated supply of sustainable redundant power, dark fibre Internet and the purchase of waste heat. In the case of larger data centres (> 10 MW), this takes place within the framework of the delivery of free cooling (Cooling as a Service). Smaller data centres receive a remuneration of 2.5 Ct/kWh of heat for supplying heat at a temperature level of 68°C.

Stockholm Data Parks is an initiative of the energy supplier Stockholm Exergi, the City of Stockholm, the Stockholm Economic Development Agency, the electricity grid operator Ellevio, and the telecommunications network operator Stokab.

The first Data Park was built in the north of Stockholm, in the ICT cluster Kista. In this Data Park, four data centres are currently connected to the heating network. With Brista and Skarpnäck, two further locations are currently being marketed. In so doing, Stockholm Data Parks is publicising the fact that a building permit for a data centre in Data Park Kista is usually granted within 10 weeks.

"With additional data centres, we will be able to recover about 40 MW of heat, enough to heat around 80,000 modern apartments."
Erik Rylander
CEO Stockholm Data Parks
and Open District Heating

Daten & Fakten
- Types of data centres: Colocation and other IT service providers
- Target total electrical power: 40 MW
- Target heated apartments: 80,000
- Foundation: 2016
- Temperature of DC waste heat approx. 35°C, fed into the heating network at 68°C

Further information: https://stockholmdataparks.com

In the context of **technology promotion**, the development towards higher waste heat temperatures from data centres could be accelerated. This can be achieved by promoting research on the relevant technologies, such as hot water cooling in particular, or by promoting the use of such technologies through investment programmes or flagship projects.

In particular at regional and municipal level, state actors could promote the **implementation of integrated urban and spatial planning concepts** involving data centre operators, and the expansion of low-temperature heating networks. It should be noted, however, that the selling of heat is outside the business model of the data centres and that relevant expertise has hardly been available to date. The example of Stockholm's Data Parks, supported by the City of Stockholm, is a good example of such an approach. Many municipalities also have corresponding holdings in the local energy suppliers, which would enable them to influence the energy suppliers' business models and could also promote the use of waste heat recovery. An obligation to give priority to the use of existing waste heat sources over fossil-fuel energy sources would also be conceivable.

By **reducing or abolishing the EEG levy** for electricity used to power heat pumps, the economic attractiveness of waste heat recovery from data centres could be significantly increased. Until now, waste heat recovery has been made considerably more expensive by the EEG levy, whereas corresponding charges are not levied on fossil fuels (Bundesverband Wärmepumpe e.V., 2020).

Last but not least, as already explained above, state institutions have a strong influence on the market through their own **procurement**. Especially in public research institutions, a further increased use of hot water cooling, in connection with the use of the hot water for heat supply or for cold generation with adsorption chillers, would be quite feasible. Data centres which are operated directly or indirectly by the public sector via corresponding holdings could in future also increasingly be equipped with hot water cooling, or at least be operated at an increased room temperature, in order to make waste heat recovery economical. It would also be conceivable, in calls for tenders, to give preferential treatment to IT service providers that utilise waste heat.

5 SUMMARY AND CONCLUSION

As has been demonstrated in the two parts of the present study on the sustainability potential of data centres, further digitalisation and economic and social development geared to sustainability can only be achieved with high-performance and reliable data centres. However, these digital infrastructures should themselves be operated in as climate-friendly and sustainable a manner as possible. Although high efficiency gains have been achieved in data centre operations over the past decade, the energy consumption of data centres in Europe have increased by the significant amount of 55%. Fortunately, CO_2 emissions from data centre operations in Europe have nevertheless been reduced slightly due to the increasing use of renewable energies in the generation of electricity. In the event of a continuation of the current trend, a further moderate increase in energy consumption can be expected in the future. However, due to the great dynamism of the Internet industry and the high pace of innovation, significantly different developments may also result. In this respect, the fact that the data centre industry has enjoyed a significant increase in public and political attention in recent years is to be welcomed. More and more initiatives at national and European level are focusing on the sustainability of data centres. This development in public and political discourse is appreciated by the industry. Industry representatives see this as an opportunity to work together with politicians and scientists to uncover the potential for more sustainability through and in data centres, and to create the framework conditions for realising this. In addition, increasing attention is making it possible to raise public awareness of the importance of data centres for digitalisation and sustainability.

The present study has shown that a variety of new technologies are available to make data centres more sustainable. Some 70 such technologies have been identified. Many of these solutions undergo rapid impementation within the industry, as they often offer economic advantages in addition to greater sustainability. However, it has also been possible to identify some technologies where barriers exist to their use. Government support could be helpful here. In detail, the study identified possible courses of action in the following areas.

In order to further increase the energy efficiency of digital infrastructures and in particular of data centres, an **expanded support for research into energy and resource-saving information and communication technology** and the supporting systems of data centre infrastructures is recommended. Otherwise, especially in view of the expected end of Moore's Law, it may not be possible to achieve the efficiency gains necessary for the sustainable operation of the still-to-be-further-expanded digital infrastructures.

Targeted support for research could be provided above all in the areas of the use of renewable energies in data centres, the adaptation of data centre loads to the existing electricity supply, and sector coupling, especially with heating networks. There also remains a need for research and development with regard to the use of fuel cells in data centres.

A possible **regulation of data centres** with regard to ecological criteria should be carried out in moderation and with the participation of the industry, particularly in view of the high importance of data centres as a basis for digitalisation geared to sustainability. Otherwise, in the international market for data centre services, carbon leakage – i.e. the migration of processing power and economic activity to regions where lower demands are placed on the sustainable operation of data centres – could occur. The development and use of voluntary labels should also be coordinated with the entire industry.

Public procurement can have a steering effect for sustainability concepts in data centres. Appropriate criteria geared to climate protection and sustainability in public tenders can therefore provide important impetus in the industry. Due to the great importance of the public sector as a customer – as well as an operator – of data centre services and as a role model for other customers, providers of sustainable solutions can in this way be promoted.

Within Europe, the creation of **fair competitive conditions in the energy market** would be welcomed. Data centres in particular are confronted with significant variation in electricity prices within Europe.

In the interviews conducted with industry representatives, the fear was expressed that the unequal competitive conditions could be aggravated in the course of efforts to operate digital infrastructures in a climate-neutral manner within the framework of the Green Deal. The desire was expressed to develop, together with politicians, a strategic plan for a smart infrastructure mix in Germany and Europe.

Waste heat recovery from data centres should be promoted more strongly as one element of a sustainable, climate-neutral supply of energy and heat. This can be achieved in particular through economic incentives and through joint initiatives involving local authorities, energy suppliers, network operators, data centres, and users of waste heat.

6 GLOSSARY

2D materials
A further reduction in the size of computer chips can be achieved using so-called 2D materials. These are crystalline materials consisting of a single atomic layer. The efficiency gains likely to result could extend the validity of Moore's Law for some time.

Adiabatic cooling
Adiabatic cooling uses the cold generated by the evaporation of water for cooling. Either moisture is added directly to the incoming outside air, thereby cooling it, or the exhaust air is humidified indirectly. This cooled exhaust air then cools the incoming outside air (Klingenburg GmbH, n.d.). Energy is only required for humidifying the air (water atomisation).

All-Flash
As an alternative to classic hard disks, flash memory drives, i.e. non-volatile memory drives, are increasingly being used in data centres. Flash drives offer significant advantages in speed and capacity with lower latency, lower failure rates, and lower energy consumption compared to most conventional storage technologies.

Automated indication of the energy consumption of appliances
The automated recording of the energy consumption of the devices involved in the overall ICT system during operation enables a more precise calculation, display and monitoring of their energy consumption and the comparison of different systems and architectures.

Carbon nanotube processors
In order to temporarily overcome Moore's Law, much hope is being placed on carbon instead of silicon as the basis for processors. Carbon nanotubes in processors can be used in a higher number of transistors per area on the chip than silicon technology allows and also reduce the energy consumption. Current processors in research do not yet achieve the same performance as silicon chips (Amarnath et al., 2019).

Chiller-free data centre
A chiller-free data centre does not use any additional cold generation (e.g. (compression-)chillers). It is exclusively supplied with cold from the immediate surroundings. This includes ambient air, ground and surface water, geothermal energy and adiabatic evaporative cooling. This requires extensive data on the cooling requirements of the data centre and the ambient conditions. In order to also achieve a uniform air flow, precise air routing within the racks is absolutely essential.

CHP
In a combined heat and power plant (CHP), in addition to the generation of electrical energy, heat is generated and made usable. This increases the degree of utilisation (up to 90%) of the primary energy source. In addition, the heat produced can be used to cool data centres by means of absorption or adsorption cooling processes. In addition, CHPs can serve as emergency power systems in data centres and thus also safeguard the supply of power.

Cloud Native programming
The high degree of virtualisation of infrastructures in the field of cloud computing allows a highly customised use of physical resources. However, the software must be designed accordingly. This includes, for example, a software architecture that consists of loosely-coupled individual components (microservices), each of which can be operated, extended and scaled independently of the others.

Cold/hot aisle containment
Cold/hot aisle containment is used to ensure that the cold supply air and the warm exhaust air in the data centre are routed separately. This construction design is achieved by placing the server cabinets so that the sides where the cooling air is supplied face each other. On the other side of the server, the warm air is removed. This results in an alternating hot aisle and cold aisle, which prevents air mixing and any associated reduction in efficiency.

Cold reservoir (e.g. liquid ice)
A cold reservoir, such as liquid ice, makes it possible to shift the timing of cold generation and use, in order to use it in times of, for example, high electricity costs and to secure cost advantages. It also makes it possible to absorb peak loads and provide cooling in an emergency. Liquid ice is produced using the vacuum freezing process, in which water is evaporated in a vacuum at a temperature of -0.5°C. It is pumpable and has a very high energy density.

Combined cooling, heat and power (CCHP)
Combined cooling, heat and power extends the concept of combined heat and power (CHP) by using the produced heat for cooling by means of sorption technology.

Containers
With the virtualisation of containers, operating systems or applications, the hardware can be better utilised. Compared to server virtualisation, this virtualisation takes place at a higher level of abstraction, resulting in reduced memory requirements and more flexible deployment and scaling.

Converged Infrastructure
As an integrated whole, the data centre (or parts of it), together with the areas of hardware, software and operations, is called Converged Infrastructure, in which the focus is placed on tasks and requirements. Already today, hardware providers offer complete solutions, where components like the server, storage, network and the orchestration of the processes are optimally adjusted to each other.

Cooling with geothermal energy
For small data centres and for office buildings with an attached data centre, a bore hole to near-surface geothermal energy can be used to discharge heat into the ground. If there is a heating requirement in winter in addition to the waste heat from the data centre, this geothermal bore hole can also be used to generate heat.

DC-DC UPS in rack
A DC-DC UPS (uninterruptible power supply) is a DC power supply for the servers, which is directly connected to the UPS without intermediate conversion to AC voltage. This is either an alternative to a central UPS, or it can provide additional security.

DCIM
Data Centre Infrastructure Management (DCIM) gives administrators a comprehensive overview of the data centre and its performance. The overall system can thus be operated optimally and enable the linking of IT and building functions of a company. The goal of DCIM is to optimise data centre processes and reduce energy consumption.

DC power supply in the data centre
A DC power supply in the data centre is the central conversion of the supply voltage into DC voltage at the mains connection. Within the data centre, the power is distributed with direct current and all components are supplied with direct current. The required voltage of a component is adjusted by electronic means (DC-DC converter).

Decentralised UPS in rack
A small UPS (usually a 19-inch rack-mount unit) in each rack provides better scalability and more optimal utilisation compared to a centralised UPS. The small efficiency potentials that are thus tapped can alternatively be achieved with a central but adaptable modular UPS.

Direct free cooling
The data centre is cooled directly with outside air. The quality of the incoming air is ensured by filters and control techniques. In case of high ambient temperatures or humidity, further cooling or dehumidification of the air may be necessary.

Direct voltage conversion (48V POL) in the data centre
In order to reduce transmission and conversion losses, servers are supplied with a constant 48 Volt direct current. This does not require a central power supply unit within the server and only at the point of load (POL) does conversion to the specifically required voltages (e.g. 0.9 V or 1.2 V) occur. The UPS can be installed decentralised in the rack.

Dynamic air temperatures
Dynamic air temperatures make it possible to adapt the inlet temperature to the current heat load. This makes it possible to allow higher temperatures of the incoming air for lower levels of heat production of the data centre, and to react dynamically to load changes. A lower temperature difference between cooling air and ambient temperature leads to greater efficiency (Energy Efficiency Ratio) of the chillers.

Dynamic circulating air volumes
The heat production of the operating resources of a data centre fluctuates with the workload, and so too do the cooling requirements. Dynamic control of the supply air volume allows for a timely reaction to these fluctuations.

Dynamic cooling water temperatures
Dynamic cooling water temperatures make it possible to adapt the input temperature to the current heat load. This in turn makes it possible to allow higher cooling water temperatures or to react dynamically to load changes with lower heat production in the data centre. A smaller temperature difference between cooling water and ambient temperature leads to greater efficiency (Energy Efficiency Ratio) of the chillers.

Energy-efficient architectures (Edge, Fog, Cloud)
With the expansion of edge computing or edge DCs, IT infrastructures are becoming increasingly decentralised. In contrast to central cloud computing, decentralised data processing takes place at the edge of the network. Fog computing, often used synonymously to edge computing, combines data processing at the edge and in the cloud: Pre-processing in the edge DCs, and transferal to the cloud (Luber & Karlstetter, 2018). Fog computing is used especially to minimise latencies and processing time. With this architecture and appropriate management, the decision on which processes are carried out at which point can be aligned with the necessary energy consumption of data processing, transmission and storage.

Energy Efficient Ethernet
Energy Efficient Ethernet (industry standard IEEE 802.3az) plays an important role in the development of load-adaptive ICT infrastructure. Following the publication of the standard at the end of 2010, it forms the basis for the development of new Ethernet network components. The advantage of EEE is that, as long as there is no active data transport in the network device, the electrical power consumption is greatly reduced.

Energy-efficient programming
The programming-related realisation of application software has a significant influence on the volume of

ICT resources (e.g. computing power, memory, network bandwidth), and as a result also on the energy, that the given software demands. Energy-efficient programming thus reduces the energy required to operate the software.

Fast bypass switching

New findings in power electronics make it possible to guarantee the uninterruptible power supply (UPS) of data centres directly via a bypass without delay and without conversions with the aid of a switching device. This replaces the double-conversion mode (the entire current is inverted, stabilised in the accumulator, and converted back into alternating current) normally used in data centres, which is highly inefficient, especially in partial load operation.

Fuel cells

A fuel cell converts chemical energy into electrical energy and can thus make various energy sources, such as hydrogen or natural gas, usable as a power supply also for data centres. The fuel cell, together with simultaneous use of electricity and heat, is an ideal solution for data centres, and it can also be used in the area of uninterruptible power supply. The oxygen-reduced air produced by the fuel cells can also be used as fire protection in data centres (Exler & Ostler, 2016).

GPU computing

To increase the speed of scientific and some technical applications, GPU (Graphics Processing Unit) computing uses GPUs in addition to classic CPUs. Due to their design, GPUs often offer advantages in performance and also in efficiency, especially with parallelisable workloads. For example, GPU computing is used for artificial intelligence, pattern recognition and crypto-mining, i.e. for applications with very high computing loads (de Vries, 2018; Ostler, 2019c).

Groundwater cooling

A groundwater cooling system uses the predominantly constant temperature of the groundwater throughout the year as a cold source for the cooling system. The ground water in the primary cooling circuit, which is extracted and filtered with a suction well, cools the secondary cooling water circuit via heat exchangers and thus extracts the heat. The groundwater is then returned via an absorption well (Nowitzky, 2012).

Hardware acceleration

Flexibly designed standard processors make versatile application possible. By means of specifically designed hardware logic blocks, it is possible to process special calculation processes with, to a certain extent, a much smaller number of steps (= faster/more efficient). Graphic calculations and coding/decoding processes are classic examples of applications. This externalisation is called hardware acceleration.

Indirect free cooling

An air-water heat exchanger is used to lower the temperature of a liquid coolant, using outside air. The coolant is then used to cool down the interior air. The advantage is that, in contrast to direct free cooling, material contamination of the outside air can be disregarded. However, depending on the coolant and temperature requirements in the data centre, free cooling is only possible within certain temperature limits.

Installation of different thermal zones in the DC

Different types of IT equipment sometimes have different temperature requirements. Central cooling systems in a data centre are usually set to the most thermally sensitive appliance. A data centre with different thermal zones, in which the IT equipment is categorised according to its temperature requirements, optimises cooling and can meet more specific requirements.

Intelligent PDUs

Intelligent Power Distribution Units (PDUs) can be installed in the racks to accurately monitor the power consumption of individual components or systems. In addition, intelligent PDUs collect environmental data, such as the temperature and load of the power supply.

KPI-based energy efficiency management

Since the numerous factors influencing energy consumption make holistic energy management very elaborate and complex, key performance indicators are used as uniform evaluation parameters. With the help of the KPIs, energy efficiency can be assessed in a technology-neutral way within certain system limits.

Li-Ion battery (UPS)

A UPS with lithium-ion batteries works – similar in nature to a UPS with lead-acid batteries – via a chemical energy storage. However, lithium-ion batteries have the advantage of virtually loss-free storage, higher load capacity, higher mass-related energy density, and significantly higher cycle stability.

Load-adaptive data centre

A load-adaptive data centre can adapt its computing load and thus also the electrical power consumption to external conditions. Data centres supplied by renewable energies, in particular, can react to the fluctuation of the power production by increasing or decreasing the computing load. Using virtualisation and orchestration, tasks or workloads can be moved either spatially (to a geographically alternative data centre) or temporally (postponable tasks).

Load shifting on servers

In order to optimise the average workload, the load on the servers can be optimally distributed by means of virtualisation and container technology. Considerable savings potentials arise if servers can be put into standby mode or turned off. In an average data centre, this can make energy savings of approx. 25%, as calculated in the AC4DC project (Hintemann, 2014).

Low Voltage CPUs

Low Voltage CPUs or Ultra Low Voltage CPUs were developed primarily for notebooks. They work with less equipment, lower voltage and a lower clock rate, thus achieving lower energy consumption. These processors are suitable for passively cooled systems (ITwissen.info, 2019). As long as the processor power is low, this processor type can also be used for very energy-efficient servers (Roderer, 2007).

Microservers

Servers with a very small construction relative to classic server designs (rack servers or tower servers) are called microservers. Microservers are installed in very small chassis or built together with many others on a small motherboard within a single chassis, and are considered as very energy efficient (Steinhaus, 2013).

Modular UPS

An uninterruptible power supply (UPS) is often significantly over-dimensioned, in order to be sufficiently equipped for a subsequent expansion of the IT infrastructure. However, partial load operation is usually very inefficient, so that a modular UPS is a solution for optimal utilisation. The modular UPS can be dimensioned for the current load and can be expanded as additional ICT components are added.

Natural refrigerants

Natural refrigerants, such as propane (R290), ammonia (R717) or water (R718), are replacing partly fluorinated hydrocarbons (HFC) in cooling systems, which have a very high global warming potential that can be 2,000 to 3,000 times higher than CO_2.

Neural/self-organising algorithms

The data collected by a large number of sensors in modern data centres is also highly relevant for energy consumption, but the generally raw data is usually difficult to interpret. Neural and self-organising algorithms, analytics tools, and AI can support data preparation and evaluation and enable energy saving potentials. Using artificial intelligence (AI), Google was able to reduce the energy required to cool a data centre by 40% (Evans & Gao, 2016).

Neuromorphic processors

In order to replicate brain function, neuromorphic processors are being developed which are used especially in pattern recognition and analysis. Because these processors are fault-tolerant, their manufacturing is easier and, as a result, make it possible to produce larger processors with lower rejection rates. They are very energy efficient because the individual neurons work in an event-driven manner and therefore only need energy periodically (Bitkom, 2018). For example, neuromorphic processors draw only a fraction of the energy of classical processors. IBM manufactured a neuromorphic chip with a real-time operating power consumption of 70mW (IBM, 2017). In practice, neuromorphic and classical chips can be used together so that the processors can each work on the process that it can carry out most efficiently.

Non-volatile RAM (NVDIMM)

Non-volatile memory (Persistent Memory, also known as NVDIMM modules), to be classified between SSDs and classic memory, retains the memory content even when the system is shut down. They are compatible with normal DDR4 memory and can be placed in the available slots. Furthermore, the connection to the processor significantly reduces latency and increases the processing speed of data-intensive workloads (Bitkom, 2018).

Operating reserve from data centres

With the offer of operating reserves, data centres can make their emergency power generator or the battery storage of the UPS available to the power grid. With the help of a control box, these components are integrated into a virtual power plant and are thus able to provide operating reserve. The provision alone is remunerated at a service price (€/MW). Depending on the actual demand, an additional work price is paid (€/MWh). In case of a power failure, the supply of the data centre still has priority.

Orchestration tools

Virtualised ICT resources are often provided in a physically heterogeneous and geographically separated manner and at the same time have high requirements for dynamic adaptation (demand, latency and resilience). The management of these resources can only be made possible through a high degree of automation. Especially for these virtual cloud architectures, there are a variety of orchestration tools that enable the task of automated management to be performed with as much agility and efficiency as possible.

PCM refrigeration systems

Phase Change Material (PCM) makes use of the release or storage of heat occurring during a phase change (change of aggregate state, usually solid/liquid) of a medium. The medium, often salt hydrates or paraffins, absorbs heat during liquefaction and releases heat during solidification (TU Berlin IZE, 2008). In PCM it is possible to store energy in a narrow and limited temperature interval and to achieve high energy densities.

Photovoltaics

A photovoltaic (PV) system can be used to generate electrical energy directly at the data centre and to cover parts of the electrical energy consumption.

Power Usage Effectiveness (PUE)

The Power Usage Effectiveness (PUE) reflects the relationship between the total annual energy consumption of a data centre and the annual energy consumption of the IT components housed within the given data centre. The PUE value is therefore a measure of the efficiency of the infrastructure (cooling, UPS, transformers, fire protection, etc.). However, due to the complex interplay of technologies within the data centre and the dependency of the PUE on a range of technological concepts, as well as on the climatic conditions, its explanatory power and validity is limited and the PUE is not suitable to function as the one and only efficiency KPI for data centres (Schödwell et al., 2018).

Quantum computers

A quantum computer works according to the laws of quantum mechanics and thus on the basis of quantum mechanical states and principles. Quantum computers, for example, enable efficient searches in extremely large databases. Research is currently being conducted into the first prototypes.

SDx – Software Defined Everything

The wide-ranging term Software Defined Everything (SDx, also known as Software Defined Anything) covers a broad field of technology. Initially in the networking area (Software Defined Networking – SDN), SDx now covers all aspects of the data centre, from Software Defined Storage (SDS) to the automation and management of the entire infrastructure. SDx allows the administrator to manage resources and equipment in a software-based manner with a single, centralised solution, without the need for physical access.

Sector coupling

Sector coupling describes the holistic consideration and optimisation of the energy sectors electricity, heat, transport and industry. The primary consideration is the exchange of energy through the conversion of energy sources between the sectors. Sector coupling makes it possible above all to use renewable energy in non-electrifiable applications (e.g. with Power-to-X). Sector coupling plays a role in ICT infrastructure, especially in waste heat recovery, in the provision of operating reserves, load-adaptive data centres, and integration of renewable energy sources.

Silicon Photonics

Silicon Photonics enable data transfer by light between computer chips by combining optical fibres and silicon technology. This results in a greater bandwidth and higher transmission speeds. The outcome is a significant increase in the processing speed and performance of computers and an improvement in energy efficiency (Asghari & Krishnamoorthy, 2011; Barwicz et al., 2007; Mrejen et al., 2017). Although pilot projects aim to double the energy efficiency (Bergman et al., 2018), it is not yet possible to make a real assessment. The Adlershof/Berlin Science Park is a world leader in research into this technology.

Software-defined power supply

The integration of many IT components of the power supply into the software-operated management of the data centre optimises the power supply. This allows for a better response to the real operating loads and, for example, the voltage can be adapted to the ageing of the respective component (DataCenter Insider, 2017; electronicspecifier.com, 2017).

Solar cooling

The energy generated by solar energy systems can be used for cooling in three ways: PV electric-powered compression chillers, thermomechanical systems, and solar thermal systems. The solar thermal systems can be open (sorption-supported cooling) or closed (absorption or adsorption technology). Sorption-supported cooling systems directly reduce the temperature and dehumidify the air. Absorption or adsorption cooling processes produce cold water for cooling (Morgenstern et al., 2016).

Stand-by/Ready architectures

In order to reduce the power consumption of unused server capacity in times of low utilisation, automated management can be used to set part of the hardware in a particularly energy-saving standby state. This state is known as standby/ready. Until now, ICT equipment when idling has still required up to 50% of the nominal power. Emergency reserves, redundancies and the ongoing expansion of data centres and data networks make standby/ready architectures significant for the efficient operation of complex ICT systems.

System on a Chip

If a large proportion – or all – of the functions of a programmable electronic system are integrated on a chip, it is called System on a Chip (SoC). Mobile systems can be kept as small and energy efficient as possible through SoC. The compact design and high energy efficiency potentials of System on a Chip can also be utilised in data centres, as demonstrated by IBM Power processors and HPE's TheMachine technology.

System-wide holistic efficiency optimisation

Optimising the energy efficiency of ICT systems has so far only been viewed from the perspective of individual elements and not from a comprehensive, holistic perspective. However, this can lead to further great efficiency potentials. For this purpose, the Enterprise Resource Planning (ERP) approach is used, in which the resources within a company are analysed and controlled in relation to business processes, usually in real time. The use of ERP in ICT infrastructure can ensure a high utilisation of ICT. The business process orientation enables the optimisation of the actual dedicated performance of the system and achieves significantly better results than current DCIM solutions.

Transformerless UPS

With the help of IGBTs (Insulated Gate Bipolar Transistors) from power electronics, transformers and thus conversion losses in the UPS are no longer necessary, as voltage conversion and inversion are possible without induction-based transformers. Efficiencies of up to 99% can be achieved with IGBTs.

Urban/spatial planning for waste heat recovery

Due to the costly transport of heat over long distances, it makes sense to consider the utilisation of the waste heat of ICT infrastructure in the energy supply for urban planning. This enables an efficient and long-term use of the waste heat from data centres. If a data centre is located nearby, development plans can, for example, include a mandatory heating supply via low-temperature district heating from the very outset.

Video compression (AV1 ff.)

The dimension of the data volume has a direct impact on future energy efficiency, and improvements in the field of video compression therefore have great potential for energy savings. Currently, license-free methods compete with proprietary video codes (e.g. AOMedia Video 1 (AV1) or the HEVC/H.265 codec).

Waste heat recovery

The electrical energy input of ICT infrastructures is converted into heat through the processes occurring. In order not to exceed the operating parameters, such as the permissible maximum temperature, this heat must be transported out of the ICT infrastructure. If this heat is not expelled into the environment, but instead used for energy-related processes, this is called waste heat recovery.

Water-cooled converter

In data centres, electrical energy is converted at various points between DC and AC voltage, as well as undergoing changes in voltage. With water-cooled components, the heat generated during the conversion processes can be removed more efficiently than through air cooling.

Water-cooled motherboards
Individual motherboards can be individually cooled by means of water cooling and a large heatsink adapted to the board. For the water cooling of these individual components of a server, water pipes connecting to other components and to the heat exchangers are necessary.

Water-cooled processors
Processors can be cooled using directly-mounted water heatsinks. The advantage of this is the particularly large heat capacity of water and the possibility of greater cooling efficiency, power densities, and space savings. In addition, the warm return water can be used as a heat transfer medium (Hanstein & Abels, 2017).

Water cooling of entire servers
The water cooling of the entire server makes compact fan-free systems (both racks and stand-alone solutions) possible. All heat of all server components is extracted using water. This makes possible savings in volume and weight, as well as energy. In addition, the return water can achieve a high temperature level, which enables versatile subsequent utilisation (Thomas Krenn AG, 2017).

Wind power
The direct use of electrical power generated with wind power in the data centre within a spatial and temporal framework.

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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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