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Sino-German Energy Transition Project

Data centre flexibility in Germany and China

Status quo and best practices

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Content

Editorial

Dear Reader,

In recent years, cloud services, new Internet applications and social media platforms have proliferated, and the energy consumed by these platforms has become a matter of concern for energy policymakers and power sector planners alike. With digitalisation increasing in almost all aspects of our everyday lives, computing and storage capacity will expand significantly. Data centres constitute the operational 'heart' of this digital infrastructure.

Over the past decades, the massive increase in additional data centre capacity worldwide has resulted in a remarkable increase in the amount of electricity required for their operation, despite increasingly efficient information technology. Considering this exponential growth, we need a clearer regulatory framework and targeted incentives promoting greener data centre operations in countries with advanced digital economies, such as Germany and China.

The high energy consumption of data centres in Germany and China is a source of concern not only for the grid but also for data centre operators. While grid operators face the challenge of capacity expansion and system integration of these large consumers, data centre operators in Europe and China must also deal with increasing electricity costs and the integration of renewable electricity. Against this background, it is crucial to improve the efficiency and flexibility of data centre operations whilst maintaining stable operations and the provision of essential services. Implementing flexibility measures may prove challenging for many data centre players, but various measures available for achieving flexibility can cater to the needs of both grid and data centre operators.

Given the urgency of achieving climate neutrality and the availability of practical ways for data centres to become more flexible, accelerating the efficient and flexible operation of German and Chinese data centres should become a policy priority for 2030. Our study aims to call attention to the potential of flexibility, energy efficiency improvements and renewable energy use in data centres and highlight business and policy solutions. Based on the analysed information, the study puts forward policy recommendations for both countries.

Our findings and the events we organised to validate them are the basis of exchanges on greener data centres between German and Chinese experts, regulators and industry representatives. The research on efficient, flexible and sustainable data centres is still at a nascent stage. We hope that our work will encourage further discussions and exploration on the role cleaner and flexible data centres can play in the German and Chinese energy transitions!

Sincerely,

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Executive Summary

Data centres have significant potential to improve energy efficiency, to operate flexibly and to use renewable energy. Since data centre capacity and electricity demand are expected to rise significantly, this potential will only grow—targeted policies are required to tap into it. Various studies show a broad portfolio of technologies and measures available to data centres for sustainable operations. Based on our interviews with key experts and industry players in the advanced digital economies of China and Germany, several barriers hinder efforts to improve the flexibility and renewable energy uptake of the data centre industry. Improving energy efficiency has been addressed through policy, sometimes to the detriment of flexibility. In the future, we expect price differentials on wholesale electricity markets to drive flexible operations. However, prices will not be enough; this study shows that it will require a range of targeted policies aimed at increasing awareness among energy and data market stakeholders, improving administrative and market incentives and removing barriers to flexibility.

As a driving force in today's digital economies, data centres are one of the world's most rapidly rising loads. In 2020, the energy consumption of data centres in Germany and China accounted for 2.9% and 2.7% of each country's total annual electricity consumption, respectively. This trend is expected to continue, placing data centres at the centre of energy transition research. Several studies have highlighted the high potential for data centres to not only increase their energy efficiency but also to provide much-needed flexibility to the power grid and enhance the integration of renewable energy (RE).

The study summarises and discusses the potential of key technologies and measures that contribute to the sustainable operation of data centres:

- Flexibilisation through energy storage, workload shifting and optimised server operation;
- Energy efficiency improvements, such as via heat recovery or improved cooling systems;
- Data centre participation in electricity markets; and
- Utilising renewable energy in data centres.

Based on interviews with German and Chinese data centre experts and industry representatives, we identify barriers to deploying these key technologies and measures, develop policy recommendations to address them and include examples of business model best practices.

While several data centre operators have taken steps towards more flexible operations, we find that there is still a long way to go. The industry's main priority is operational reliability—many data centre operators see flexibility and providing services to the grid as matters outside their core business and, in certain cases, as a risk to it.

On the other hand, data centres have widely adopted energy efficiency improvements as well as renewable energy uptake, which they view more positively since they have little impact on data operations compared to flexibility measures.

Our analysis and interviews suggest that existing data centre policies are insufficient for driving the adoption of flexibility or clean energy, though some new measures recently adopted in China could have a major impact. Prior policies lacked comprehensive, targeted regulation and incentives to foster the widespread adoption of renewable energy or activation of flexibility. Specific recommendations for policymakers to address this gap are put forward in this study.

MAIN POLICY SUGGESTIONS

1. **Improve the transparency and information sharing** between grid and data centre operators, as well as between data centre operators and their customers, to encourage both energy efficiency and renewable uptake.
2. **Simplify existing regulations**—especially concerning the EEG levy in Germany—to enable a wider utilisation of existing battery storage.
3. **Introduce stronger incentives**, including both administrative and market incentives, to encourage data centres to shift their electricity consumption patterns and participate in demand response.
4. **Establish programmes** further promoting efficient heating and cooling practices in data centres.
5. **Enable intermediary actors** to aggregate and coordinate flexibility and energy efficiency services and measures.
6. **Adopt sectoral carbon neutrality plans** to accelerate the deployment of renewable energy in data centres.
7. **Provide lower connection costs or grid fees** to incentivise the grid-friendly allocation of data centres.
8. **Enable priority grid connections** for data centres willing to provide some degree of flexibility to the grid.

1 Current development of data centres in Germany and China

The IT sector has a large energy and carbon footprint, and its energy consumption is likely to grow exponentially over the next several decades. Several measures exist for making data centre operations greener and more flexible, such as purchasing power from renewable energy, adjusting workloads and investing in energy efficiency measures. Implementing these measures involves data centre operators as well as policymakers, market regulators and grid companies. It is crucial to establish a solid regulatory framework and incentives to enable the deployment of these measures, thereby providing a path to greener data centres.

1.1 Data centres and the energy transition

Germany

German data centres are among the most energy-efficient in the world. Power usage effectiveness (PUE), which is a measure of the energy efficiency of data centre infrastructure, improved by 10% on average between 2010 and 2015. However, this cannot offset the continuously increasing demand for computing power in data centres.[1]

The total energy demand of data centres in Germany is steadily increasing. It reached 16 TWh in 2020, the equivalent of approximately 2.9% of final electricity demand, exceeding all projections. According to a study from RWTH Aachen, the energy demand of data centres is expected to increase to about 18.8 TWh by 2025.[2]

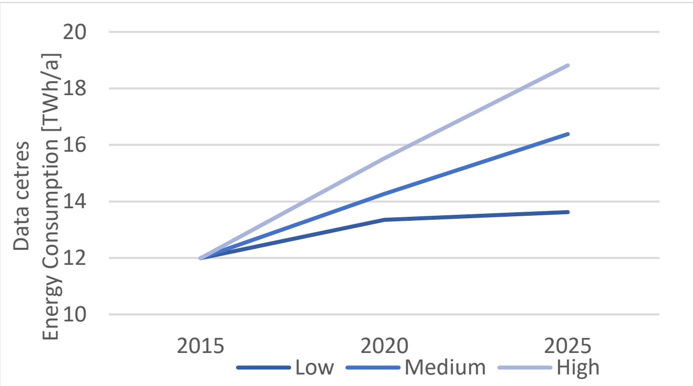


Figure 1: Forecasted development of yearly energy demand (2015 to 2025) for data centres in Germany[3]

However, these estimates are also likely to be exceeded if we take the 2020 figures as a baseline. The German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection stated that according to expert estimates, the energy demand of servers, in particular, will increase due to the high demand for computing power in German data centres, rising by more than 60% between 2015 and 2025.[4]

Most of Germany's data centre capacity is located in the Rhine-Main region. The city of Frankfurt is home to a large number of data centres, mainly due to its proximity to the world's largest Internet exchange, the German Commercial Internet Exchange (DE-CIX), as well as the demand for fast data from Frankfurt as the most important financial hub of continental Europe. Other major cities with significant data centre locations—which also happen to be urban regions of high energy consumption—are Munich, Berlin, Hamburg, and Düsseldorf.

This study focuses on data centre flexibility, energy efficiency improvements and the deployment of renewable energy (RE). While German research and business applications currently tend to focus on renewables, flexible data centre operations will gain importance in the future. Introducing those changes in data centres can contribute to lowering their energy cost.

Overall, data centres can become an integral part of the German energy transition. The German government has set a 2030 target of an 80% share of renewable energy (RE) in the country's overall electricity consumption. As Germany enters the next phase of the energy transition, a major challenge will be to use electricity from renewable sources when it is available and to adjust electricity demand when the renewable supply is lower. Due to Germany's phase-out of nuclear and coal power plants, ensuring a stable power supply with constant grid frequency might be increasingly challenging.

These increasing shares of RE in the power system are driving the need for flexibility to ensure the stability of the power grid. Having sufficient balancing energy in place is an important prerequisite for the uninterrupted operation of the German power system. Apart from network and power plant operators, consumers, such as data centres, also have significant flexibility potential, which they can provide through demand-side management measures or participation in the wholesale electricity market and in the ancillary services markets.

Similarly to China, existing policies in Germany mainly focus on energy efficiency improvements in data centres. In its “Digital Policy Agenda for the Environment”, published in 2020, the Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection primarily put forward measures to increase the energy efficiency of German data centres. Among other measures, the “Blue Angel” ecolabel will set standards regarding energy-efficient data centre operation, climate-compatible co-location data centres, resource- and energy-efficient software products and server and data storage products.[5] In addition, the German Environment Agency is planning to set up a register for data centres to get an overview of how large data centres are organised, what their energy consumption is and how they utilise waste heat.[6] The agency is also working on a rating system to evaluate the energy efficiency of servers. Currently, Germany does not have all-encompassing legislation in place addressing the need for flexible data centre operations or encouraging data centre demand response.

A study by Bloomberg New Energy Finance (BNEF) estimated the total flexibility of data centres in Germany and other countries with a view to 2030. While BNEF estimated the potential flexible capacity in Germany at 3,800 MW, the study authors expect an actual flexible capacity of only 660 MW due to the low willingness of data centres to participate.[7] To increase the actual flexible capacity, data centres need to make full use of their existing flexibilities and invest in tried-and-tested flexibilisation improvements. These improvements can be tailored to the needs of the different data centre types and can also lead to significant cost savings.

China

The number of data centres has grown rapidly, keeping pace with China’s booming Internet use. China’s data centre and 5G sectors consumed an estimated 201 TWh of electricity in 2020 or approximately 2.7% of electricity demand.[8] A 2021 analysis by Greenpeace East Asia and others projected that by 2035, China’s digital infrastructure will consume 782 TWh, almost four times the amount in 2020. This would account for 5–7% of China’s total power consumption at that time. In addition, 5G will consume 297 TWh of electricity or almost five times the current level.

Currently, China’s Internet communication infrastructure capacity has the greatest bandwidth density in the regions near the country’s largest and most developed cities. Most data centre electricity consumption comes from five provinces in China: Hebei, Jiangsu, Beijing, Guangdong and Zhejiang. These provinces represent the most economically developed coastal regions with the highest demand for data services.[9]

Several policies issued in 2021 imply that the government will seek to gradually shift data centre electricity load to less developed provinces with surplus clean electricity, such as Guizhou, Gansu and Inner Mongolia.[10] This could result in greater absorption of cleaner, renewable power, but it will also entail greater development of communications infrastructure in widely dispersed regions far from major cities. Of course, the Internet communication infrastructure would have to be expanded accordingly in these provinces in order to accommodate this data centre capacity.

Energy efficiency has been the main focus of policies aimed at data centres: In 2015, China established pilot programmes with targets for measuring and improving PUE at selected data centres.[11] The 13th Five-Year Plan (2016–2020) set a target for the largest data centres to achieve a PUE better than 1.4.[12] In 2021, China’s Ministry of Industry and Information Technology issued a three-year target for data centres to achieve a PUE of under 1.3.[13] This could encourage data centres to relocate to cooler climates and seek higher utilisation, both of which could work against flexibility or renewable utilisation, depending on how they are implemented.

China’s policymakers also recognise that data centres constitute a new type of load with potential for integration with renewable energy and more flexible power markets. In September 2017, China’s National Development and Reform Commission (NDRC) and six other ministries and commissions jointly issued a policy on demand-side management (DSM) outlining five dimensions of DSM: electricity conservation, environmental protection, orderly electricity, green electricity and smart electricity. Smart electricity refers specifically to the integration of information and communication technology to support DSM.[14] Since then, provinces such as Jiangsu and Shandong have undertaken DSM pilots involving data centres in demand response—which will be described in detail in the next chapter.

China’s power market reform is at an intermediate stage: most regions lack highly liquid spot electricity markets, and even in provinces with spot markets, most power trading takes the form of mid- to long-term bilateral contracts. These contracts have a duration from one month to one year and would usually require constant power consumption—and hence place limited value on flexibility and discourage fluctuation in electricity loads. Since 2018, some provinces have introduced spot market pilots, but these remain at an early stage with limited liquidity.

New reforms in mid-2021 have increased power prices and provided additional incentives to consume renewable electricity. In October 2021, regulators expanded the regulated range of benchmark coal power price fluctuations, raising the upward limit of coal power benchmark prices from 10% to 20%. The central government will not cap the coal power price fluctuation for high-emissions and highly energy-intensive industries.[15] The retail electricity tariff catalogue will no longer apply. The grid company will serve as the purchaser and set prices for many smaller customers or industrial parks. However, end users will have the option to enter the bilateral market directly. Finally, the central government has included the data centre industry as its own category of high-emissions and/or high energy-intensive industries (known as *dual high* industries), implying strict efficiency and energy consumption quotas. However, data centres that consume local renewable energy can obtain more favourable or flexible quotas. Moreover, under a policy announced in late 2021, incrementally added renewable energy consumption will be exempt from the dual high controls, meaning new 100% renewable data centres will not detract from a province's energy quotas.[16] Higher and more volatile coal power prices and policies to encourage renewable adoption both represent major incentives for flexibility measures to enable greater renewable uptake.

To fully realise China's 2030 carbon peaking and 2060 carbon neutrality targets, China's electricity sector will need to further improve operational flexibility of all aspects of the power system—generation, storage, transmission and load. Many researchers expect electricity spot prices to play a greater role in signalling the need for flexibility on the demand side and view data centres as promising future participants in electricity spot markets, ancillary service markets and cross-provincial and cross-regional trading markets. Greater flexibility can enable data centres to contribute to a green power system and the realisation of China's carbon neutrality goal, and earn extra income by doing so, while also continuing to meet the country's rapidly rising demand for reliable data services.

1.2 Marketing the flexible loads of data centres

The growing penetration of renewable energy in the power system brings both cleaner and more variable energy to the grid, making it increasingly complex for power dispatchers to ensure the balance of supply and demand in real time. According to a 2019 International Energy Agency report, data centres can be used in power systems to help balance grid operations and provide other system services, help absorb wind power resources and play an increasingly important role in demand-side response, which can be regulated through price signals.[17]

Data centres are increasingly diversified in form, based on their size (small- or large-scale data centres) as well as the types of activities they are performing (data centres in universities and research centres, company-owned data centres, co-location data centres, hyperscale data centres). Due to the potential of data centres to adjust power demand in real time by shifting workloads, either spatially or through temporal shifts, they are particularly suitable for providing flexibility to the power system. Data centres also have significant potential to provide control power through emergency power generators and batteries for uninterruptible power supply. All of the above aspects can be utilised to relieve grid congestion. However, as outlined in the German Regulation on Interruptible Loads (Verordnung zu abschaltbaren Lasten, AbLaV), Germany only allows negative reserve power, not positive reserve power.

In Germany, demand-side flexibility—also called demand-side management (DSM)—is increasingly seen as an important albeit still untapped resource. Team Consult estimates Germany's current industrial DSM potential at between 3 and 5 GW.[18] This potential is set to grow in Germany, reaching 6.6 GW in 2050, of which 76% (5 GW) will be exploited.[19] Nevertheless, it remains a challenge to find additional providers of flexibility. In several dena studies focused on DSM, researchers determined that most industrial sectors are capable of offering demand-side flexibility by reducing their load to match electricity production. Data centres are excellent candidates for providing demand response due to their flexible loads. Workload management, in particular, seems to provide a high flexibility potential.[20]

China has traditionally encouraged demand-side flexibility via a static framework of peak and valley tariffs. Future sources of power system flexibility will need to expand. System supply and demand will rely more on market signals to guide the power system more dynamically via prices. China also has policies to encourage demand response but, so far, there are no policies targeting data centres to participate in the market directly. This reduces the willingness of data centre operators to provide flexibility, given that data centre operators view provision of reliable data services as their core competence and primary profit driver.

1.3 Barriers to deploying data centres' flexibility

Even though several studies have shown that data centres can offer substantial flexibility on the demand side, there are barriers hampering its activation. At a series of two closed-door workshops held by dena and GIZ, industry experts and insiders provided an overview of the challenges data centre flexibilisation faces. Three dimensions are the foundation for later identifying the challenges across the different data centre types. An expert at the workshop put forward these dimensions:

- Technical dimension: Is it technically feasible to achieve a flexible data centre?
- Organisational dimension: Does the data centre operator have the necessary tools and responsibility to operate the data centre flexibly?
- Business dimension: Is it financially attractive for the data centre operator to sell its flexibility in the electricity market?

For all three dimensions, several challenges were identified:

The main business of data centres remains to provide data centre services to customers, not to participate in electricity markets or coupling with power and heating networks. Ensuring uptime is of the utmost importance. At the study workshops, several participants mentioned this point, estimating the cost of downtime for certain data centre types at approximately US$ 1.2 million for 1 second of downtime. Therefore, operators view the introduction of energy efficiency or flexibility measures that might affect data centre operations as too risky.[21] The conflict between flexibility and reliability is a concern for many industry practitioners.

- Operators view participation in demand response programmes or power markets as administratively complex. Even though participation can result in financial gains, the market's complexity and data centre operators' lack of experience hinder data centres from entering the markets.
- There are also significant challenges from a grid operator's perspective. A study by the California Institute of Technology analysed the potential of data centres to manipulate market prices. Focusing on large-scale data centres, the authors observed that very large data loads could potentially lead to market power and the potential of data centre operators to manipulate prices in their favour. This makes grid operators nervous about relaxing certain rules regulating data centre demand response participation.[22]

Policy should provide appropriate incentives to encourage the sustainable development of data centre operation as well as their flexible behaviour. Further barriers identified in the interviews with German experts may be found below:

- With regard to the flexibility provided by energy storage, German data centres have to pay the renewable energy (EEG) levy for charging and discharging the battery storage, which makes the storage unprofitable for some.
- According to one interviewee, in many data centre facilities, the value chain is distributed between various stakeholders. For example, in co-location facilities, the IT hardware is owned by an IT service provider that rents it to a customer, whilst the building and infrastructure are operated by a co-location operator. The multitude of different actors combined with tight service level agreements makes it hard to introduce operational changes, as an agreement would have to be reached between all parties.
- Some European and German self-regulatory initiatives for achieving climate-neutral data centres by 2030 are already in place.[23] However, apart from these initiatives, there is often a lack of comprehensive regulation at the national level or incentives to encourage flexibility and energy efficiency investments.

China has years of experience encouraging demand response (or demand-side management) in industry, but there remain many barriers to demand response in practice.

China has established time-of-use pricing (TOU) for industry in most provinces. A typical peak-valley price differential is 2-to-1 or 3-to-1. A policy issued July 2021 by the National Development and Reform Commission encourages provinces and localities to set the TOU ratio to at least 4-to-1 in regions where the generation difference between peak and base is higher than 40%,[24] and several provinces have already responded accordingly. In addition, China has explored policies to encourage the development of virtual power plants to aggregate electricity loads, as well as encourage demand-side participation in power markets.

For over a decade, China has also promoted specific demand-side management programmes for industry, including both energy efficiency programmes as well as interruptible load programmes for large customers. A long-standing historical problem with these programmes is that they depended on administrative planning and subsidies from local government rather than revenue from participating in power markets. Hence, even peak load reductions that result in major cost savings would be perceived as a costly endeavour by officials.

Given that existing market incentives for data centres focus only on data service reliability and overall energy efficiency (as measured by PUE), our interviews suggest that current efforts to introduce larger real-time electricity price signals, data centre participation in the power markets and other market measures will fall short of what is needed to incentivise flexible data centre operation. The IT sector will likely wait for more direct administrative regulations, which could include small administrative measures by provinces to require a certain degree of flexibility or on-site energy storage for peak load periods or grid company requirements for flexibility as a condition for interconnection.

It is possible that the IT sector could develop an overall plan on a national scale for carbon neutrality that includes consuming renewable energy, peak shaving and energy efficiency through the use of waste heat in certain regions. Given existing incentives in the industry, advanced flexibility measures such as time shifting or geographical shifting of computing loads are unlikely without administrative regulations that go beyond what electricity markets could directly incentivise via price signals.

1.4 Need for policy support

Germany

To better understand issues relating to data centre participation in markets and renewable energy utilisation, we conducted interviews with experts from the German data centre landscape. The interviewees ranged from data centres and research institutions to network operators and others active in this sector.

We asked the interviewees to comment on the potential of flexibility and energy efficiency improvements for data centres in Germany, the policies necessary to enable such improvements and the policies needed to incentivise data centres' participation in the electricity market and utilisation of renewable electricity.

The respondents provided insight regarding the flexibilisation of data centres and the use of energy storage devices for that purpose. While data centres already have high-performance batteries in place as a backup power supply in case of power failure, the respondents were not aware of concrete regulatory incentives that incentivise data centres to install batteries for providing services to the grid.

The interviews highlighted several options for data centres to provide grid services. The respondents referred to load shifting and the utilisation of emergency power supply as possible ways to balance the grid. However, ensuring operational security remains the paramount concern for data centre operators. Generating additional revenue by providing services to the grid is seen as a side business, which may only become attractive to data centres with greater financial incentives.

Some respondents noted that such incentives should be designed as simple as possible to encourage uptake by data centres. Another suggestion was to introduce policies that ensure the transparent exchange of data between data centres and the grid. For example, grids need data on the data centre's energy consumption and the available grid capacity. A public or semi-public information platform could lead to more flexible data centre behaviour by indicating the need for adjusting electricity loads and the available incentives for doing so.

When it comes to data centres participating in the electricity market, most respondents do not perceive this as the main business of data centres. Some respondents believe that any initiative to engage data centres should originate from state authorities or grid companies and that data centres are unlikely to provide such services on their own without such initiatives. Industry interviewees also favoured sticking to voluntary incentives for data centres to participate in the ancillary services market instead of mandates. The challenges faced by grid operators with integrating larger consumers such as data centres were also brought into the discussion.

The respondents were more aware of ongoing developments in the field of energy efficiency improvements and the corresponding regulatory framework. The interviewees mentioned various examples of innovative waste heat utilisation, such as a regional incentive programme that promotes the use of waste heat from data centres, among other sources of heating. This concept could also apply to cities such as Berlin, which lacks heavy industry to supply waste heat for the city's heating networks.

When asked about the main drivers for deploying renewable electricity in data centres, the interviewees identified two main arguments: corporate responsibility to achieve carbon neutrality and carbon pricing.

Overall, the interview findings show that there is no concrete legislation in place in Germany governing data centre operations. The interviewees mentioned several policies at the European level, such as the Code of Conduct and Digital Strategy, which could also eventually be adapted into German legislation.

Data centre owners and operators would likely welcome concrete policies in the areas addressed in this study, provided that they do not significantly affect their main data-related operations. In general, considering that data centres need to ensure continuous uptime, data centre owners and operators are hesitant about new flexibility measures, especially if they affect their operations.

A possible solution provided by one interviewee was for intermediary enterprises to assume responsibility for providing an entire package of flexibility and efficiency measures, covering waste heat utilisation, participation in electricity markets and workload management.

China

As in Germany, the interviews with Chinese industry experts and scholars suggest that the role of the data centre industry in providing demand flexibility and integrating renewable electricity in China is still insignificant. The interviewees provide a variety of explanations, focusing on the large and growing revenue available for providing reliable and fast data services, which likely far outweighs the potential gains from participating in electricity markets. In addition, the Chinese interviewees focused on several barriers to participation in electricity markets:

- Physical bandwidth limitations discourage regional load shifting;
- The absence of high-volume spot markets or ancillary services markets hinders time shifting or geographical load shifting;

- Further incentives and planning measures are needed even after such markets develop since electricity price differentials are unlikely to be large enough to justify costs to enable load shifting.

Given the existing incentives in the power markets, not only do data centres have limited incentive to become more flexible, but the Chinese power market structure actively encourages data centres to maintain constant loads, focusing instead on rewarding efficiency. Indeed, attaining a favourable PUE often depends on achieving steady and high utilisation, which inherently works against flexible operations such as load shifting.[25] Therefore, the interviewees believe the industry will likely await more concrete policy measures, including mandatory requirements related to flexibility, before data centres take any action to become flexible loads.

Just as the German interviewees illustrated the potential value of information platforms, it is possible that greater data transparency could help promote greener and more flexible practices at Chinese data centres. Reliability, speed, and efficiency are the main metrics customers can access for most data centres. A handful of data centre providers have begun to install distributed renewable energy or purchase renewable power, but this remains a minority practice and does not relate to data centre participation in power markets.

The interviewees believe that the flexible use of cooling or heating has potential in some regions. Introducing adjustments that can ramp up or down the power consumption for heating and cooling could contribute significantly to data centre demand response. Again, the interviewees agree that data centre heating and cooling practices depend on supportive policies that encourage the participation of the data centre industry and industrial parks.

In general, the largest step the data centre industry in China will need to take in order to integrate greater flexibility and clean energy practices relates to the incorporation of carbon neutrality plans—for individual companies, for the industry and for the provinces. Doing so will enable data centres to physically relocate to provinces with cleaner energy sources or make active use of renewable electricity through other ways.

2 Options for the flexibilisation of data centres

Integrating higher proportions of renewable energy into the grid requires greater flexibility on both the generation and the demand side. Enhancing demand-side flexibility can improve the dynamic balancing of supply and demand and reduce the costs for consumers. Data centres can play a significant role in providing demand-side flexibility, but this potential remains far from fully realised. Data centres can provide flexibility in many ways; in most cases, they only need to optimise their operations.

This chapter will examine various ways of how data centres can provide load flexibility:

1. Data centres have varying workloads that can be rescheduled and shifted throughout the day to better accommodate the grid's needs. Given their ability to shift their workload and operations, data centres are particularly suited to act as flexible loads.
2. Batteries used for data centre uninterruptible power supply systems can also enable flexible operations.
3. Optimising the operation of servers enables significant savings and can improve the management of data centre power loads.
4. A further option is the spatial shift of workloads between different data centres—instead of shifting workloads in time within one data centre. A cluster of data centres can shift workloads in both space and time, thus effectively shifting load from high power demand areas to low demand areas, alleviating the grid or matching local renewable output.[26]

It is important to note that, as also discussed in the study validation workshops, there is no one-size-fits-all solution when it comes to improving flexibility. Different types of data centres will require different solutions. Take the field of control, for example: For a co-location data centre, the heating, ventilation, cooling, UPS and EPS belong to the operator's field of control, whereas in an enterprise data centre, the IT hardware is also part of the field of control.[27] This chapter will look at several flexibility options and how they apply to various types of data centres.

2.1 Shifting workloads in time

The shifting of workloads is considered a straightforward method for making data centres more flexible and for assisting with the integration of renewable energy. However, despite its potential, load shifting remains rare in the industry in practice. In this part of the study, we discuss some of the findings and examples found in the literature on load shifting as well as related policies and practices in Germany and China.

The workloads processed daily by data centres are the demands for computing services submitted by users via fixed and various devices. Each workload varies in its computing service time requirements. For workloads that can be processed over a longer period, server load can be shifted for processing at a time when electricity prices are lower or when renewable energy is more abundant, or even for the purpose of providing balancing energy or resolving grid bottlenecks. In addition to enhancing the flexibility potential of data centres, load management can also present financial advantages for the data centre operator through dynamic electricity prices. From a grid operator's perspective, the application of load management enables better grid management.

Various models and experiments have shown how load shifting might work in practice. For time shifting, a simulation conducted by Tudor Cioara et al. shows how the load might be shifted at a data centre that normally experiences peak loads in the morning and evening.[28] A substantial portion of the delay-tolerant workload could be shifted to midday when electricity prices were at their lowest. A series of experiments in 2012 by the Lawrence Berkeley National Laboratory (LBNL) showed how several small data centres were able to reduce their overall load by as much as 30% by rescheduling low-priority backup workloads. The experiment required manual shutdown of some server banks and, in one instance, the manual adjustment of cooling setpoints. While such tasks could be automated, doing so may require additional investment and planning at the design stage. The LBNL study also proposed geographical load shifting but did not undertake such an experiment due to the absence of such automated controls.[29]

When applied in practice, data centre workload scheduling needs to consider factors such as quality of service, requirements of workloads, server processing capacity limits and workload scheduling time delays. In certain circumstances, such as when servers have sufficient memory, complete data and a CPU margin, the server processing load can be shifted from time periods with higher workload density to time periods with lower density.

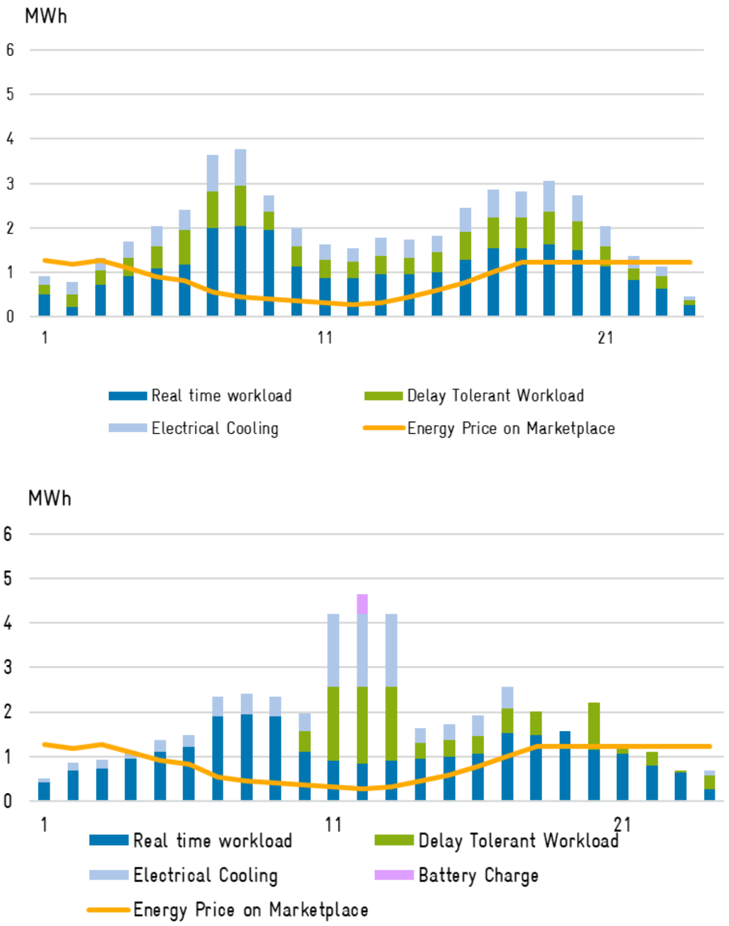


Figure 2: DC baseline energy profile (top) and DC energy profile adjusted considering the convenient energy prices (bottom) [30]

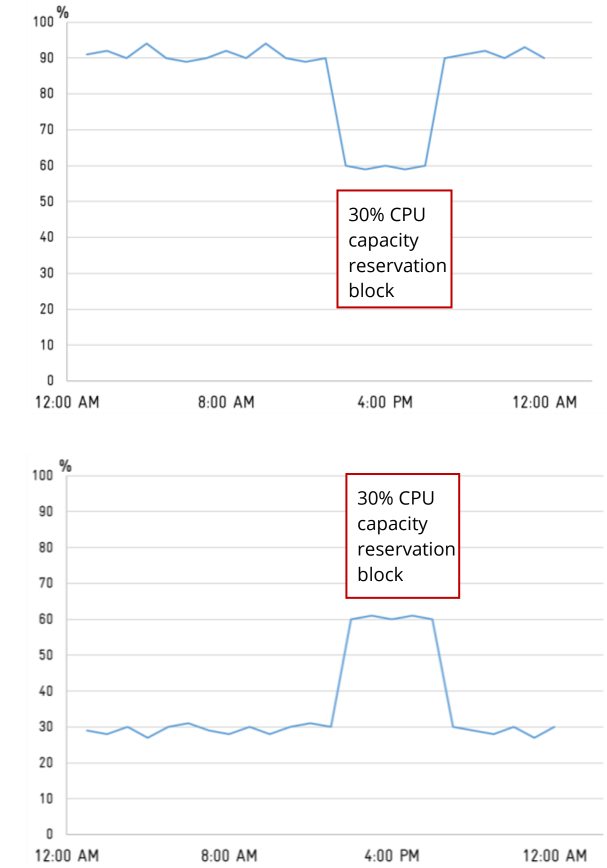


Figure 3: Decrease in CPU utilisation in one cluster (top) and increase in CPU utilisation in the other cluster (bottom)[31]

Figure 4: Daily load shape in 2008 of a research/ academic data centre (left) and a mixed-use data centre with a lower average daily load factor (right)[32]

The shape and predictability of data centre load curves partly determine how load shifting might work in practice. LBNL has shown that data centres differ substantially in this respect, depending on the type of data centre, type of workload and seasonal cooling needs.[33] In some conditions or when averaged over long time periods, data centre loads may be flat—but in other cases, their loads can fluctuate, even on a daily basis. In some seasons, data centre cooling loads coincide with peak grid loads, resulting in higher electricity costs. This may make thermal energy storage attractive for such loads.

However, some modelling studies suffer from a drawback: They assume the ability to plan workload adjustments long in advance. Doing so requires advanced predictions and global data—hardly the real-world situation of most data centre operators. Moreover, many load shifting models themselves require long computing time, making them unsuited to real-time scheduling demands. At best, they may be applied to day-ahead planning or for evaluating overall workload scheduling routines. Lastly, geographical load shifting requires coordinating several data centre locations, which may only be feasible for the largest operators.[34]

Another critical point is that research on data centre flexible scheduling lacks integration with research in the field of computing, paying little attention to issues such as data task size, fibre bandwidth and the topology of cloud computing networks. This reduces the feasibility of implementing these flexibility approaches.

Data centres perform a complex and diverse range of tasks with different impacts on server power consumption. For flexible scheduling to make sense in practice, data centres need an incentive to adjust workloads and participate in grid balancing and sector coupling with renewables in their actual operations. According to a recent study by Bloomberg NEF, there is a strong indication that larger data centre operators might adopt new flexibility approaches faster than others; they were among the first to start with RE utilisation by signing PPAs, a move that co-location data centres followed.[35] However, whether co-location data centres will try to become a flexibility provider in the energy market remains open.

Germany interview results and examples

An example of shifting workloads in data centres was put forward by the AC4DC project. User-oriented solutions were an important aspect of the AC4DC project, and interviewees in this study also highlighted the same point.

AC4DC PROJECT

The temporal and spatial shifting of workloads was also among the research topics of the three-year research programme AC4DC (Adaptive Computing for Green Data Centres), funded by the Federal Ministry for Economic Affairs and Energy. Within the framework of this project, various possibilities for load management in data centres were analysed and solutions to optimise data centre operations were put forward.

With the help of the algorithms developed in the project, the potential of migrating individual services between servers within a data centre was explored—while also observing quality-of-service requirements for workloads. This made it possible to temporarily switch off parts of the hardware completely, which, in turn, reduced the overall energy consumption of the data centre.

A very high level of system stability remains a top concern of data centre operators. Availability and reliability are of utmost importance, especially for business-critical applications. One interviewee stated that it would be of no interest to implement flexibilisation in High-Performance Computing (HPC) data centres.

Quote 1 – Germany data centre researcher: “What is most important for data centres, though, is that a very high level of system stability in the data centre needs to be ensured at all times, regardless of grid stabilizing services.”

Quote 2 – Germany data centre operator: “We run cost-intensive high-performance computing hardware that is operated 24/7 in an overbooked state under full load. I do not see a business model in which load management would be lucrative. When operating supercomputers, load management is hardly conceivable, unlike in ordinary data centres.”

However, some interviewees agreed that certain tasks might be shifted, depending on the different types of services provided.

Quote 3 – Germany data professional: "(...) services are more requested during the day than during the night. (...) Accessing an online store or your emails need to be immediate, while backups, renderings of videos, scientific models, keyword tagging, crawling, data processing and other tasks are more delay-tolerant. These kinds of tasks can be shifted and computed at other times of the day based on the power grids' state."

The interviewees identified types of data centres for which load shifting might be of interest, such as data centres employed by universities or research centres and hyperscalers. On the other hand, co-location providers generally cannot apply load shifting, as they do not operate the IT themselves. Dividing the demand among distributed smaller data centres was another proposal one interviewee put forward.

Quote 4 – Germany data centre researcher: "Data centres for universities or research centres, for example, are especially suited to flexible operation, as their complex calculations aren't necessarily time critical, which means they can be shifted according to the electricity market situation. Of course, this expense must be rewarded financially."

Quote 5 – Germany data centre researcher: "Another possibility would be to have smaller distributed data centres at different locations with different grid situations so that the demand can be divided according to the grid situation, such as using a location near a PV plant during the day and a location near a wind farm in the evening."

China interview results

Our interview results in China show that there are many policy and market obstacles to data centre load shifting for balancing renewable energy or providing demand response services.[36] A first obstacle is power markets' preference for stable loads instead of flexible loads. Large electricity users typically sign contracts for monthly or annual power consumption, enabling high utilisation of grid resources and generation assets such as coal plants. However, by their very stability, stable loads hinder the development of various flexibility options such as energy storage, load management and grid optimisation.

Quote 6 – China data centre professional: "The concept of flexible power use in the power system is of less interest to data centre customers because, at present, data centre power use is relatively smooth and is a premium load for the power system. Hence, data centres can get lower prices for their electricity load."

Quote 7 – China data centre professional: "Data centre loads are a premium load for the power system, which offers lower prices for such loads. [Coal] power plants prefer this kind of load to reduce startup and shutdown losses. Flexible operation could result in data centres losing the benefit of their current low electricity tariffs on bilateral contracts."

Furthermore, depending on the type of data centres, some might have relatively flat loads, while others have highly variable ones.

Quote 8 – China data centre professional: "The company has a lot of real-time business, and the users' demand time period varies quite a bit, which means that the data centre's IT load isn't flat."

Quote 9 – China data centre professional: "The peak-to-valley load fluctuations in our data centres usually do not exceed single digits, remaining below 10%."

Quote 10 – China data centre professional: "Data centre load priority is determined according to complex procedures, such as classifying and sorting loads. But the proportions of the loads at all levels have not been specifically determined."

Our interviews in China also pointed to the lack of public information that would help grid planners and energy policymakers differentiate between data centres and prevent one-size-fits-all data centre policies. The interviewees also cited communications infrastructure—access to bandwidth—as a bottleneck for both time shifting and geographical load shifting. Indeed, bandwidth helps explain why most data centres are located near large cities (closer to customers), and this limitation hinders policies to shift data centres to remote regions such as Guizhou and Inner Mongolia.

Quote 11 – China power sector professional: "Bandwidth has not yet reached a state where it can be interconnected. It would be unacceptable if cross-regional scheduling of tasks were to cause business delays."

Quote 12 – China academic expert: "Data centres mainly follow traditional business load scheduling. Electricity market reforms are incomplete and price signals are not yet available. Therefore, scheduling is currently based on traditional habits and does not take the temporal and spatial variability of electricity prices into consideration."

Quote 13 – China academic expert: "The power grid and the computing power network will be integrated in the future. But scheduling is difficult because it involves standards, confidentiality, agreements, and so on."

2.2 Load migration and alleviating grid congestion

Integrating renewable energy across large geographical areas generally requires high-voltage transmission lines; however, the variability of renewable output makes this an expensive proposition in practice, especially once renewable energy penetration exceeds 30–40%. Utilising the flexibility provided on the load side by data centres can contribute to renewable electricity integration across a wider area. However, grid planners in certain regions—both in Europe and China—have simply categorised data centres as an energy-intensive industry without adequately considering them in grid planning. This can result in a higher concentration of data centres only in specific areas, leading eventually to grid congestions. Incentivising data centres to flexibly transfer workloads between regions could enhance the efficient utilisation of both the electricity and communication networks and reduce bottlenecks in the power grid. However, it should be noted that this workload transfer may lead to increased energy consumption in the data centre.

An important step in alleviating grid bottlenecks is migrating the load of services between data centres. Establishing a network of data centres by merging several data centres into a single virtual resource can provide significant demand response.

The processing load is constantly distributed or migrated automatically according to defined rules between the individual data centres of the Data Centre Federation (DCF). For example, requests can be assigned to the nearest data centre or, if that data centre is overloaded, redirected to another equally suitable data centre from the DCF without users even noticing.[37] Whilst within a single data centre, the load is only shifted in time, within a DCF, loads can be shifted in both space and time, thus providing the necessary flexibility.[38] Doing this resolves local grid congestion while maintaining data centre operational reliability.

Especially in cloud-connected or hyperscale data centres, workloads can be shifted and processed off-site. This entails shifting workloads to regions with cheaper electricity or more abundant renewable energy or special load requirements for processing within the processable timeframe. By adjusting the processing time and processing area for workloads, data centres can enable the optimal allocation of resources on a larger scale.

However, not all workloads can be transferred off-site; for example, some workloads involve little computation but require the retrieval of huge data files. Scheduling such workloads requires packaging and transferring this data as well. Most importantly, differential scheduling of workloads requires a common definition of workload categories and their relative priority.

Grid-oriented allocation can be incentivised by system operators—they can provide lower connection costs or grid fees to data centres that choose to locate in areas with lower congestion. Again, this option may apply to certain types of data centres that can afford to move their operations further away from the usual data centre hubs.

Germany interview results

In a system with high shares of renewable energy, system operators increasingly face challenges in balancing supply and demand. DSOs have to manage more complex tasks than in the past and integrate more decentralised assets, such as data centres. Data centres will also have to adapt their operations to the grid situation to ensure grid balance. From a grid operator's perspective, further expansion of the industry must be based on grid-friendly principles and take the grid's needs into consideration. Interviews with German experts suggested that distributing data centres to match the grid's needs would lead to relocating various data centres and eventually to a more grid-friendly geographical layout.

Quote 14 – Germany data centre researcher: "Another possibility would be to have smaller distributed data centres at different locations with different grid situations so that the demand can be divided according to the grid situation."

Quote 15 – Germany data centre operator: "A more distributed data centre structure where they are not only concentrated in congested areas could be beneficial and also incentivise industries to relocate, leading to a more grid-friendly allocation."

China interview results

Since China has recently prioritised the construction of data centres in resource-rich regions, geographical load shifting is a high priority for further research. This is particularly the case for remote regions where the government has prioritised new data centre clusters that will integrate a large amount of bandwidth connectivity, data centres, and renewable energy.

2.3 Unlocking the potential of energy storage

Energy storage systems can provide ancillary services to power networks and ensure their reliability. Aside from storing energy, batteries are excellent providers of short-term electrical flexibility: they can switch from zero power to maximum charge or discharge power in a matter of seconds or less, and they can continue charging or discharging at peak capacity for up to an hour. Flexible resources that can adapt quickly to changes in demand or renewable supply are crucial to the power system.

Most data centres have energy storage and backup generators on-site to provide backup power for their servers in the event of grid power failure. The charging and operating times of installed battery systems in data centres are automatically controlled and can often be shifted over many hours or even days. In addition to using UPS equipment as a backup power supply in case of power failure, data centres also use it to smooth out any voltage disturbances.

During periods of low data utilisation, data centre energy storage can earn revenue through electricity frequency regulation and load levelling. In a 2011 paper, Rahul Urgaonkar et al. developed an online control algorithm for optimising data centre UPS scheduling to reduce costs and improve efficiency.[39]

Similarly, in 2012, Vasileios Kontorinis et al. showed the economic benefit of using data centre energy storage for peak load levelling.[40] A 2016 study by Yuanyuan Shi et al. showed that optimising data centre UPS operation for reducing peak loads would reduce both time-of-use power tariffs and demand charges, as well as contribute to frequency regulation—with a potential for reducing costs by up to 20%.[41] When shaving the power demand from the power grid, lower electricity and grid connection costs can be achieved due to a lower maximal capacity and, therefore, lower capacity price. Since the profile of a data centre's IT load is relatively flat, peak shaving mainly makes sense when the cooling load increases during the summer.

Germany interview results and examples

MASTER+ BATTERY

One example of an innovative flexible application is a battery system developed by the companies RWE and Riello, which was integrated into a data centre to provide increased storage capacity and an integrated battery monitoring system. This enables the Master+ battery unit to automatically withdraw power from the grid or supply power to the grid in case of grid imbalances.

This UPS battery is marketed with the support of the energy trading company RWE, leading to additional revenue for the data centre from the energy market. The data centre expanded incrementally, beginning with a first expansion stage, where two "Master+" UPS battery systems with 250 kW each and a 1,100 kW emergency generator were integrated to secure the emergency power supply. In the next stages, the UPS capacity is set to increase to 2 MW, and a second emergency diesel generator is to be added.

Batteries in data centres, either as stand-alone large-scale batteries or as virtual power plants (VPPs), can enable time-shifted consumption, thereby decreasing the load from the public power grid in times of low electricity feed-in. In general, only the battery's additional capacity, as opposed to its full capacity, is used for the power market. The decreasing costs of small-scale batteries and increasing power prices could work as incentives for the widespread use of these technologies. However, current power markets provide limited or inadequate incentives for data centres to use battery storage as a flexible resource. Apart from missing incentives, many data centres view using UPS batteries for purposes other than backup as too risky. It is also worth mentioning that the maximum number of operation hours in Germany are limited in their permit, typically at 200 or 500 hours per year.

Quote 16 – Germany data centre operator: "As data centres integrate battery storage as backup power, there are possibilities to use these technologies to create a more flexible demand from the grid (decouple the demand from the grid). Furthermore, the storage can be used to provide grid services. When the application of the data centre allows it, the operation can be carried out more flexibly. Experience could predict when the service will be needed—for example, access to cloud applications."

Quote 17 – Germany data centre expert: "Data centres are implementing battery storage to enable high reliability, so there is a huge barrier to use this backup power for grid purposes, possibly resulting in a lack of energy in an emergency. Any risks that decrease the reliability will be avoided, so appropriate incentives are needed to make this additional use of the battery appealing."

For large-scale battery storage (LSB), a proper framework must also address the ongoing problem in Germany regarding levies or taxes on electricity stored in LSBs. The latest changes to EEG 2017 and the EU directive 2019/944 abolished the double charging of levies. However, the unclear status of exemptions from levies and taxes affects the operation of LSBs and, by extension, their business case. According to the latest policy developments in Germany, the EEG levies will likely disappear completely by 1 July 2022. Ideally, simplified regulations would enable more widespread utilisation of battery storage applications in data centres.

2.4 Optimising server utilisation

Another measure that can significantly contribute to a data centre's flexibilisation is optimising the utilisation of servers. A suitable management software can help to determine the average utilisation of servers. When utilisation is very low, a large part of the installed computing power remains unused, while power continues to be consumed in idle mode.[42] The actual energy consumption should be proportional to the actual utilisation rate of a server (known as energy proportional computing). A guideline published by dena on energy-efficient data centres notes that there is no generally recognised procedure for determining the energy efficiency of servers, i.e. the computing power per watt. However, the SPECpower_ssj2008 V1.11 benchmark from the American Standard Performance Evaluation Corporation (SPEC) already makes differences in efficiency clear. The application of the SPEC test shows that servers at the middle performance level offer the most favourable ratio between computing power and energy consumption.

While servers are usually configured for maximum performance, more dynamic configurations exist that can trade performance for greater energy efficiency and ultimately contribute to adjusting a data centre's power consumption.[43] Dynamic Voltage and Frequency Scaling (DVFS) can enable servers to process workloads with a minimum of required power. This technology is particularly important for data centres that seek to reduce energy consumption while increasing flexibility.[44]

Virtualising servers can also help group multiple workloads running on several servers onto one server at times of low utilisation, effectively reducing the servers in operation. As every server has a baseload energy consumption for the components in idle mode, reducing the number of active servers can significantly reduce the energy consumption of a data centre.

2.5 Policy recommendations—Germany

Data centre operators view participation in demand response programmes as difficult. Despite the many available load shifting techniques, it remains challenging for data centre operators to optimise their participation in demand response.[45]

In several interviews, data centre experts noted that an important prerequisite to demand-side participation is transparency and information sharing between grid and data centre operators since data centres would need to base any load adjustments on reliable information on grid needs to confidently schedule these adjustments in advance. Policymakers and grid officials must work with demand-side management actors to develop policies and information platforms to enforce this transparency.

Demand-side management in Germany mainly takes the form of interruptible loads contracted directly by the transmission system operators (TSOs) with large, energy-intensive consumers.[46] However, smaller data centres can also play a significant role in DSM by offering their flexibility potential through virtual power plants (VPPs). Through a load control agreement, a smaller data centre could transfer the right to manage the electricity consumption of one of its electrical devices to the distribution system operator (DSO) for a limited time. Currently, the German grid code requires a minimum capacity of 5 MW for minute reserve and 1 MW for primary control. In exchange for providing such a service, the data centre could receive a discount on the network tariff charged by the DSO.[47] Nevertheless, data centre operators might consider such arrangements too risky for operational reliability.

System operators could also offer priority grid connections to data centres on the condition that they provide a certain amount of flexibility to the grid, whether generation, demand response, or storage.[48] Many data centre operators could find this incentive compelling, given their desire to obtain a quick grid connection, especially in regions with more grid congestion. However, there is still much debate on this issue, as such a flexibility connection in the hands of the system operator might inhibit the incentive for participation in wholesale power markets and lead to discriminatory treatment of other data centres applying for a connection.[49]

Time-of-use tariffs, which better reflect actual wholesale power prices, might incentivise data centres to shift their consumption to cheaper and less constrained periods. In any case, the power market should assume a central role in communicating these incentives for additional flexibilities to data centres, as also mentioned in the study validation workshops.

2.6 Policy recommendations—China

Although time-of-use prices exist for industrial loads in China, the interviewees note that the power sector presently puts a premium on stable loads, effectively disincentivising flexibility and worsening the problem of system peak loads. Given the recent rapid growth of peak loads in most Chinese provinces, policymakers should identify and eliminate preferential treatment for stable loads and enhance policies aimed at load flexibility. Recent time-of-use power price reforms aimed at increasing the peak-valley price differential can help, but further steps will likely be needed to ensure that other incentives do not work against load flexibility.

As in Germany, information transparency is a critical missing piece of demand-side participation in power markets and contributing to meeting grid needs. Real-time information on spot power prices, including both intraday and day-ahead prices, is a prerequisite to the functional participation of the demand side. Beyond this, given that data centre operators do not consider electricity as a core business, data centre operators likely need access to aggregation services, such as VPPs, as well as industry data platforms to share best practices on power market participation. Data centre customers also lack information on the renewable uptake of data centre operators beyond what the operators themselves choose to provide. Industry information platforms could help bridge this gap.

Current Chinese policy favours the development of data centres in remote regions with surplus power and cooler climates, which provides obvious benefits for efficiency and renewable integration. However, the lack of bandwidth and transmission in remote regions hinders this process and reduces the potential of data centres to engage in geographical shifting of data loads to absorb excess energy supplies in one region or reduce peak loads in another. Energy and IT policymakers should work together to craft a joint policy to encourage the flexible utilisation of the data and transmission infrastructure.

Given data centre operator reluctance, it may be necessary to introduce pilot projects and quotas for peak load shifting to demonstrate feasibility, such as during a handful of super peak days in the summer months. During periods of regional electricity shortages when the government orders power cuts to industry, participation in load shifting could enable data centres to improve their priority for reliable power under Orderly Electricity Consumption policies. If geographical load shifting could reduce the scope of a summer power outage in a single province, that would visibly demonstrate the potential for data centre demand-side flexibility.

3 Energy efficiency and flexibility measures: waste heat recovery and cooling loads

Given the importance of cooling loads in data centres, cooling and heat recovery technologies as well as supporting regulations that incentivise energy savingsin data centres are particularly important. Cooling and air-conditioning typically account for more than half of data centre infrastructure energy consumption. Improving waste heat recovery and cooling loads can contribute to increasing energy efficiency as well as to the provision of flexible loads.

A recent dena report on energy-efficient data centres identified several ways of adjusting their power consumption of heating, ventilation and air conditioning (HVAC) systems.[50] Among them are the consideration of alternative cooling concepts and the intelligent adaptation of temperatures. Such changes would allow the HVAC system to act as a flexible load, effectively addressing the grid's needs without affecting IT loads or data reliability.

The academic literature contains examples and best practices on data centre HVAC flexibility and waste heat recovery. A 2015 paper by Tran et al. looked at ways HVAC control systems and standby motor energy management could provide grid services.[51] The study did not establish a thermal model of the server room, nor did it consider that the temperature inside the data centre server room changes on a time-by-time basis rather than instantaneously. HVAC loads depend on factors such as the size of the server room space, ventilation, external temperature and humidity.

These concerns were addressed in a 2016 study by Cupelli et al. using a detailed thermal model of the server room and a dynamic thermal load model.[52] The study showed how HVAC control and backup diesel generators could achieve load shifting for frequency reserve and how using liquid cooling systems in data centres could minimise energy use and reduce carbon emissions. In this case, a 3.5 MW data centre could save over 1,020,000 euros. Another study conducted by Liu et al. showed how liquid cooling systems can enable greater flexibility and substantially increase the proportion of energy obtained from renewable energy sources while still meeting service-level agreements.[53]

3.1 Data centre waste heat utilisation

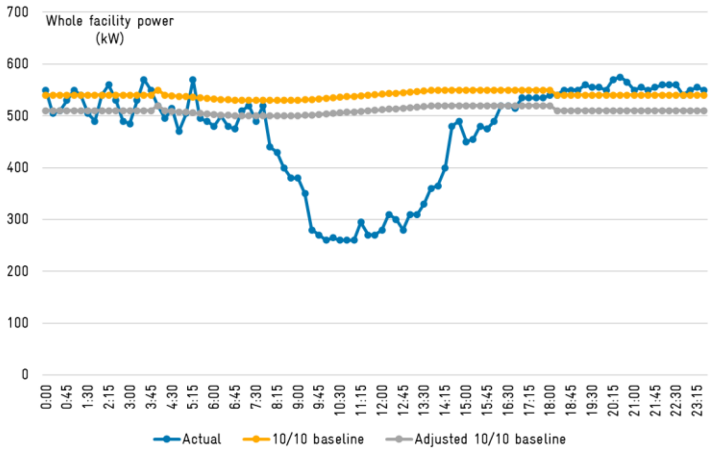
Data centre waste heat recovery has been studied in various scenarios and scales. Qi and Ji (2016) showed that low-temperature waste heat from data centres could be used to preheat feedwater for power plants, saving fuel in power plants and increasing power plant efficiency by 2.2%.[54] Zhi et al. (2013) showed that the payback period for retrofitting a 10 MW data centre with a waste heat recovery system could be as low as 4–5 months.[55]

Waste heat can also enable absorption chillers to absorb and cool waste heat from IT equipment and then return the cooled air to the server room if the waste heat can be tapped at temperatures above 60 °C. A 2020 paper by Gao et al. evaluates the energy efficiency and waste heat capture potential of real data centres in Finland, showing that about 97% of the electricity consumption could be recaptured as waste heat.[56] 1 MW of waste heat from a data centre can satisfy the thermal demand of more than 30,000 m^2 of non-residential buildings per year. In 2012, Aikema et al. studied a case of a data centre supplying waste heat to a spa in northern Finland and showed that waste heat from a data centre could satisfy 60,000 m^2 of heat load. Davies, Maidment and Tozer showed how data centre waste heat could replace gas heating in an urban district heating system in London.[57]

3.2 Optimising the cooling system

Cooling loads account for the vast majority of data centre infrastructure energy consumption. Cooling loads depend primarily on the IT load rather than on the outside temperature. Even in cases where shifting IT loads might not be entirely feasible—for the reasons discussed in the previous chapter—cooling loads have time shifting potential. A 2012 study at LBNL showed this in practice: the temperature set point was adjusted upwards for certain hours of the day when electricity prices were high (see Figure 5). Since cooling systems are more efficient at lower ambient air temperatures, pre-cooling can help save energy, even without more sophisticated thermal energy storage.

Figure 5: Baseline analysis during server and computer room air conditioning partial shutdown[58]



Furthermore, introducing adjustments to the data centre's cooling system can positively impact power consumption. Having the lowest possible heat accumulation in a data centre is mainly dependent on energy-efficient IT hardware and how well the building is insulated. The lower the temperature to which a data centre is cooled, the higher the technical effort and power consumption. Therefore, it is advisable to confirm which temperature is necessary for each data centre and, if possible, operate the data centre at the maximum temperature permitted by the manufacturer.

3.3 Germany interview results and policy recommendations

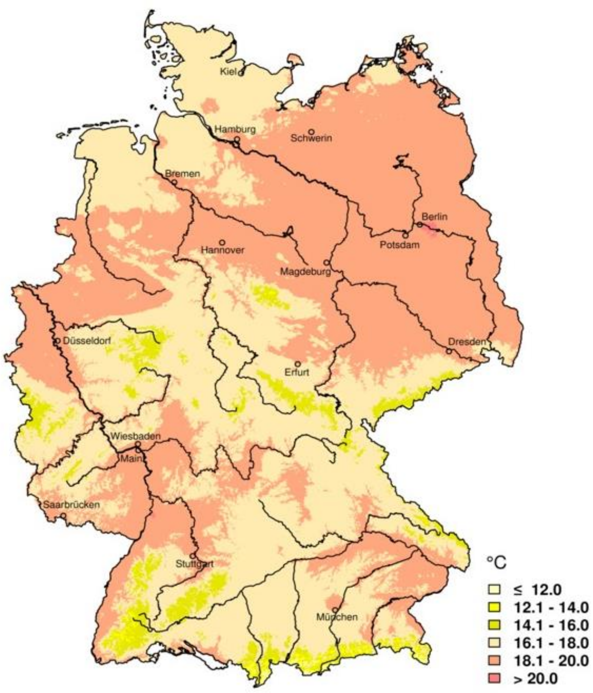


Figure 6: Summer temperature differences in Germany[59]

In Germany, the cities with the highest density of data centres are Frankfurt, Berlin, Munich, Hamburg and Düsseldorf. The relatively high summer temperatures (see Figure 6) in these locations speak for utilising the flexibility provided by cooling loads.

Waste heat produced by data centres is a particularly sustainable solution and, if utilised properly, can contribute significantly to the decarbonisation of the heating sector. While there are already some examples of successful waste heat utilisation (such as for heating buildings) in some German data centres, this solution is not yet widely applied for various reasons. The high electricity costs for operating the necessary heat pumps (namely powering the heat pump to bring the heat up to a suitable temperature) are subject to the EEG levy, making such a business model unprofitable. A further reason is the lack of interested customers for using the waste heat of data centres.

> Quote 18 – Germany data centre researcher: "Combining computing power and using the waste power to heat buildings sounds promising. So far, its application isn't profitable, as the electricity needed to power the heat pumps is too expensive due to the EEG apportionment."

> Quote 19 – Germany data centre expert: "There is no specific regulatory framework for waste heat utilisation. Every community can apply it as they wish, as can every energy producer. Energy providers or communities show no particular interest in taking on the waste heat from data centres. There is, however, some movement."

According to one interviewee, the German region of Baden-Württemberg offers an interesting case in which the region's 100 largest communities and towns of the region are carrying out an extensive planning of their heating networks and identifypossiblenew heat sources, including data centre waste heat. With The introduction of an incentive programme, the utilisation of data centre waste heat has been significantly promoted. An interviewee suggested that such a concept would be especially suited to cities such as Berlin that lack alternative industries to provide waste heat.

> Quote 20 – Germany data centre expert: "Such concepts would make sense, especially in areas with a large number of data centres, like Frankfurt am Main, but also Düsseldorf and Berlin. Even though the number of data centres is incomparable between Berlin and Frankfurt, Berlin does not have any heavy industry. For example, in the area around Düsseldorf, it could be argued that it makes a lot more sense to utilise the waste heat from steel plants. In cities such as Berlin, it is indeed worthwhile to utilise data centre waste heat."

Quote 21 – Germany data centre operator: "Although the waste heat from data centres is of low grade, it can be used for heating. In the concept we developed called 'Gebäudebeheizung mit Serverabwärme (Reuse waste heat from data centre servers for heating in buildings)', we already use the waste heat from servers without transformation to heat the nearby office space. The waste heat from data centres could supply the local district heating grid and has potential as an energy resource."

Having the proper legal framework and incentive mechanisms in place is key to increasing the use of waste heat from data centres. At the European level, the recast *Renewable Energy Directive* significantly promotes enhanced utilisation of waste heat.[60] Further documents with provisions on waste heat utilisation are the *EU's Digital Strategy* as well as the *Code of Conduct for Data Centres' Energy Efficiency*. Adapting these goals and provisions into German legislation could prove very helpful for domestic data centres already applying or planning to apply waste heat utilisation. In the German context, the following steps could accelerate waste heat utilisation:

- The Wärmenetze 4.0 programme (Heating Networks 4.0) is a key funding programme promoting innovative heating network systems with a predominant share of renewable energies and waste heat. This programme should be expanded to consider and evaluate the economic and energy-saving potential of new waste heat technologies. Currently, the programme mainly addresses municipalities and municipal companies. Making non-public providers eligible for funding could also provide the necessary financial incentives for data centres to invest in such technologies.[61]
- The upcoming amendments to the German Combined Heat and Power Act (KWKG) could lead to the funding system being further adjusted to offer long-term support for new heating networks or the optimisation and expansion of existing heating networks to use the waste heat potential of data centres effectively.[62]
- The electricity used by heat pumps should not be subject to high grid charges, and the EEG levy should be reduced accordingly. The levies have already been reduced as of 1 January 2022 and will likely be abandoned by 1 July 2022.
- Considering the impending phase-out of fossil-based heat sources, waste heat is an important source for covering heat demand. In cases where heat is produced as a by-product—as is the case with data centres—it should be mandatory to feed this heat into the heating networks, provided that the necessary infrastructure is in place. A *connection and use* obligation requiring the heat network operators to accept waste heat from data centres could also be established.[63]

For cooling processes, many data centre operators are implementing or have implemented free cooling for times of low ambient temperatures. Free cooling does not require the operation of a chiller to achieve the required cooling duties. Free cooling can be realised:

i. either as air to air cooling by using a rotating heat exchanger that transfers the heat from inside the data centre to the outside air. This is often referred to as "Kyoto cooling".[64]

i. or through a water circuit that transfers the waste heat from the servers via the cooling loop to an air heat exchanger that releases the heat to the atmosphere. This heat exchanger can be a dry heat exchanger, a wetted heat exchanger (adiabatic) or a wet cooling tower.

Free cooling requires the temperature of the heat stream being released into the environment to be higher than the outside temperature. Small temperature differences require large heat exchange areas or the support of water evaporation. Therefore, even if free cooling is applied, a chiller is typically available as a backup to ensure heat removal even at high outside temperatures. Alternative cooling concepts, such as direct water cooling, enable waste temperature to always be above ambient temperature. This, in turn, enables the utilisation of the waste heat in other processes or the provision of sanitary hot water or the use of free cooling year-round.

Quote 22 – Data centre researcher: "The use of water cooling should be required as standard use as it can be transported easily into the environment, or the waste heat can be used. The backup power can be provided by a Combined Heat and Power plant (which can be powered by hydrogen, for example), which could also provide the cooling load.

Quote 23 – Data centre researcher: "Automated management could be very efficient. For example, when negative control power is needed, cooling could simply be reduced so that the servers consume more energy."

An example where both the waste heat utilisation and the cooling processes are integrated is provided below:[65]

ADSORPTION COOLING SYSTEM

The LRZ data centre in Munich is among the data centres that have implemented innovative efficiency measures, specifically an adsorption cooling system. The FAHRENHEIT adsorption system converts the waste heat from the HPC data centre computer into cooling energy for the cooling system. An adsorption chiller cools water, which is in turn used to air-condition rooms or to cool servers, among others.

As a result, the data centre has reported a significant reduction in electricity costs whilst saving energy and reducing CO_2 emissions. The FAHRENHEIT adsorption cooling system with a performance cooling capacity of 600 kW is currently one of the largest in Europe.

The investments needed for increasing the energy efficiency of data centres can be boosted using a power usage effectiveness (PUE) indicator to calculate the effectiveness of individual data centres. On behalf of the German Environment Agency, the Institute of Energy Economics and Rational Energy Use (IER) of the University of Stuttgart is currently working on developing a register for data centres as well as a rating system (www.peer-dc.de). This type of indicator increases transparency for companies when choosing a data centre and might, in turn, incentivise data centre operators to make such investments.

Cooling and waste heat utilisation offer immense potential for reducing the energy use of data centres. Recommendations to accelerate energy efficiency improvements in data centres may be found below:

- Adopting these solutions at the level of local heating grids is a first step. Existing heating networks will need to be further expanded, and the available waste heat from data centres should be carefully considered when planning the heating networks.
- In general, implementing small scale solutions and pilot projects promoting innovative cooling and waste heat utilisation concepts at the local level—in municipalities or certain regions—can prove easier for a wider deployment of these concepts than a top-down approach.
- Implementing mandatory requirements for efficient data centre operations can lead to a behavioural change of these enterprises, as mentioned in the study validation workshops. Electricity cost savings might offer inadequate motivation for data centres to implement these efficiency improvements, and mandatory requirements may be a better solution. Including the data centre industry in its own category of high-emissions and/or high energy intensity industries is a measure the Chinese government has already implemented (see Chapter 1.2). This would result in strict quotas for the energy efficiency and consumption of data centres.
- As mentioned in the previous chapter, having a mediating actor—in the case of energy efficiency improvements, an energy services company (ESCO)—that concentrates on providing integrated solutions can also increase the quantity of energy-saving measures implemented.

3.4 China interview results and potential

Given China's large land area and varied climate zones, heating and cooling have an immense potential to contribute to both improved efficiency and greater renewable energy uptake in China. Encouraging the relocation of data centres to remote regions, such as Inner Mongolia and Guizhou, can already help integrate these loads with renewable energy sources in these regions while reducing the overall cooling load due to their climate characteristics.

Daily temperature variability is a major consideration for the time shifting of cooling loads. In the summer, the temperatures in China's northern regions are much more variable.

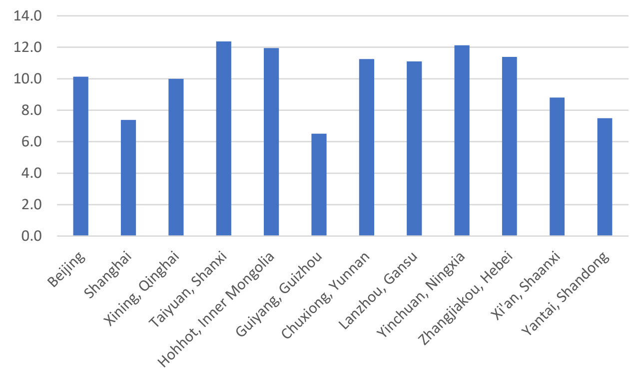


Figure 7: Average annual daily temperature difference (°C)[66]

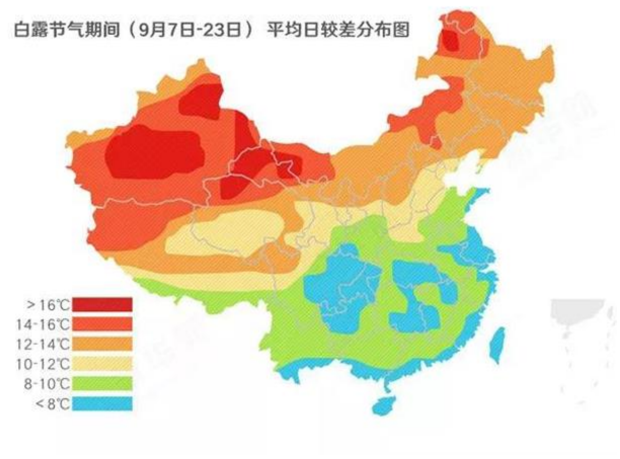


Figure 8: Summer temperature differences in China[67]

Diurnal temperature differences across major Chinese cities are somewhat more constant, varying between 7-10 degrees daily, with a standard deviation between 3-4 degrees. Most northern cities show a daily average temperature swing around 10 degrees, but some southern regions, such as Yunnan, also show a 10-degree swing. This could increase the potential for thermal energy storage or cooling load shifting in these regions.

Chinese data centre experts recognise the potential for waste heat recovery and modulating cooling loads, both as an energy efficiency measure and for flexibility.

Quote 24 – Data centre professional: "The location of data centres is an important determining factor for waste heat recovery. Data centres in northern China and with water cooling towers are suitable for providing waste heat for heating and cooling."

However, there remain many barriers to improving waste heat utilisation or cooling flexibility. The most common issue is the need to integrate energy across multiple users and to provide greater policy guidance. Data centres are often located in industrial parks, but industrial parks may lack the incentive to recover waste heat or to modulate cooling loads to improve the integration of renewable energy. On the contrary, industrial parks may have the incentive to encourage industries to flatten their loads.

Quote 25 – Data centre professional: "In order to accommodate waste heat utilisation needs, advanced planning is needed to support comprehensive industrial park policy and zoning policy."

3.5 China policy recommendations

Optimising cooling loads in China offers significant potential to both increase energy efficiency and boost flexibility, but taking advantage of this potential will require significant policy support to overcome the barriers described above.

Regional and national policymakers can do more to encourage data centre integration with local heating networks for the utilisation of waste heat, particularly in cold climates. In suitable climates, administrative targets may be appropriate for encouraging such planning. Given the low price of heat in many regions and the focus of data centres on their core business of providing reliable data services, it is unlikely that market incentives will suffice to incentivise waste heat recovery, even in regions where it is attractive.

Information platforms aimed at linking data centres with data customers can also boost the incentives for data centres to either utilise waste heat or use cooling more efficiently. Interviews have shown that PUE is an insufficient metric for enabling users or policy officials to evaluate the overall energy performance of data centres. Providing additional measures and mandating their disclosure—at least to energy planners and data customers—would incentivise best practices in both the investment and operational phases of the data centre industry.

As discussed in an earlier chapter, energy service companies and virtual power plants should play a larger role in energy management at data centres. Aggregators are needed to mediate between data centre operators and the grid, but also to optimise data centre loads based on power prices, renewable energy availability and outside temperatures. This will require greater information sharing between grid companies, aggregators and data centres—not only regarding power prices and load forecasting but also regarding forecasting and prioritising different data loads to enable time-shifted and geographically shifted loads for optimising cooling based on the weather and grid conditions.

4 Enhancing participation in ancillary services and spot markets

Developing the ability to shift workloads in real time would allow data centres to provide ancillary services such as peak shaving and frequency control. This ability is also a prerequisite for efficient use of their control power. When positive control power is needed, some tasks can be interrupted and continued later. And when negative control power is necessary, additional tasks can be added to the workload. Data centres could offer their flexibility on the secondary control energy markets and would then be bound to adapt their load in the event of an activation. To provide these services, data centres require higher levels of automation and flexibility.

4.1 Policy options—Germany

The European Power Exchange (EPEX) is one of the main wholesale markets for trading electricity in Germany. The European power exchange has different power product classifications depending on the delivery period of each power product. Short-term traded electricity quantities are either sold one day in advance—i.e. one day before the physical delivery of the electricity from the producer or trader to the buyer—or on the day of the physical delivery of the electricity itself in intraday trading.[68] To trade on the EPEX, market participants have to be able to trade at least 100 kW.[69] High revenues are expected in this flexibility market, especially when a data centre employs a combination of DVFS (dynamic voltage and frequency scaling) with load shifting.

To balance the feed-in and withdrawal of electricity from the power grid, TSOs use three different control energy products:

- Primary control energy or frequency containment reserve (FCR);
- Secondary control energy or Frequency Restoration Reserve with automatic activation (aFRR);
- Tertiary control energy or Frequency Restoration Reserve with manual activation (mFRR).[70]

One of the data centre interviewees reported participating in the primary frequency response market using the battery storage capacity installed in the data centre. Secondary control energy is also an attractive option, according to the interviewees. Negative balancing power is likely the most prominent application, as the battery installed in the data centre could be charged at times of high generation and discharged at times of high demand.

Secondary control energy needs to be made fully available within 5 minutes after activation and provided for up to 15 minutes—a requirement that most data centres can meet. The auctions are separated into six blocks of four hours per day and divided into positive and negative control energy.[71] However, the prequalification process is complex, and the minimum bid size is currently 5 MW, a limit that most German data centres cannot reach. Nevertheless, an aggregator could integrate these smaller data centres into a virtual power plant and facilitate their participation in the power market.[72]

The interviewees mentioned two relatively straightforward ways to help data centres integrate their operations into the ancillary services market.

In-depth discussions and cooperation—initiated by the regulator and grid operators—could assist data centres in understanding the potential of an additional revenue stream and expand their understanding of how the various ancillary services operate.[73] Accordingly, such cooperation could assist grid operators with understanding the load profile of different data centres, how to make the best use of their flexibility and how to more effectively integrate them into the grid. As a result, grid and data centre operators could launch joint activities—such as pilot projects, gap and potential analyses—to identify possible synergies and common solutions.

As already mentioned, the main business of data centres is to provide data centre services to customers, not to participate in the electricity market. An energy aggregator could act as an intermediary and operate these services, thereby avoiding burdening data centre operators with additional complexity while minimising risks.

ENERA FLEXIBILITY PLATFORM

Local flexibility markets are key to solving congestion in both transmission and distribution grids, as they enable the participation of decentralised consumers, such as data centres, in the energy market, making full use of their flexibility potential.

An example of an advanced flexibility market is the "enera" project in Germany, which is part of the Smart Energy Showcase—Digital Agenda for the Energy Transition (SINTEG) programme initiated in 2017 by the German Federal Ministry for Economic Affairs and Climate Action. TSOs and DSOs created a common flexibility market and traded capacity in that specific market to balance overloads at the different voltage levels. The system operators shared their grid capacities in real time and could offer available and unused capacities in case they were needed. The results of this project show how the participation of local users and providers of electricity, such as data centres, can be enhanced.

4.2 Policy options—China

In recent years, China has introduced several guidelines for demand-side management and grid-connected microgrid operation to incentivise flexible demand-side resources to actively participate in the future power system. These guidelines provide a nurturing environment for the formation of new power system dynamics and market players. However, for the time being, there are no relevant policies that explicitly mention the potential of data centres for the optimisation of the power system.

Even so, the recent policies introduced one after the other give the impression that the central and local governments at every level are starting to pay attention to new ideas and technologies that can provide demand-side flexibility. This chapter focuses on policies related to promoting data centre participation in the electricity market at the national and regional levels in recent years:

In February 2018, the National Development and Reform Commission and the National Energy Administration jointly issued the Guidance on Enhancing the Regulation Capability of Electric Power Systems, which pointed out that energy storage equipment, demand-side resources and third parties are encouraged to participate and provide electricity ancillary services.[74] In November 2019, the North China Energy Regulatory Bureau issued the draft Pilot Program for Third Party Independent Subjects to participate in the North China Electricity Peaking Ancillary Services Market.[75] This programme calls for an extension of participation in electricity ancillary services to energy storage devices, electric vehicles, electric heating, virtual power plants and other flexible control devices.

In April 2020, the Department of Industry and Information Technology of Fujian Province and three other departments jointly issued the Notice on the Registration of Electricity Market for Large Data Centre Enterprises, which addresses the registration of large data centre enterprises in the electricity market. This document includes supercomputing centres and data centre companies in Fujian above a certain size.[76]

China is clearly working to establish a vibrant ancillary services market open to demand-side participants and to encourage the participation of VPPs. As we have noted previously, establishing a functioning ancillary services market open to demand-side players and aggregation is likely just one way to encourage data centre participation. Given the absolute priority attached to reliable data services, it will likely be necessary to begin with demonstration projects for data centres that result in published best practices and their contribution to both stabilising the grid as well as boosting revenue for data centres participating in such pilots. Without such examples, we believe data centres are unlikely to participate actively in the ancillary services market.

5 Promoting the use of renewable energy

Many global players providing digital infrastructure are procuring renewable energy to reduce the environmental footprint of their energy-intensive data centres and to establish an environmentally-friendly corporate image. They have a variety of choices, including building their own wind farms and photovoltaic power plants, purchasing green energy power certificates and signing green power purchase agreements. Matching power consumption to renewable output is an increasingly important challenge, and some companies are responding with innovative strategies for 24/7 renewable procurement.

5.1 Pathways for an increased uptake of renewable energy

Several global IT giants in the U.S. and Europe have established net-zero targets and started purchasing renewable energy to power their operations. In order to match the data centre's power consumption to the renewable energy output 24/7, major IT companies have pioneered new methods for purchasing green energy and are among the leading participants in voluntary green energy markets.[77]

The academic literature includes a number of studies that illustrate how data centres can increase uptake of renewable energy. A 2013 study by Chen et al. investigated power dispatch for variable renewable generation to minimise the purchase of power from the grid by installing PV on data centre rooftops.[78] Nguyen et al. investigated scheduling schemes for integrating renewable energy sources in data centres and suggested the dynamic modelling of data centre energy consumption to improve energy use efficiency in data centres.[79] Time shifting of workloads in data centres can enable higher utilisation of renewable energy.[80] In a 2016 study, Shi et al. analysed the temporal and spatial complementarity of data centre workloads with renewable energy sources, proposing a predictive algorithm to guide data centre load allocation.[81]

5.2 Data centres and renewable energy in Germany

There are different ways for data centres to purchase renewable energy:

- purchase power directly from a plant operator within the framework of a Power Purchase Agreement (PPA);
- purchase green power from an electricity supplier;
- operate their own renewable energy power plants.[82]

Interviews with German data centre experts showed that many data centres in Germany purchase renewable electricity to power their operations. Most perceived the switch to renewable power positively.

Regarding the previously listed three ways to procure renewable energy, there is considerable debate about the path forward. According to a roadmap on sustainable German data centres, green electricity certificates are not really expected to significantly contribute to CO_2 reductions,[83] at least not at the current stage of discussions surrounding these certificates. Therefore, the study recommends that data centres procure green electricity via PPAs with renewable energy plants.[84] However, a study by Eco Association on data centres in Europe states that PPAs have been used to a limited extent in Germany, which can mainly be attributed to the existence of a support regime that does not incentivise the use of PPAs.[85] It remains to be seen whether PPAs will be used more in the future.

Data centres have also installed solar or wind plants on their premises and purchased the electricity directly. While there might be some economic benefits for data centres to purchase their own electricity, it is typically not enough to power the data centre alone. Furthermore, it should be done flexibly to accommodate the grid's balancing needs.

> Quote 26 – Data centre researcher: "From a sustainability perspective, the addition of data centre based flexibility will actually help integrate renewables into the electricity grid. This ecological aspect may help a data centre stand out from its competitors."

> Quote 27 – Data centre researcher: "Decoupling from the grid seems to be an attractive option as well; it would make autonomous operation, without any grid connection, possible in the future. Domestic production can reduce energy demand from the grid. Photovoltaic generation correlates well with the additional cooling load during the summer. PPAs are an easy opportunity to enable renewable data centre operations."

WINDCORES

An innovative example of an all-round successful RE deployment in data centres are the colocation data centres of "Windcores." By using existing wind turbines as data centre buildings, the supply of the data centre with clean electricity takes place directly on site. This provides the data centres with sustainably generated electricity, but also prevents the unecessary shutdown of wind turbines.

The data centres are particularly suitable for high-performance computing applications and the individual locations are directly connected to the data centre node DE-CIX in Frankfurt. The existing network and data connections are another benefit which comes with using this infrastructure. In the event where power is not provided by the wind turbine's generator, two additional transmission lines can ensure the data centre's power supply. Due to the large number of buildings already available, windCORES allows for a fast commissioning of new data centres.

5.3 Data centres and renewable energy in China

Only a few IT companies in China have announced net-zero targets: Chindata and AtHub were among the first to do so.[86] According to a 2021 annual report from Greenpeace East Asia on major Chinese data centre companies that report renewable energy utilisation, the average fraction of renewables in consumption was just 3%. Only Baidu broke into the double digits with 51%.[87] Though renewable energy procurement by Chinese Internet cloud service companies has increased since 2018, most have not made net-zero commitments or plans and lack energy disclosure relative to international players.

Despite this discouraging result, there is a greater trend among those in the Chinese data centre industry that recognise the future importance of integrating data centres and renewables. This integration is sometimes included as an element of the Energy Internet concept, or multi-energy complementarity, which includes integrating renewable energy with storage and loads. The Chinese consultancy firm Guanyin World concluded that the future of data centres, especially cloud computing, is closely related to the development of the Energy Internet, noting that the physical infrastructure of the Internet has synergies with that of the power sector—such as with the locations of power lines and Internet cabling, transmission towers and 5G Internet communication towers, and so on.[88]

In 2016, China's National Development and Reform Commission (NDRC), National Energy Administration (NEA) and the Ministry of Industry and Information Technology (MIIT) jointly issued a policy promoting "Internet Plus and Smart Energy Development" discussing the integration of the Internet and energy production, transmission, storage, consumption and energy markets. The policy establishes a national data centre to support such integration and share information with market participants.[89]

Multi-station convergence refers to integrating data centres, power plants, substations, energy storage, and communications infrastructure. In 2020, the Information and Communication Technology Industry Group of State Grid Corporation, the country's largest power grid corporation, announced plans to establish national multi-station convergence infrastructure, upgrading traditional substations into data centre stations, 5G base stations, and repeater stations, particularly in densely-populated areas with land-use restrictions.[90]

Local governments have also been active in integrating data centres with energy infrastructure, including renewables. In 2020, Qingdao announced a demonstration park that would integrate clean energy and data centres as a revival strategy for the city.[91] Qinhuai Data Group in Datong, Shanxi province, is another regional example of integrating data centres with renewables, particularly local wind and PV, taking advantage of the newly built circular transmission line to connect to renewable energy sources across the Jing-Jin-Ji (Beijing, Tianjin, Hebei) region.[92]

5.4 Policy recommendations—China

China has already begun to promote the uptake of renewable energy in data centres by adopting overarching supportive policies as well as through specific demonstration projects, such as in Datong and Qingdao. However, these developments are at an early stage, and few IT companies have announced aggressive plans for renewable energy.

As with flexibility, waste heat utilisation, and cooling efficiency, our interviews suggest that information platforms can offer more incentive to encourage the uptake of renewable energy. Policymakers should encourage the industry to broaden its focus beyond PUE and towards greater renewable utilisation.

To avoid the risk of worsening the problem of integrating renewable energy into the grid, data centres should be encouraged to match their load with local renewable energy production with the direct procurement of renewable energy tied to the time of production rather than the gross annual output. Present green certificate markets do little to encourage time matching and should be adjusted accordingly.

Flexible operation goes hand-in-hand with the integration of renewable energy. Policymakers should pair incentives and administrative measures designed to increase renewable uptake with measures that enable full integration with the power markets, especially the ancillary services markets, with heating/cooling incentives, energy storage and data network optimisation. Mandating a certain percentage of renewable energy procurement or a certain share of energy storage could be a first step towards such integration.

6 Successful business models to enhance data centre system integration

Socomec—Energy management, flexible storage and UPS solutions

Socomec is a company that holds several patents for innovations in the UPS and metering fields, with data centre customers worldwide, including Germany and China.

A prerequisite for successfully performing load management is **accurate and detailed measurements**. 100% accuracy is not currently a given in many data centres due to cabling errors and the wrong sizing of current transformers (CT). The company's Digiware System minimises errors caused by registered jack (RJ) connections as well as errors in the assignment of current and voltage inputs. The product ensures very wide measurement ranges, which is the basis for accurate load management.

The practical implementation of load management is done with the help of **the Sunsys HES L and XXL storage systems, which are controlled by a management software** (EMS—Energy Management System). This energy management software is capable of managing peak shaving and enables a fast response time, operating with a 20-millisecond update rate. A relay output allows control of a load under a demand response contract. This energy management software can allow storage systems to perform data centre load management and smooth the load via peak shaving. In particular, energy storage systems can smooth power peaks in the summer when cooling loads often coincide with system loads. Overall, the storage systems coupled with the EMS enable more steady power consumption, which in turn improves grid stability.

These options make sense if data centres make their storage available to an aggregator in a further step. They can also use the EMS to determine the time periods and the available power for a demand response contract and then define its scope together with the aggregator. Making this storage system available to an aggregator may contribute to absorbing a high wind or solar output throughout the year and recharging the lithium batteries. In winter, the battery system can, in turn, be very profitable for the data centre operator by making energy available to an aggregator for a specific period of time and supplying the required power when grid demand is high. This provides two benefits:

- A stability lever for the grid operator, as the data centre's consumption is smoothed out and fluctuations in the grid are easier to manage
- Additional profit for the data, thus a shorter investment payback period

Additionally, the company focuses on the **adaptation and flexibilisation of UPS systems**. Compared to standard UPS systems, *Flex UPS systems* can interrupt their own consumption at times when the data centre's energy consumption is strained, thus optimising the data centre's load curves. Part of the consumption of the UPS systems will be covered by the power of the batteries, which must be sized appropriately. If each UPS can deliver 100 kW, 10 UPS systems in a data centre quickly bring the total to 1 MW. Nevertheless, the primary function of the UPS as an uninterrupted power supply remains a priority.

Chindata Group—geared towards system integration and carbon neutrality

Founded in 2015 and headquartered in China, Chindata is a hyperscale data centre solution provider focusing on the Asia Pacific emerging markets and operating data centres in Malaysia, China, and India. Chindata provides a whole life cycle solution for data centres, such as facility planning, location selection, design, construction and operation. Chindata also invests in green power and smart energy utilisation.

Zero carbon emissions is a core principle for ChinData, and their leading customers also mandate it. In 2020, up to 51% of the energy consumption of Chindata's hyperscale data centres in China was covered by renewable energy. The company's goal is to achieve carbon neutrality for all the group's data centres in India, Malaysia, China and other emerging markets by 2040.

When choosing a location for their data centres, Chindata focuses not only on aspects related to data but also on the availability of renewable energy and power grid infrastructure. However, one of the existing challenges when choosing a location remains that remote areas with abundant renewable energy often lack the necessary network infrastructure.

Chindata is currently investing in the construction of the world's first **super energy complex** in China—a zero-carbon digital infrastructure industry cluster that will connect the high-performance computing data centres with various sectors, such as renewable energy storage, snow sports in the cities, cold chain logistics, cooling supply, the agricultural industry and the municipal heating system.[93] The data centre can also feed power into the grid when renewables are unavailable and balance the power system in the region. The project, located in Shanxi province, has received the government's permission and support and could become a leading example for successful power grid and data centre integration, especially in urban areas.

Customers focus on data centre PUE, which Chindata is improving through innovative measures. Chindata has patented technologies such as the **HUABC and building technologies,** which improve the data centres' PUE by 30% compared to the industry average. Furthermore, Chindata has developed a microgrid, increasing energy efficiency from 33% to 66.7%. This microgrid has been integrated into the power system.

Besides investing in renewable energy power stations, supporting energy storage facilities that can directly supply power to data centres is also crucial. Combined with a microgrid, these solutions can lead to the integration of generation, load, grid **and storage**. This enables the dynamic adjustment of a data centre's power consumption and can enhance the operation reliability of the power system.

7 Conclusions

As the heart of the digital economy and a rapidly growing electricity load, the global data centre industry has an essential role to play in achieving the world's shared goal of carbon neutrality. A review of the literature, policy documents, and industry best practices suggests that many techniques and strategies for improving efficiency, increasing flexibility and directly procuring renewable energy to power data centres exist.

Our interviews and workshops suggest that the data centre industry is making progress regarding energy efficiency but that the barriers to flexibility and renewable integration are too great to be overcome without significant policy support. Indeed, even in Germany, with its advanced electricity spot market without any price caps or floors and the possibility of negative electricity prices at certain periods of high wind and solar production, data centres still hesitate to apply certain flexibility solutions. Though some global IT giants have sought to purchase green energy via PPAs, this practice still remains the conventional energy provision in most data centres.

Through our workshops and interviews, we developed a general understanding of the ongoing discussions and challenges in the aforementioned areas. Industry experts emphasise that the importance of undisturbed data centre operations is non-negotiable; therefore, energy efficiency measures were evaluated more positively as there is not as much interference in data centre operations when such measures are implemented. As a quick-win flexibility measure, the time shifting of cooling loads is simpler and more widely feasible. However, researchers view the time shifting of IT loads as more effective and faster. The type and location of the data centre remain key in identifying the best solution.

In each chapter, we put forward specific recommendations for Germany and China. Some relate to enhancing existing market incentives through information sharing and new platforms for cooperation. Other recommendations entail administrative measures and new standards. All will require further discussion and tailoring to the unique circumstances of each country and each market segment of the data centre industry.

Indeed, one of the starkest findings of this study is that the data centre industry needs more research and cooperation on data loads and data centre types. While the distinction between different data centre operations may seem fairly clear to the typical user, privacy restrictions and rules favouring net neutrality may make it impossible for data centre operators to prioritise and shift data loads to enable greater flexibility or renewable uptake. Many data centre operators also do not see the business case in applying such solutions, as the risk of downtime and non-reliable operations is far too crucial to ignore. Then there is also a degree of technical difficulty in implementing such measures, followed by the question of who should take responsibility for implementing these measures. This can be a difficult task, especially in some types of data centres with different sets of actors. Some of these barriers may prove insurmountable, but others can easily be overcome with the right incentives and policy measures.

We believe that data centres can and must do more to make their full contribution to achieving carbon neutrality, but also that the data centre industry cannot do it alone. Policies, standards—whether in the form of best practice documents or academic work—and incentives are needed, some of which will require voluntary cooperation by industry players, and some of which will depend on sustained international coordination. The challenge is great but given rapidly growing data centre loads and the short timeline to achieve the world's climate goals, the need for data centre operators and policymakers to cooperate to ensure the industry has a path towards sustainability is urgent.

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