CENTRAL OFFICE 2030 – EFFEKTIVE, NACHHALTIGE UND RESILIENTE TELE-KOMMUNIKATIONSNETZE IM ENERGIESYSTEM

Qualitative Analysis of Central Offices Load Shifting Opportunities

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IMPRESSUM

KURZTITEL

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Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen

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ZITIERVORSCHLAG

Steinmetz, A., Mollaeivaneghi, S. & Steinke, F. (2024). Qualitative Analysis of Central Offices Load Shifting Opportunities. Berlin: CO 2030 Konsortium.

FÖRDERMITTELGEBER

Das Projekt CO 2030 wird vom Bundesministerium für Digitales und Verkehr (BMDV) sowie seinem Projektträger TÜV Rheinland Consulting GmbH gefördert.

Gefördert durch:

Bundesministerium für Digitales und Verkehr

aufgrund eines Beschlusses des Deutschen Bundestages

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ABBREVIATIONS

BNetzA	Bundesnetzagentur
CO	Central Office
DC	Direct Current
DSM	Demand-Side Management
DSO	Distribution System Operator
DR	Demand Response
DT	Deutsche Telekom
GHG	Greenhouse Gas
HVAC	Heating, Ventilation, and Air Conditioning
ICT	Information and Communication Technology
KPI	Key Performance Indicator
OPEX	Operational Expenditure
PUE	Power Usage Effectiveness
pPUE	Partial Power Usage Effectiveness
PV	Photovoltaic
SLA	Service Level Agreement
TSO	Transmission System Operator
UPS	Uninterruptible Power Supply

SUMMARY

Der vorliegende Bericht liefert eine qualitative Analyse der Möglichkeiten zur Lastverschiebung in den Central Offices (COs) der Deutschen Telekom. Der Schwerpunkt liegt dabei auf den Potenzialen der räumlichen und zeitlichen Flexibilität innerhalb dieser COs zur Steigerung der Energieeffizienz und Wirtschaftlichkeit. Es wird herausgearbeitet, dass die räumliche Lastverschiebung primär im IKT-System anwendbar ist, während die zeitliche Lastverschiebung sowohl im IKT- als auch im Energiesystem effektiv genutzt werden kann. Diese Strategien bieten nicht nur Potenziale zur Kostenreduktion durch effizientere Energienutzung, sondern eröffnen auch Möglichkeiten zur Generierung von Einnahmen. Die Umsetzung dieser Flexibilitätsmaßnahmen steht im Einklang mit den übergeordneten Zielen der CO2-Reduktion und trägt zu den Nachhaltigkeitszielen des IKT-Sektors bei. Abschließend wird empfohlen, dass sich zukünftige Forschung auf die Verfeinerung dieser Strategien und ihre Umsetzung in größerem Maßstab konzentriert, unter Berücksichtigung der Entwicklung der Energienachfrage und der zunehmenden Integration erneuerbarer Energiequellen.

1 Introduction

In the recent decade, there has been a significant rise in the demand for Information and Communication Technologies (ICT) services, such as video streaming, video conferencing, and artificial intelligence (AI). The United States' ICT sector experienced a noteworthy 11.5% increase in consumer electronics production in 2021, eclipsing the anticipated slower growth rate of 1.5% in 2022. This sector is expected to be among the fastest-growing in the manufacturing industry, driven by increasing trends in digitalization and industrial automation (Atradius, 2022). The ICT sector's energy consumption accounts for 5-9% of the global electricity usage, with an estimated annual growth rate of 6-9% (Enerdata, 2018). In Germany, the ICT sector's annual energy consumption reached 59.8 TWh in 2020, making up 12% of the country's total electricity usage, which was 474.9 TWh in the same year (Blume & Keith, 2023; Bundesnetzagentur, 2021).

The ICT sector's total energy consumption is divided into four main categories: servers and data centers, network access and core networks (including routers, switches, and transceivers), business devices (such as PCs, displays, printers), and consumer devices (like PCs, displays, and TVs) (Cremer et al., 2003).

Telecommunication networks are organized around Central Offices (COs) situated strategically near users. These COs serve as network nodes, managing the communication traffic flow throughout the network. The growing volume of internet traffic is expected to result in an increase in the energy consumption of these COs. Despite advancements in efficiency, telecommunication networks have traditionally prioritized capacity to maintain functionality during peak loads, leading to over-provisioning and redundancy, thereby causing excess energy consumption.

In light of the increasing focus on sustainability and decarbonization in society and politics, there is a pressing need to reduce and transform energy consumption across all sectors, including telecommunications within the ICT industry. The European Union's Green IT regulations highlight the necessity of significantly reducing CO2 emissions in various sectors, including ICT. The European Climate Law aims to decrease net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels, as part of a broader strategy to achieve climate neutrality by 2050 (Europian Commission, 2021). This goal involves reducing emissions, investing in green technologies, and preserving natural habitats.

GSMA Europe emphasizes the crucial role of the ICT industry in helping Europe attain its climate neutrality objectives by 2030. This involves not just improving energy efficiency but also incorporating sustainable supply chains and aiding decarbonization in other sectors (GSMA Europe, 2020). The mobile industry, under GSMA's guidance, is progressing towards net-zero carbon emissions by 2050, with numerous companies aligning their goals with the Paris Agreement and adopting environmentally friendly practices.

The European Commission, under the EU Green Deal, recognizes the ICT industry as an essential element of the circular economy, owing to its significant climate impact. The focus is on prolonging the lifespan of electronics and prioritizing recycling, particularly in data centers, which are major energy consumers in Europe (GSMA Europe, 2020).

Reducing energy consumption is not only environmentally crucial but also economically beneficial. Energy expenses constitute a significant portion of the operational expenditures (OPEX) for communication networks. Thus, minimizing energy consumption offers economic advantages for telecommunication network operators.

Apart from reducing energy usage, decreasing supply costs is another effective cost-reduction strategy. Adopting renewable energy sources like wind and solar power, which generally have lower marginal costs, can lead to reduced energy prices. However, their variable generation patterns may not always align with current demand. The paradigm has shifted from relying solely on generation capacities for grid stability to a combined approach where loads, through Demand Side Management (DSM), contribute to grid stability (Ragab et al., 2023). The telecommunication network, as a part of the ICT sector, is well-positioned to provide load flexibility in terms of time and space, assisting in integrating renewable energies and enhancing grid stability.

This report commences with an exploration of the economic aspects of flexibility in telecommunication networks. The objective is to analyze the potential for spatial and temporal flexibility in the pools of telecommunications central offices (COs) across Germany. The analysis leverages technical data from Deutsche Telekom (DT) and Power and Air Condition Solution Management GmbH (PASM) and includes extensive research to offer a comprehensive perspective on the opportunities and challenges in this domain.

Subsequent sections delve into the detailed characteristics and technological designs of telecom COs, focusing specifically on their power systems and consumption patterns. This is followed by an in-depth review of relevant literature on spatial and temporal load shifting, showcasing both existing practices and theoretical frameworks. The potential for demand shifting and flexibility within these COs is then assessed, exploring how such strategies can enhance operational efficiency and sustainability. The final chapter synthesizes key findings and presents insightful considerations for future research directions, underscoring the significance of energy management and flexibility in the evolving landscape of telecommunications networks.

2 Flexibility in the Evolving Energy Landscape

As Germany advances in its comprehensive energy transition, emphasizing the growing significance of variable renewable energy sources, the need for enhanced flexibility among energy system stakeholders becomes increasingly vital (Burger & Hanisch, 2023) . This chapter delves into the concept of grid-serving flexibility, defined as the capacity of an energy system, especially the electric grid, to adapt to fluctuations in energy supply and demand while ensuring operational stability. This capability is crucial for alleviating grid congestion and guaranteeing balanced energy distribution throughout the network (Kurmayer, 2022; Zhang et al., 2023).

Traditionally, grid-serving flexibility relied mainly on generation capacities. However, recent advancements and research have expanded this view, acknowledging the significant roles of loads and electric storage facilities in contributing to grid stability and reliability (Bundesnetzagentur, 2017). The Bundesnetzagentur (BNetzA) describes electricity system flexibility as "the ability to change electricity feed-in or consumption in response to an external signal, such as a price or activation signal, with the objective of delivering essential services to the energy system" (Bundesnetzagentur, 2017). This broad definition includes various strategies under Demand Side Management (DSM), which encompasses both simple load reduction and complex adjustments in electricity consumption patterns.

DSM involves strategies and programs to control energy consumption on the consumer side of the electric grid, aiming to encourage consumers to modify their usage, particularly during peak times, thus reducing overall energy consumption and the need for additional power generation (Bakare et al., 2023; Nasir et al., 2021). DSM activities include:

(1.) **Energy Efficiency Measures:** Implementing technology or practices that reduce the amount of energy required for the same service. This could include upgrading to more efficient appliances or improving building insulation.
(2.) **Demand Response (DR):** Encouraging consumers to reduce or shift their energy use during peak periods in response to time-based rates or other forms of financial incentives. For instance, reducing air conditioning use during peak afternoon hours when electricity demand is high (Kholerdi & Ghasemi-Marzbali, 2022).
(3.) **Load Shifting:** Moving energy use from peak to off-peak periods. This doesn't necessarily reduce total energy consumption but helps in balancing the load on the grid, which is particularly important when integrating renewable energy sources.
(4.) **Peak Load Reduction:** Strategies aimed at reducing the highest level of energy demand within a specific period. This is crucial for preventing overloading of the grid infrastructure.

Demand Side Management itself is a multifaceted concept, extending from short-term load adjustments, commonly categorized under Demand Response (DR), to long-term efficiency measures that form part of a broader spectrum of DSM strategies (Palensky & Dietrich, 2011). These strategies are increasingly recognized for their potential to transform the energy landscape, offering innovative solutions to the challenges posed by the integration of renewable energy sources.

2.1 Economic Implications of Flexibility in Energy Markets

The monetization of flexibility in energy markets can be approached through several avenues. The primary method is market-oriented flexibility utilization, where market prices serve as the key external signal. The second approach involves system-supportive flexibility use, driven by the demand for control energy from the Transmission System Operator (TSO). A third method is the grid-supportive utilization of flexibility.

2.1.1 Market-Oriented Flexibility Utilization

In the context of wholesale electricity trading, the spot market plays a pivotal role, acting as the central control signal for participants to balance generation and consumption. This becomes increasingly crucial with the rising proportion of variable renewable energy sources. On the consumer side, flexibility can be economically leveraged by adjusting consumption patterns—increasing usage when electricity prices are low and decreasing during high-price periods. Besides the direct cost of electricity, consumers also face levies and surcharges, which can form a substantial portion of the overall electricity bill. Effective management of grid charges, particularly through peak load minimization or atypical grid usage, is another area where flexibility proves beneficial. Consequently, flexibility emerges as a critical element for ensuring cost-efficient electricity supply in the long term, as highlighted by (Bundesnetzagentur, 2017).

2.1.2 System-Supporting Flexibility Utilization

To maintain short-term grid frequency stability in the electrical energy system, flexible generators and consumers offer various balancing power products. These products, differentiated by their activation times and duration of provision, include primary, secondary, and tertiary control powers. The TSO demands these services as needed. Market participants negotiate compensation for flexibility utilization in the control energy market. Suppliers of control energy must meet specific prequalification criteria and offer a minimum output—1 MW for primary control energy and 5 MW for other balancing energy products, as noted by (Bundesnetzagentur, 2017; E.ON, n.d.). The revenue potential from providing these control energy services varies with the fluctuating market prices for control energy.

2.1.3 Grid-Supporting Flexibility Utilization

The local electricity grid must mirror market behaviors in line with market outcomes. When grid congestion prevents this, the Distribution System Operator (DSO) must intervene, using options like redispatch measures on the generation side (Müller & Lens, 2021) and contractually agreed flexibility in load management (Boscán & Poudineh, 2016). These arrangements can be tailored bilaterally between the flexibility supplier and the DSO. Third-party aggregators, bundling flexibility from various entities, also play a role in this ecosystem (Migden-Ostrander et al., 2018).

Although specific prices for flexibility are often confidential, concepts for flexibility premiums, proposed by aggregators, are based on a quota system (Bundesverband Neue Energiewirtschaft e. V., 2020). Thus, the revenue potential from grid-supporting flexibility largely depends on local market conditions.

3 Telecommunication Network and Energy

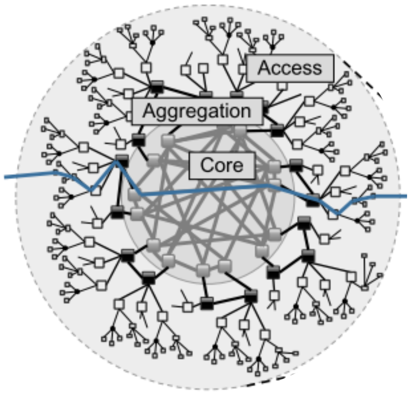
3.1 General Structure of the Telecommunication Network

The network of Deutsche Telekom (DT) reflects the intricate history and evolution of telecommunication in Germany. The geographic distribution of network nodes, known as Central Offices (COs), spans across the country, mirroring the population density and economic activities. This spatial arrangement of the telecommunication network is a result of both contemporary needs and historical influences, such as the limitations of early technologies like copper wire transmission.

The architecture of DT's telecommunication infrastructure is organized into three distinct levels: Access, Aggregation, and Core. This hierarchical structuring is driven by the goals of optimizing infrastructure and bandwidth utilization, and minimizing latency for customers. Despite technological advancements, the impact of historical site choices, based on earlier technology constraints, is still evident in the current distribution of COs.

At the Access level, the network topology is similar to a star topology. Here, the access nodes act as switches connecting individual customers. Multiple Access-COs feed into an Aggregation-CO. The Aggregation level, representing the middle layer of the network, takes the form of a daisy chain configuration, with the ends of these chains linking to Core-COs. The Core level, which is the highest in the network hierarchy, comprises Core-COs interconnected in a mesh network. This level is responsible for the actual data transfer and communication exchange, primarily through a fiber optic network, and connects to public Internet exchange points (IPX). This structural design is illustrated in Figure 1.

Figure 1: Telecommunication Network Topography



(Lange et al., 2016)

Based on data from PASM, Deutsche Telekom manages 7520 locations to deliver fixed network services. Of these, approximately 6600 are Access locations, about 900 are Aggregation sites, and 20 are Core sites. These COs vary in terms of telecommunication capacity, size, and electrical infrastructure requirements, influenced by the number and type of connected customers, as well as their specific functions. However, it's important to note that the telecommunication network is constantly evolving, which means that these figures and the proportion of each type of CO are subject to change.

3.2 Energy Systems in Telecommunication Central Offices

3.2.1 Current Technologies in Central Offices

Central Offices (COs) are integral to the telecommunication infrastructure, consisting of both the telecommunication equipment (like routers, switches, and transmission gear) and the physical systems ensuring reliable electricity supply and optimal environmental conditions for ICT operation. These physical systems are divided into electrical and mechanical equipment.

COs can be standalone structures or integrated within existing buildings, but generally comprise similar components. This section focuses on the entirety of the CO system.

3.2.1.1 Electricity Supply and Backup Systems

The primary power source for a CO is the local electricity grid. To maintain uninterrupted operations, COs are also equipped with Uninterruptible Power Supply (UPS) systems, primarily using lead-acid batteries. These batteries provide immediate power during grid outages, preventing data loss or damage to ICT equipment. The duration of backup power varies, lasting from minutes to hours, depending on the system's size and the time needed to switch to backup generators. These generators, typically diesel-powered, can supply energy for several days but are more common in Core- and Aggregation-level COs due to higher redundancy requirements. AC/DC converters and transformers are also integral to the electrical system, as most ICT devices utilize direct current (DC).

3.2.1.2 Heating, Ventilation, and Air Conditioning (HVAC) Systems

A crucial component of COs is the HVAC and cooling system. Since every kilowatt-hour consumed by ICT equipment generates waste heat, it's essential to remove this heat to maintain operational temperature and humidity levels. COs often use a combination of free cooling and active cooling. Active cooling is engaged when external temperatures exceed 18°C to maintain the set-point temperatures in the cooling airflow. For detailed insights into the climate model for Deutsche Telekom's COs, see (Filipczak et al., 2023).

3.2.2 Future Trends and Emerging Technologies

3.2.2.1 Renewable Energy Integration

The ICT sector's significant electricity consumption necessitates the adoption of sustainable energy sources. Photovoltaic (PV) and onshore wind power are particularly viable due to their proximity to CO locations. Deutsche Telekom has already installed solar power on some sites and plans to expand this initiative (T_HQ, 2022; Telekom, 2021). The increasing share of renewable energy in the power network and the need for flexible storage solutions, like lithium-ion batteries, are critical for continuous CO operation.

3.2.2.2 Innovative Technologies and Virtualization

Emerging technologies, such as hydrogen fuel cells, could potentially replace diesel generators for backup power. Additionally, integrating excess waste heat into local district heating networks could further reduce the COs' carbon footprint.

A significant trend in the ICT infrastructure is virtualization, extending beyond data centers to telecommunication infrastructures, including COs. This transition to commodity hardware running software frameworks, known as the Next Generation CO, mirrors the evolution seen in data centers and is expected to reduce operational expenses. For more on this, see the work by (Ruffini & Slyne, 2019).

Virtualization can enhance flexibility and control over ICT equipment utilization, leading to greater efficiencies (Bitkom e.V. & Bundesverband Informationswirtschaft, 2015). Moreover, continuous improvements in equipment efficiency are expected to increase energy densities and heat dissipation.

3.3 Energy Consumption of a Telecommunication CO

On average only half of the energy consumption in an ICT-facility like a data center or a CO is consumed by the actual ICT-equipment. The remainder is due to the additional mechanical and electrical equipment (Bitkom e.V. & Bundesverband Informationswirtschaft, 2015). Despite technological efficiency gains in both the ICT-devices as well as in the additional electrical and mechanical infrastructure, there is still potential to reduce overall consumption (Bitkom e.V. & Bundesverband Informationswirtschaft, 2015).

To determine the efficiency of a system, the quotient of effort and benefit is usually formed. In the case of a CO the effort is the total energy consumption whereas there are different approaches to determine the benefit. Hence, there exists different Key Performance Indicators (KPIs) to describe the efficiency for a CO.

One of the most important KPIs is the Power Usage Effectiveness (PUE), which is defined as the total power consumption of the whole system divided by the power consumption of the ICT-equipment.

$$PUE = \frac{Total\ Energy\ Consumption}{Energy\ Consumption\ of\ ICT\ Equipment} \tag{1}$$

By definition the PUE is greater or equal to one. The lower the value the more efficient an ICT-site. Deutsche Telekom reports a total PUE of around 1.5 for 2022 (Deutsche Telekom, 2022). This indicates, that the power consumption of the additional infrastructure is equivalent to half of the energy consumption of the ICT-equipment.

Since the PUE only differentiates between the energy consumption of the ICT-equipment and the remainder as a total, counteracting efficiency effects cannot be differentiated. To evaluate the efficiency of different infrastructure components, the concept of partial Power Usage Effectiveness (pPUE) is used.

The pPUE is defined as the sum of the power consumption of the ICT-equipment and a specific infrastructure component divided by the total power consumption of the ICT-equipment.

$$pPUE_{equipment} = \frac{Energy\ Consumption\ of\ ICT\ Equipment + Energy\ Consumption\ of\ Equipment}{Energy\ Consumption\ of\ ICT - Equipment}$$

(2)

The equipment component in the equation above can be any additional infrastructure component of a CO. Since the energy consumption of the cooling system accounts for a high proportion of the total energy consumption, the pPUE of the cooling system is often used. The $pPUE_{cooling}$ determines the energetic efficiency of an ICT-facility regarding its cooling system.

For more information on energy consumption of exemplary COs, please refer to (Filipczak et al., 2023).

4 Review of Scholarly Works on DSM in ICT and Energy Systems

This chapter presents a comprehensive literature review focused on the integration of Demand Side Management (DSM) in telecommunication and energy systems, particularly emphasizing spatial and temporal load shifting.

4.1 Understanding Spatial and Temporal Load Shift in Telecommunication and Energy Systems

DSM is an evolving concept, shifting from a utility-driven to a customer-driven approach. It encompasses a variety of measures aimed at improving energy consumption on the demand side. These measures can vary in their time horizon, effect duration, and impact on the overall process, as highlighted in (Palensky & Dietrich, 2011). The primary focus of DSM has been on temporal load shifting, primarily within a single location.

4.1.1 Spatial Load Shifting and Its Impact in Data Centers

The concept of demand flexibility extends beyond just temporal aspects, especially in the case of geographically distributed ICT systems like data centers. Cloud service providers, operating multiple data center sites in various geographical locations, demonstrate the potential of spatial load shifting. This capability allows them to distribute workload across different sites, effectively shifting power loads spatially. Such a strategy is not commonly suitable for most energy consumers but is particularly relevant for data centers due to their unique operational characteristics.

The impact of spatial load redistribution on the power grid has been a subject of study (Wang et al., 2016). For instance, data centers can respond to load redistribution signals based on dynamic pricing set by electricity providers. This approach not only helps stabilize the grid locally but also creates a mutually beneficial situation for both the grid and the data center operators. In environments where smart grids and tiered electricity pricing are implemented—such as in the US, Japan, and China—simulations have shown that grid stability can be enhanced while data center operators reduce their energy bills, all while adhering to workload and quality (delay) constraints.

Moreover, spatial load shifting in geographically dispersed data centers can optimize the use of geography-dependent and fluctuating renewable energy supplies (Kiani & Ansari, 2016). This approach involves integrating quality constraints with the supply of local renewable energy to power the workload demand, particularly relevant for globally distributed internet-scale data centers.

One significant area where spatial load shifting plays a crucial role is in the operation of data center cooling systems. Cooling is a major component of a data center's total energy consumption, and the power required for free and hybrid cooling systems is highly dependent on external air temperature. Therefore, geographic load redistribution can leverage temperature differences across different times and locations to reduce energy consumption, thereby decreasing the total operational costs. Studies have explored geographic load shifts based on temperature-dependent energy consumption and costs for data centers located across multiple continents (Xu et al., 2015). These studies often combine such strategies with the allocation of different types of workloads, such as interactive-type and batch-type, as part of a joint optimization process.

4.1.2 Advanced Energy Management and Economic Implications

In the realm of holistic energy management, some authors propose the introduction of a dynamic Energy Management System (EMS) for Data Centers. This system aims to minimize overall energy consumption and reduce peak loads. The optimization process within such an EMS involves orchestrating a portfolio of measures, including workload management, cooling system operation, and UPS system management. Notably, it incorporates both spatial and temporal load shifting capabilities. Temporal load shifting can be achieved using thermal and electric buffer capacities, while spatial shifting involves the redistribution of workload across different locations. Additionally, these systems often incorporate hardware-level efficiency measures like virtualization and the switching off of unused ICT equipment. The introduction of green Service Level Agreements (SLAs) also plays a role in relaxing quality constraints for the workload. In simulated cloud-based lab environments, such EMS implementations have shown significant reductions in energy consumption and peak power usage, demonstrating the effectiveness of these diverse flexibility measures.

Even at a more localized level, within the same electricity market, urban neighboring data centers can leverage spatial flexibility to influence local electricity prices, specifically locational marginal prices. This ability to shift workload spatially not only enhances the market power of these data centers as electricity consumers but also benefits the grid operators. The simulations of (Wang et al., 2016) show that such strategies result in win-win situations for both the data center operators and the grid, showcasing the potential of spatial flexibility in practical applications.

4.1.3 Research Trends and Environmental Impact of DSM

The exploration of spatial and temporal flexibility in the context of geo-distributed data centers is an ongoing area of research (Niu et al., 2021). For instance, some studies focus on the flexibility related to different types of workloads in data centers, distinguishing between delay-sensitive and delay-tolerant tasks. These studies aim to create cost-efficient workload schedules that take into account the varying costs of power supply in a smart grid, as well as the different delay penalties associated with various tasks. The findings from such research indicate that strategic scheduling and load management can lead to more efficient and economically viable operations for data centers.

The field of DSM in data centers is not limited to operational costs and energy consumption; it also extends to the exploration of emission reduction potential. For example, (Zheng et al., 2020) focuses exclusively on the spatial flexibility aspect, investigating the load shifting potential of data centers based on server utilization rates. The goal of such studies is to minimize the curtailment of renewable energy sources, thereby reducing the net Greenhouse Gas (GHG) emissions. This area of research highlights the environmental benefits of DSM, showing that strategic load management can contribute to broader sustainability goals.

As the demand for energy and the supply of renewable resources do not always align, the challenge of managing this variability becomes a key focus for data centers. The spatial load shift between geo-distributed data centers is researched in (Niu et al., 2021), particularly in light of the uncertainties associated with both energy demand and supply. In models like the stochastic economic dispatch model, geo-distributed data centers are incorporated to minimize the total cost of both the power system and the data center operations. These models also aim to maximize the integration of renewable energies, taking into account factors like low generation costs and penalties for curtailment. Case studies in this area have shown that spatial load shifting can indeed help power systems integrate renewable energies more effectively while also reducing costs, even when considering the uncertainties inherent in both demand and supply.

Another approach to addressing the variability in both demand and the availability of renewable energies, as well as fluctuating power prices is shown in (Imran et al., 2022), with the consideration of power supply costs. This includes integrating power purchase options as a proxy for volatile renewable generation. In addition to spatial load shifts between data centers, these models also consider temporal load shifts based on the use of energy storage devices. Such devices store renewable energies, allowing for more flexible and cost-effective use of these resources. Experimental setups testing these approaches have demonstrated that total costs for geo-distributed data centers can be reduced through these combined spatial and temporal load management strategies.

4.1.4 DSM in Telecommunication Networks: Strategies and Benefits

The multifaceted nature of spatial and temporal load shifting in the ICT sector is evident from the diverse range of studies and perspectives. A comprehensive review, such as (Chen et al., 2020), categorizes the literature based on how load is modeled, the regulatory mechanisms with respect to operational and economic aspects, and the underlying paradigms of demand response programs. This categorization helps in understanding the various dimensions of load management and the different approaches that can be taken.

The body of literature on DSM, particularly in the context of data centers, demonstrates the benefits of using spatial and temporal flexibilities. These benefits extend not only to the operators of the data centers but also to the stability of the local grid. For example, (Takci et al., 2021) analyzed the impact of DSM with varying diffusion rates on a nationwide power system. This study looked at various aspects, including economic and environmental implications. The researchers examined how data centers participating in DSM programs could influence factors like load and loss factors, power losses in the transmission system, and the costs and emissions avoided by reducing the demand for fossil-based power generation capacities.

The similarities between telecommunication sites and data centers, in terms of structure, energy system, and consumption behavior, make the former another relevant area for the application of DSM strategies. Even though data centers and telecommunications networks perform different functions and process different types of workloads, the principles of spatial load shifting are applicable to both sectors. (Ricciardi et al., 2013) illustrated a range of measures through which telecommunication networks can reduce energy consumption or integrate renewable energies, thus becoming more sustainable. These measures were categorized into three general areas: *energy efficiency*, *energy awareness*, and *energy-oriented awareness*. This categorization represents a paradigm shift in the traditional design of telecommunication networks, with a growing emphasis on sustainability. The study considered spatial and temporal flexibility in the context of energy efficiencies within a telecommunication CO, as well as dynamic network topologies that take into account the efficiency and availability of renewable energies.

The potential for temporal load shifting within telecommunication networks was thoroughly analyzed in (Lehmann et al., 2011). This research focused on optimizing a joint cost function that incorporates both the telecommunication network and the smart grid. The authors propose a control architecture that leverages integrated energy storage capacities. These capacities are beneficial for optimizing consumption patterns within the telecommunication network and also serve a critical role in providing control energy to a smart grid.

QUALITATIVE ANALYSIS OF CENTRAL OFFICES LOAD SHIFTING OPPORTUNITIES

In (Lange et al., 2016) the spatial and temporal load shifting capabilities of telecommunication networks were further investigated, highlighting the economic advantages in terms of energy supply cost reduction. The study emphasizes how battery capacities offer temporal flexibility, which aids in minimizing peak loads and allows for more cost-effective electricity procurement in the energy market. An important aspect of this research is the implementation of traffic adaptive control of Information and Communication Technology (ICT) equipment. This adaptation not only leads to energy consumption savings but also aligns with the capability of network reconfiguration. This reconfiguration is designed to direct traffic through energy-efficient routes without compromising the reliability and redundancy of the entire network.

A noteworthy extension of this energy-aware network configuration approach is the carbon-aware routing strategy for data transmission, aiming to reduce the carbon footprint associated with network traffic. Presented in (Tabaeiaghdaei et al., 2023), this approach integrates a path-aware network architecture with predictive analytics. The prediction focuses on the carbon intensity associated with different traffic routes, offering a novel and environmentally conscious method for data transmission within telecommunication networks.

5 Qualitative Assessment of Flexibility in Deutsche Telekom COs

5.1 Potential and Feasibility of Demand Shift and Flexibility in Deutsche Telekom COs

This section assesses the potential for realizing flexibility through spatial and temporal load shifting in the two main domains of a Central Office (CO): the ICT-system and the energy-system.

5.1.1 Spatial Load Shifting in Telecommunication COs

In the realm of telecommunication Central Offices (COs), spatial load shifting presents a unique opportunity to optimize energy usage. This process involves transferring computational workloads via an optical fiber network to different regions or locations for processing. For instance, during periods of peak demand at one site, workloads can be shifted to another site where energy costs are lower or renewable energy availability is higher. This strategy not only leads to a reduced electrical load at the originating location but also efficiently utilizes resources at the receiving site.

A practical example can be seen in Deutsche Telekom's network, where spatial load shifting has been implemented to manage data traffic during different times of the day. By rerouting data to COs in regions with lower energy costs or to sites where renewable energy sources are available, Deutsche Telekom has been able to reduce operational costs and carbon footprint.

However, spatial load shifting requires significant changes in the control and management of the ICT infrastructure. It involves a paradigm shift from traditional practices that focus on maximizing asset utilization and minimizing latencies, to a more dynamic approach that also considers energy efficiency. For instance, non-communication workloads such as data processing and storage can be reallocated to COs with higher energy efficiency or lower grid costs, thereby optimizing overall energy consumption.

5.1.2 Temporal Load Shifting in Telecommunication COs

Temporal load shifting in telecommunication COs involves modifying the timing of energy usage to align with periods of lower energy costs or higher renewable energy generation. In the ICT-system, this can be achieved by delaying non-critical computational tasks to off-peak hours. For example, data centers within COs can schedule batch processing tasks during nighttime when energy demand is lower, thus benefiting from lower energy prices.

In the energy-system domain, COs can utilize battery storage capacities to shift energy consumption. Energy can be stored during periods of low demand or high renewable generation, and then used during peak hours. This strategy not only helps in managing energy costs but also contributes to grid stability. For instance, Deutsche Telekom COs equipped with battery storage systems can store energy generated from solar panels during the day and use it during peak evening hours, effectively reducing reliance on the grid and enhancing sustainability.

Temporal load shifting thus offers a dual benefit – it aligns energy usage with cost-effective and sustainable energy sources while also ensuring the efficient operation of COs.

5.2 Technical and Economic Evaluation of Flexibility Utilization in Telecommunication COs

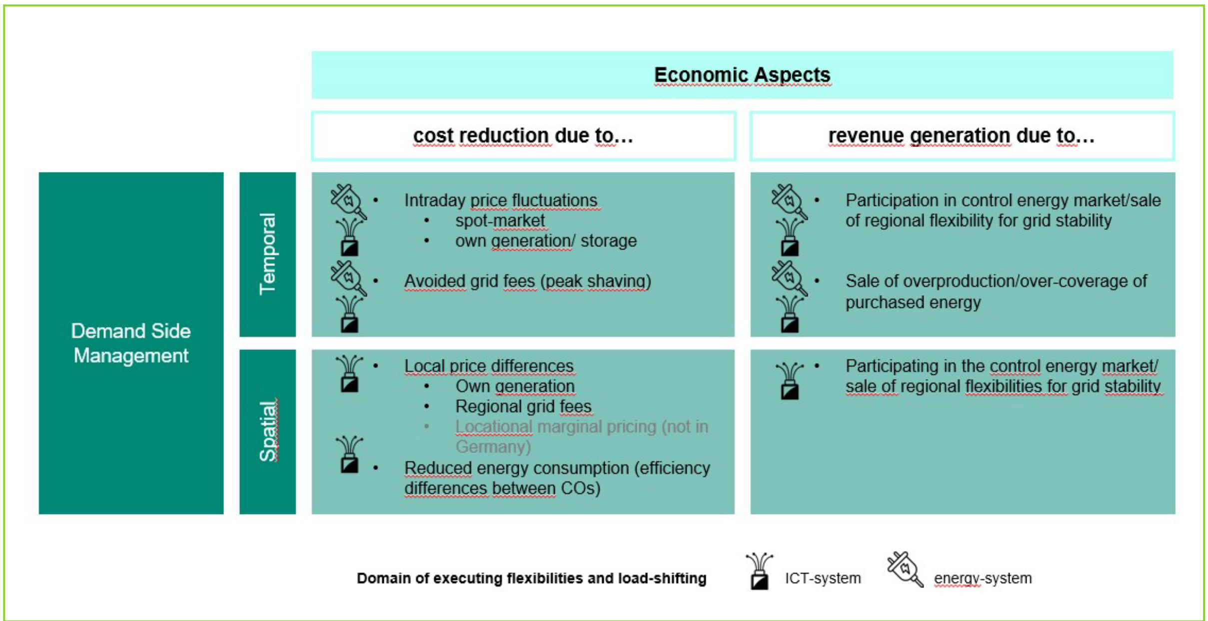
The utilization of flexibility in telecommunication COs, through both spatial and temporal load shifting, offers significant potential for cost savings and revenue generation. Spatial load shifting enables cost reductions through efficient workload management across different locations. For example, rerouting data traffic to COs with lower grid charges or excess renewable energy can significantly reduce energy costs.

Similarly, temporal load shifting can be economically advantageous. By aligning energy usage with periods of lower energy prices or high renewable energy generation, COs can reduce their energy procurement costs. Additionally, 'peak shaving' – the practice of reducing energy usage during peak demand periods – can lead to substantial savings in grid charges.

Furthermore, both spatial and temporal load shifting can create opportunities for revenue generation. COs can participate in energy markets by offering their flexibility in energy usage as a service. For example, by reducing demand during peak hours or shifting load to times of excess renewable energy generation, COs can receive compensation through performance pricing models.

This section combines the load shifting options explored in Section 5.1 with economic considerations from Section 2.1 to evaluate the technical and economic aspects of utilizing flexibility in telecommunication COs. Both spatial and temporal load shifting offer the potential to save costs in energy procurement and generate revenue. Figure 2 gives an overview of the approaches for cost reduction and revenue generation using flexibility in telecommunication COs, which is described in the following subsections.

Figure 2: Approaches for cost reduction and revenue generation based on temporal and spatial flexibilities



Overall, the technical and economic evaluation of flexibility in Deutsche Telekom COs underscores the significant benefits of these strategies. Not only do they contribute to more efficient and cost-effective operations, but they also align with broader sustainability goals, making them a valuable aspect of future energy management in telecommunication networks.

5.2.1 Cost Reduction via Flexibility

Spatial load shifting, as discussed in Section 5.1.1 , enables cost savings in various market-oriented ways. Although the German electricity market has uniform pricing, local differences in grid charges and surplus from decentralized renewable energy generation provide opportunities for cost reduction and emission reduction through increased self-consumption.

Likewise, efficiency differences between COs can lead to energy savings by shifting loads to more efficient locations, reducing overall energy consumption, emissions, and operating costs.

Temporal load shifting, using time-based price differences, allows shifting loads to periods with favorable market prices or high self-generation from renewables, reducing energy procurement costs and emissions. Peak shaving, reducing load-dependent grid charges by minimizing peak loads, is another cost-saving strategy.

5.2.2 Revenue Generation from Flexibility

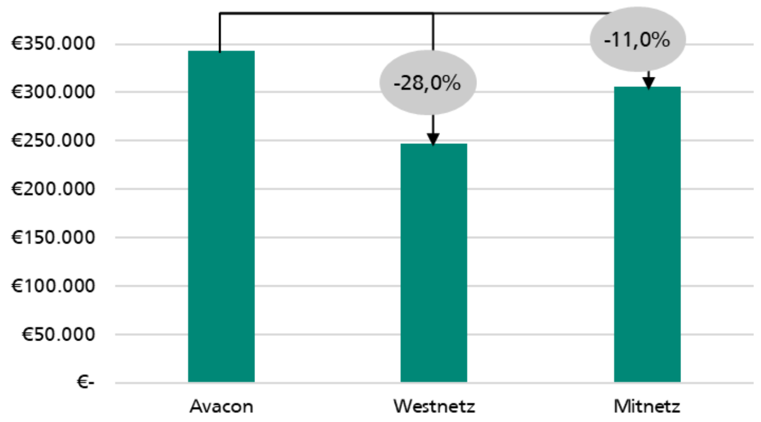
Spatial and temporal load shifting can directly generate revenue. Flexibility provision is compensated through a performance price, and the actual work performed is compensated through a labor price. These income sources can be tapped both in the balancing energy market and in local grid-supporting flexibility markets. The economic viability of such flexibility marketing requires a comprehensive analysis of the associated direct and indirect costs (Haupt et al., 2020).

This chapter thus provides a qualitative overview of how Deutsche Telekom COs can harness spatial and temporal flexibility to reduce costs and generate revenue, contributing to more efficient and economically viable operations.

5.3 Quantitative Estimation of Flexibility in Telecommunication COs

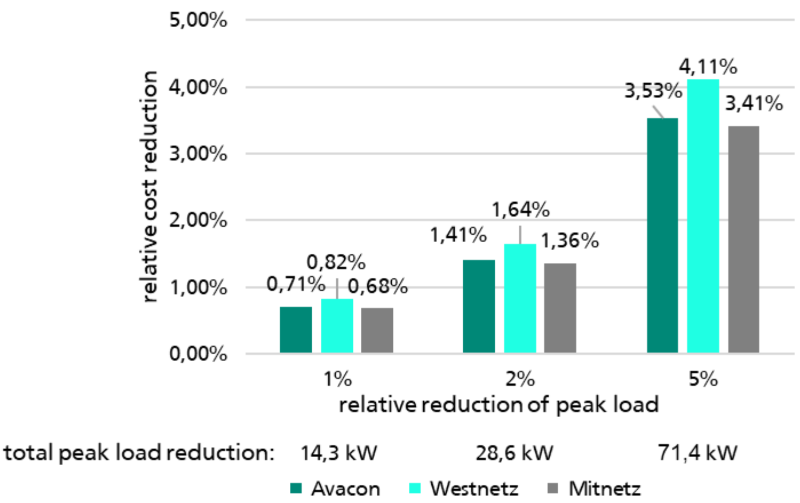
Based on the load data provided by PASM for a core-CO the potential for spatial load shift is analyzed by comparing the difference in the grid charges for three exemplary DSOs. These DSOs operate medium voltage networks in different geographical areas. The respective grid tariffs for Avacon AG, Westnetz, and Mitnetz Strom are publicly available (Avacon Netz GmbH, 2022; Mitnetz Strom GmbH, 2022; Westnetz GmbH, 2022). The same load profile for a core-CO results in different total grid fees at different locations. Figure 3 shows the grid fees for the reference CO in different areas of the grid. The relative difference in the charges of the grid is as high as 28%. This shows a significant cost-reduction potential to shift loads between telecommunication CO with different electricity network operators.

Figure 3: Analysis of Spatial Load Shift Potential Based on Differences in Grid Fees



One major feature of using spatial and temporal flexibilities is the reduction of peak loads. With the provided load profile, the relative reduction in grid fees was analyzed with respect to the relative reduction in peak loads. This is shown in Figure 4 for the exemplary DSO.

Figure 4: Analysis of Temporal Load Shift Potential Based on Peak Load Reduction



With a reduction of 14.3 kW representing 1% of the peak load of the reference CO, the reduction in the grid fees ranges from 0,68% to 0,82% depending on the DSO. This trend can also be observed for a reduction of 2% and 5% of peak loads as well. This shows not only the viability of using the temporal load shift to reduce peak loads, but also for shifting loads in space, since the relative reduction varies between different DSOs.

Telecommunication COs have the option of benefiting from the spatial and temporal load shift. As this flexibility can be used to reduce costs related to energy consumption or generate revenue, generic options were presented in this chapter and discussed with respect to feasibility in telecommunications COs. Since the industry's predominant preference is to use flexibility to reduce grid fees, this approach was investigated in a preliminary analysis based on realistic load profiles of a core-CO and has shown viability for spatial and temporal load shifting.

6 Conclusion

The analysis in this report shows that the implementation of spatial and temporal load shifting strategies in Deutsche Telekom's central offices (COs) holds great promise for improving energy efficiency and economic performance. Specifically, we found that while spatial load shifting primarily benefits the ICT system, temporal load shifting offers opportunities for optimization in both the ICT and energy systems. This nuanced understanding is critical for effectively tailoring load shifting strategies.

Furthermore, our findings suggest that these load shifting strategies are not only a way to reduce energy costs, but also offer potential for new revenue streams. This dual benefit is particularly important in the context of ongoing efforts to combat climate change, as it aligns closely with the broader goals of reducing CO2 emissions and promoting sustainability in the ICT sector.

However, our study also highlights the need for further research in this area. Future work should focus on refining these load shifting strategies, with a particular emphasis on scalability and adaptability in the face of rapidly evolving energy demand patterns and the increasing integration of renewable energy sources. This future research should aim to develop actionable guidelines for the widespread implementation of these strategies, thereby contributing to a more sustainable and economically viable energy landscape in the ICT sector.

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