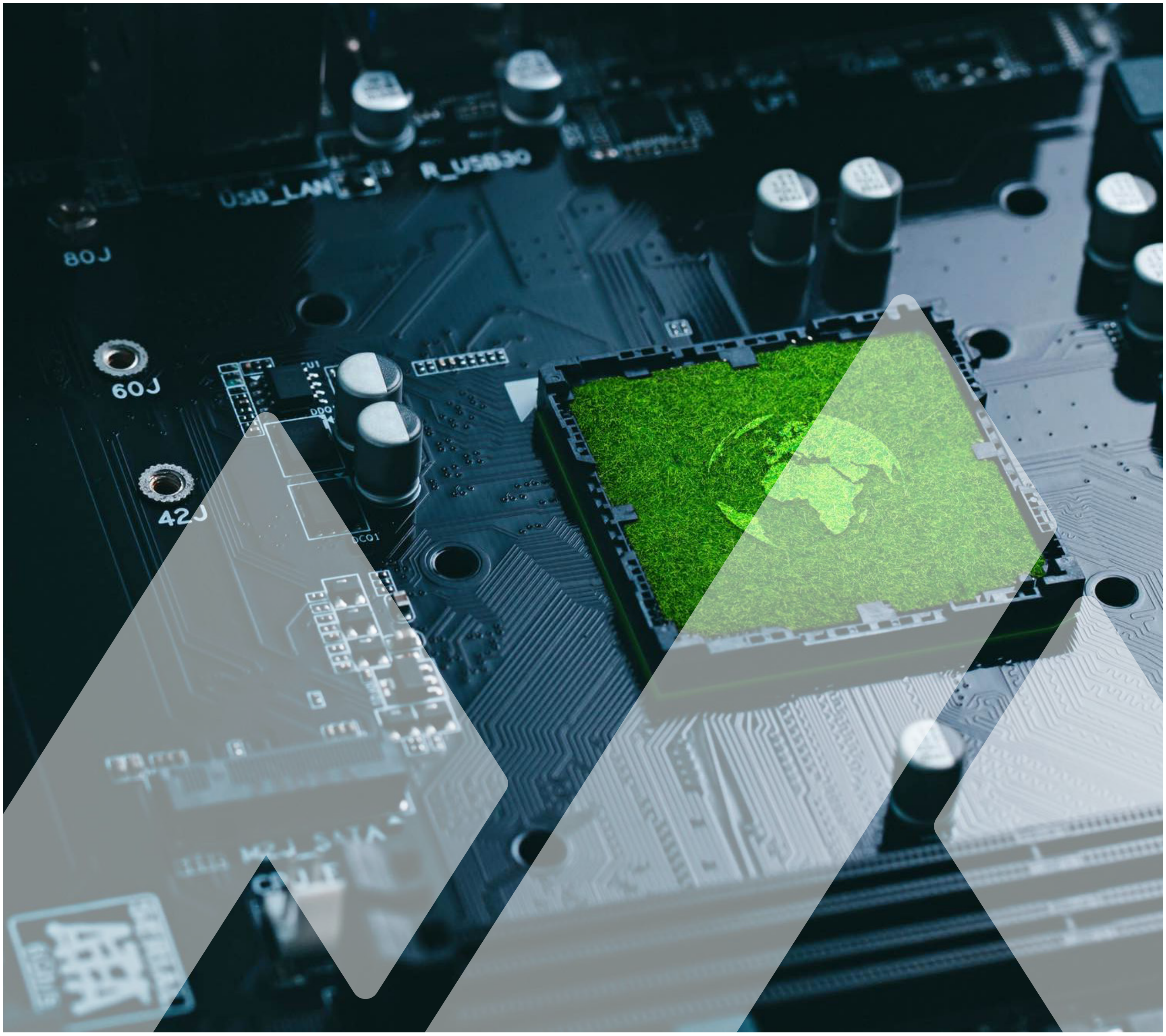
Powering the Data-Center Boom with Low-Carbon Solutions

China's Perspective and Global Insights



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RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut climate pollution at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; Abuja, Nigeria; and Beijing, People's Republic of China.

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Decarbonizing Data Centers in Global Climate Actions

Computing power growth is driving significant increases in data-center energy consumption and carbon emissions

As the global digital and intelligent transformation accelerates, the demand for computing power has been rising rapidly.[i] According to International Data Corporation data, the average proportion of the digital economy in the gross domestic product (GDP) of the 15 major global economies increased from 44.1% in 2017 to 50.2% in 2022 and is projected to reach 54.0% by 2026, exceeding $40 trillion.[1,ii] Major economic regions such as China, the United States, and the EU have issued strategic policies to accelerate the development of computing power, digitalization, and artificial intelligence (AI). According to estimates from the China Academy of Information and Communications Technology (CAICT),[iii] the global computing power capacity of computing devices reached 1,369 EFLOPS in 2023,[iv] with an annual growth rate of nearly 50% for two consecutive years. It is further expected that the growth rate will exceed 50% in the next five years.[2]

Data centers, as the physical entities that host computing power, are rapidly evolving from general purpose computing providers to intelligent computing. Over the past 20 years, the global data-center market has experienced an average annual growth rate of over 20%, undergoing three major phases: private localized data centers, cloud computing data centers, and AI data centers.[3] China's data-center market has also experienced rapid growth. By the end of 2023, there were over 8.1 million standard data-center racks in use across the country, with a total computing power capacity reaching 230 EFLOPS. Over the past five years, the average annual growth rate was nearly 30%, with intelligent computing power reaching 70 EFLOPS — an increase of over 70% compared with the previous year.[4]

The exponential growth of computing power has led to a significant increase in data-center energy consumption, resulting in increased carbon emissions for the entire industry. In 2022, global data centers consumed approximately 460 terawatt-hours (TWh) of electricity, accounting for about 1.7% of global electricity consumption, with corresponding carbon emissions of approximately 220 million tons (see Exhibit 1).[v] Depending on the speed of data-center deployment, improvements in energy efficiency, and the development trends of technologies such as AI and blockchain, it is estimated that from 2022 to 2026, data-center electricity consumption will grow at an annual rate of 8%–23%, potentially reaching

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i Computing power refers to the capacity of data-center servers to process data and produce output, serving as a comprehensive metric for assessing a data center's computing capabilities. It encompasses general computing power, supercomputing power, and intelligent computing power.

ii The 15 economies are the United States, China, Japan, Germany, India, the United Kingdom, France, Canada, Italy, Brazil, South Korea, Australia, Ireland, Singapore, and South Africa (ranked by 2022 GDP).

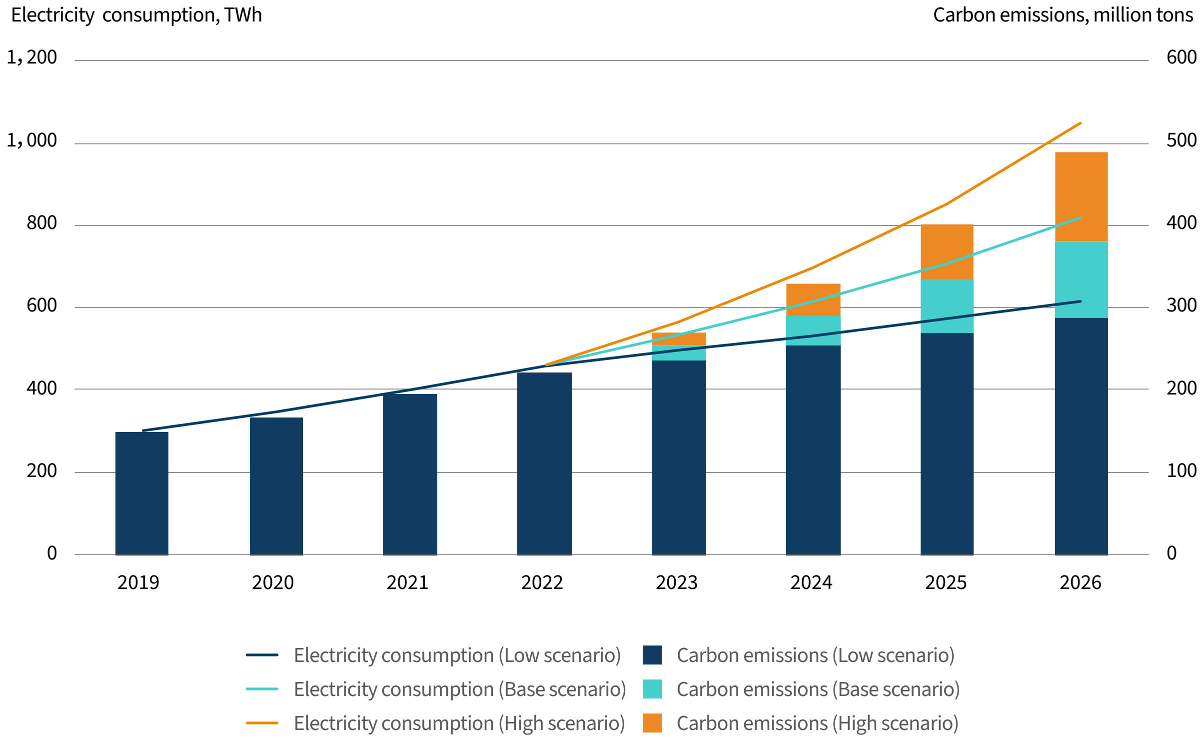
iii Calculated based on the cumulative annual server shipments since 2017 multiplied by the average computing power of servers in each respective year.

iv The common unit of measurement is floating-point operations per second (FLOPS, 1EFLOPS=10^18 FLOPS). A higher value indicates greater overall computational capability. It is estimated that 1 EFLOPS is equivalent to the computing power output of approximately 5 Tianhe-2A supercomputers, 500,000 mainstream server CPUs, or 2 million mainstream laptops. Source: *High-Quality Development Action Plan for Computing Power Infrastructure by* the China Ministry of Industry and Information Technology.

v Carbon emissions for 2019–2023 are calculated based on annual electricity consumption multiplied by the global grid average emissions factor for each respective year published by EMBER. Emissions factors for 2024–2030 are extrapolated using an annual change rate of -0.9%.

620–1,050 TWh by 2026,[5] corresponding to carbon emissions of 290 million to 490 million tons. Looking ahead to 2030, global data-center electricity consumption is projected to further increase to 750–2,300 TWh, with corresponding annual carbon emissions of approximately 340 million to 1,040 million tons, about 0.9%–2.8% of global carbon emissions based on the 2023 level.[6]

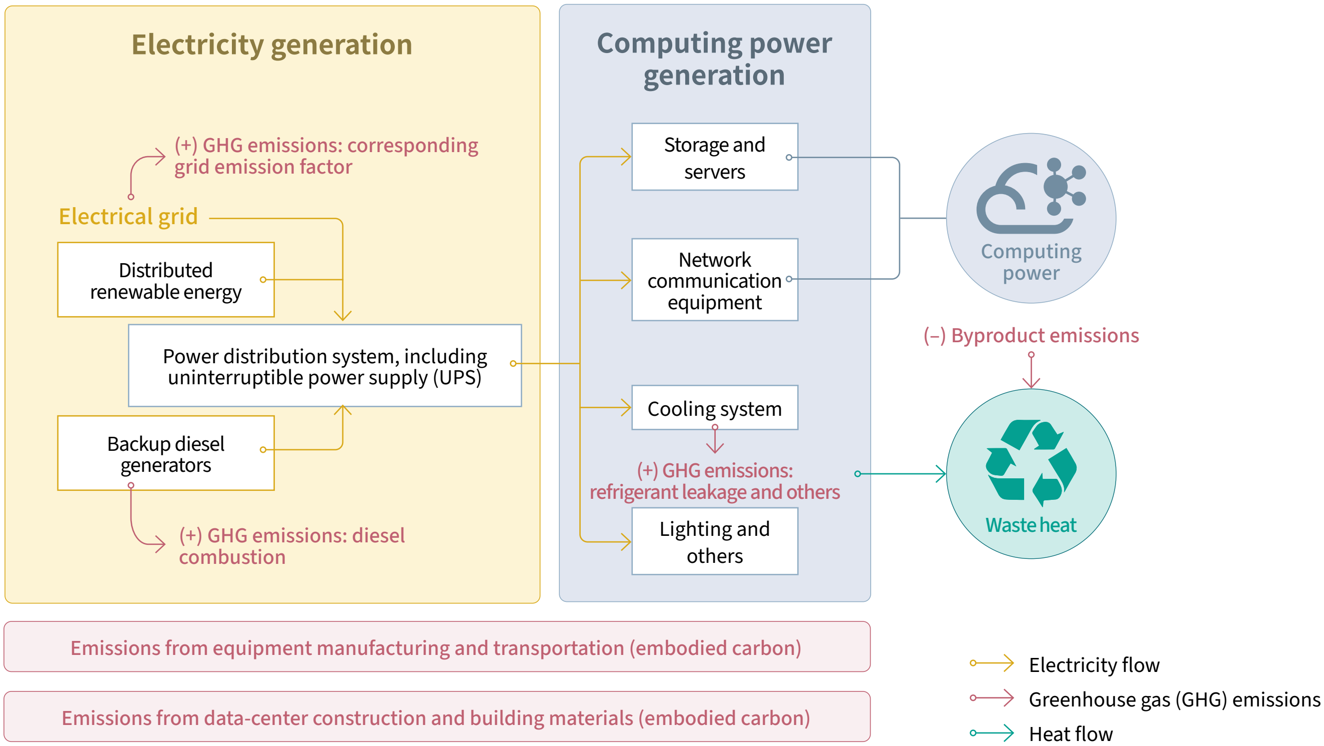
Exhibit 1 **Global data-center electricity consumption and corresponding carbon-emissions**



RMI Graphic. Source: International Energy Agency (IEA), EMBER, RMI analysis

In addition to indirect emissions from grid-sourced electricity, greenhouse gas emissions (GHG) from data-center operations should also take into account emissions from backup diesel generators, refrigerant leakage, and other sources (see Exhibit 2). Furthermore, from a life-cycle perspective, emissions embedded in the production of equipment and the construction of data centers must also be considered, which further increases the carbon footprint of computing power.

Exhibit 2 Emissions and energy flows of computing power



RMI Graphic. Source: RMI analysis

Decoupling computing power growth from carbon emissions is a necessary choice

Transitioning data centers away from emissions has become a global call. Major data center–developing countries and regions have set ambitious policy goals to advance this transition. In the United States, a series of policies, including the Federal Data Center Consolidation Initiative,[7] are driving energy-efficiency improvements through measures such as upgrading or decommissioning outdated and inefficient data centers,[8] increasing server utilization, and enhancing facility availability.[9] The EU has taken the lead by setting carbon-reduction targets specifically for the data-center industry. Through initiatives like establishing energy-efficiency frameworks and promoting best practice guidelines, the EU aims to reduce data-center energy consumption and ensure that data centers achieve climate neutrality by 2030.[10]

In China, policies are in place to optimize data-center site selection and planning, enforce strict energy-efficiency standards for new projects, and advance energy-efficiency retrofits for existing centers. By 2025, China aims to bring the power usage effectiveness (PUE) of newly built and upgraded large and extra-large data centers down to 1.25 or lower (compared with the national average PUE of around 1.48 in 2023).[11,vi]

Beyond regulatory policies, leading global players in the data-center market have also committed to carbon neutrality goals. Among the Global 500, most technology companies and data-center service providers have set carbon neutrality targets for 2030 or earlier, ahead of the 2050 targets set by many other industries. Global internet companies like Google, Microsoft, Adyen, and Zalando have already achieved carbon neutrality in their operations and are now working toward a goal of a 24/7 carbon-free energy supply. In China, at least 12 data-center and cloud service companies have pledged to achieve carbon neutrality in their own operations. Alibaba Cloud and Tencent have led the way, announcing they will achieve carbon neutrality in their operations and supply chains by 2030.

If the development of computing power can overcome the constraints of energy consumption and carbon emissions to achieve scalable growth, it could become the engine for digital and intelligent transformation across industries, creating synergistic effects with low-carbon transition. Taking the power sector as an example, digital technologies and AI can significantly improve the accuracy of renewable energy forecasting on the generation side, optimize electricity market trading strategies, and enhance the profitability of renewable assets. On the transmission and distribution side, extensive use of digital technologies in grid equipment, generation units, and dispatch management systems can strengthen predictive and preventive capabilities for grid management. Additionally, the use of drones and robots for equipment inspections will greatly enhance grid operation and maintenance efficiency. On the consumption side, digital technologies enable comprehensive, real-time monitoring of energy supply and consumption, supporting enterprises and industrial parks in conducting energy-efficiency analyses and optimizing production processes.

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vi Power usage effectiveness (PUE) of a data center is the ratio of the total energy consumed by the data center to the energy consumed by its IT equipment. A PUE value closer to 1 indicates a higher proportion of energy used by IT equipment, with a lower proportion consumed by non-IT systems such as cooling and power distribution. According to the definition by the Ministry of Industry and Information Technology, an extra-large data center is defined as having more than 10,000 standard racks, whereas a large data center is defined as having between 3,000 and 10,000 standard racks. In this context, a standard rack is a unit of measurement, with a power consumption of 2.5 kilowatts (kW) considered as one standard rack.

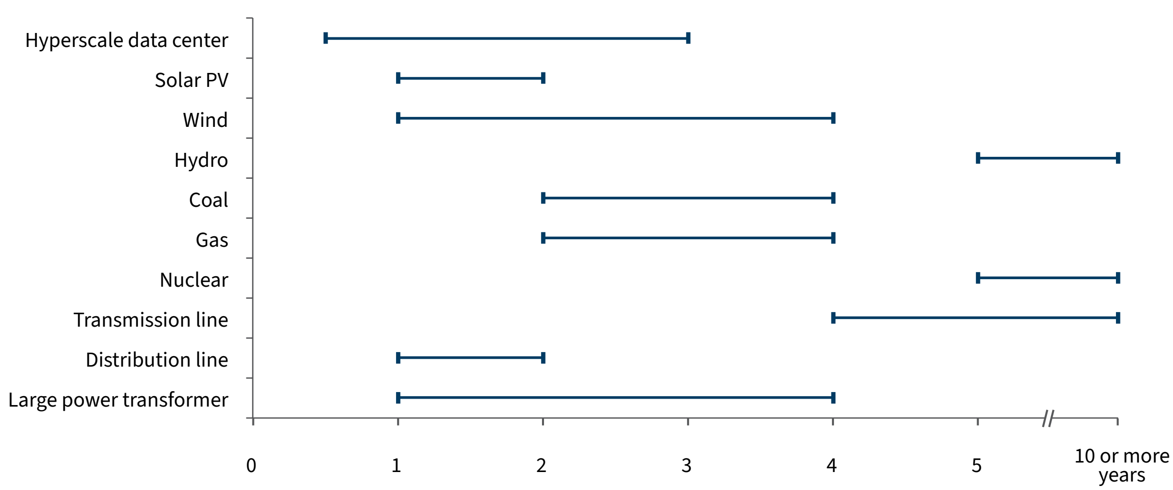
Systematic Challenges to Decarbonizing Data Centers

In the AI era, computing power, with data centers serving as the primary carriers, has become a new productive force for digital transformation across industries. However, as computing power scales up, issues related to energy consumption and GHG emissions are becoming increasingly prominent. Driving energy-efficiency improvement and carbon-emissions reduction of data centers is essential, yet it faces four major challenges.

Growth of data centers surpasses the development of energy infrastructure

The large-scale development of intelligent computing power is expected to drive data-center electricity demand beyond current projections, adding pressure to the planning of power generation units and grid networks. According to the *Global Data Center Trends 2024* report by Global Commercial Real Estate Services, ongoing power shortages globally are significantly constraining the growth of the data-center market, with data-center operators in North America, Europe, Latin America, and the Asia-Pacific region prioritizing access to electricity.[12] Power infrastructure usually has long planning cycles with complex construction processes, and the short-term surge in electricity demand will likely create considerable balance pressure. This is especially true as planning and development of transmission and distribution networks often lag planning and development of data centers, which may lead to a long grid connection queue for data-center projects in certain regions (see Exhibit 3).

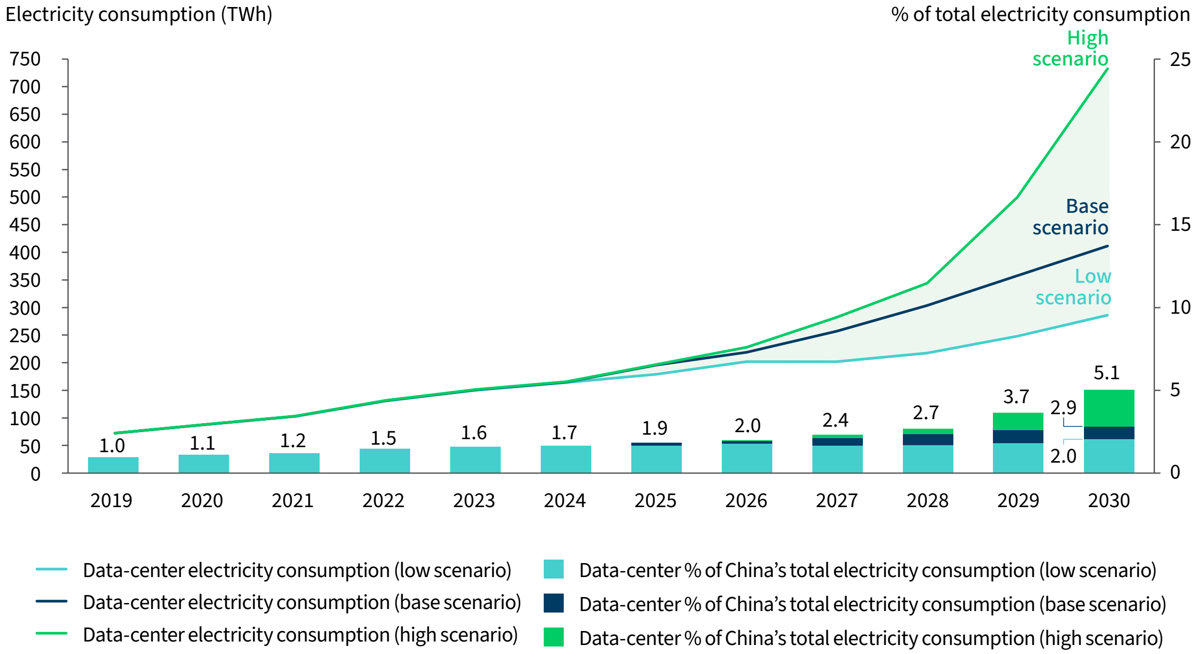
Exhibit 3 **Comparison of planning and construction cycles for data centers, power generation units, and transmission and distribution networks, based on the overall global situation**



RMI Graphic. Source: IEA, *Average Lead Times to Build New Electricity Grid Assets in Europe and the United States 2010-2021*, **https://www.iea.org/data-and-statistics/charts/average-lead-times-to-build-new-electricity-grid-assets-in-europe-and-the-united-states-2010-2021**, and *Cost and Performance Characteristics of New Generating Technologies, Annual Energy Outlook 2023*, **https://www.eia.gov/outlooks/aeo/assumptions/pdf/elec_cost_perf.pdf**

China's data-center electricity consumption is also accelerating, and its share of China's total electricity consumption has the potential to increase from 1.6% in 2023 to approximately 5% by 2030. CAICT estimates China's total data-center electricity consumption reached 150 TWh by the end of 2023, marking a 15.4% year-on-year increase and accounting for 1.6% of China's total electricity consumption, with total carbon emissions of approximately 84 million tons.[13] By 2030, under low, base, and high growth scenarios, data-center electricity consumption is expected to reach 300, 400, and 700 TWh respectively, which would be two to five times the levels of 2023,[vii] and the share of China's total electricity consumption could rise to 2.0%–5.1% (see Exhibit 4).

Exhibit 4 **Forecast of electricity consumption for data centers in China, 2019–30**



Note: This assumes a 6.7% compound annual growth rate in China's total social electricity consumption over the next seven years.
RMI Graphic. Source: CAICT, China Electricity Council

At the same time, data centers are becoming larger and increasingly clustered in specific regions, further exacerbating challenges to grid stability in certain areas. According to Synergy Research Group data, the number of hyperscale data centers worldwide rose to 992 by the end of 2023 and surpassed 1,000 in early 2024, doubling from the end of 2018.[viii] This number is expected to double again over the next four years.[14] The trend toward larger and more clustered data centers can cause local grid overload, congestion on upstream transmission lines, and other issues that affect power supply quality and stability.

In the United States, the Electric Power Research Institute (EPRI) projects that by 2030, 80% of data-center electricity consumption will be concentrated in 15 states.[15] According to TD Securities, local power systems in data-center concentration areas such as Dallas, Texas; Northern Virginia; New Albany, Ohio; and Silicon Valley, California, are likely to face challenges in maintaining system flexibility and reliability (see Exhibit 5).

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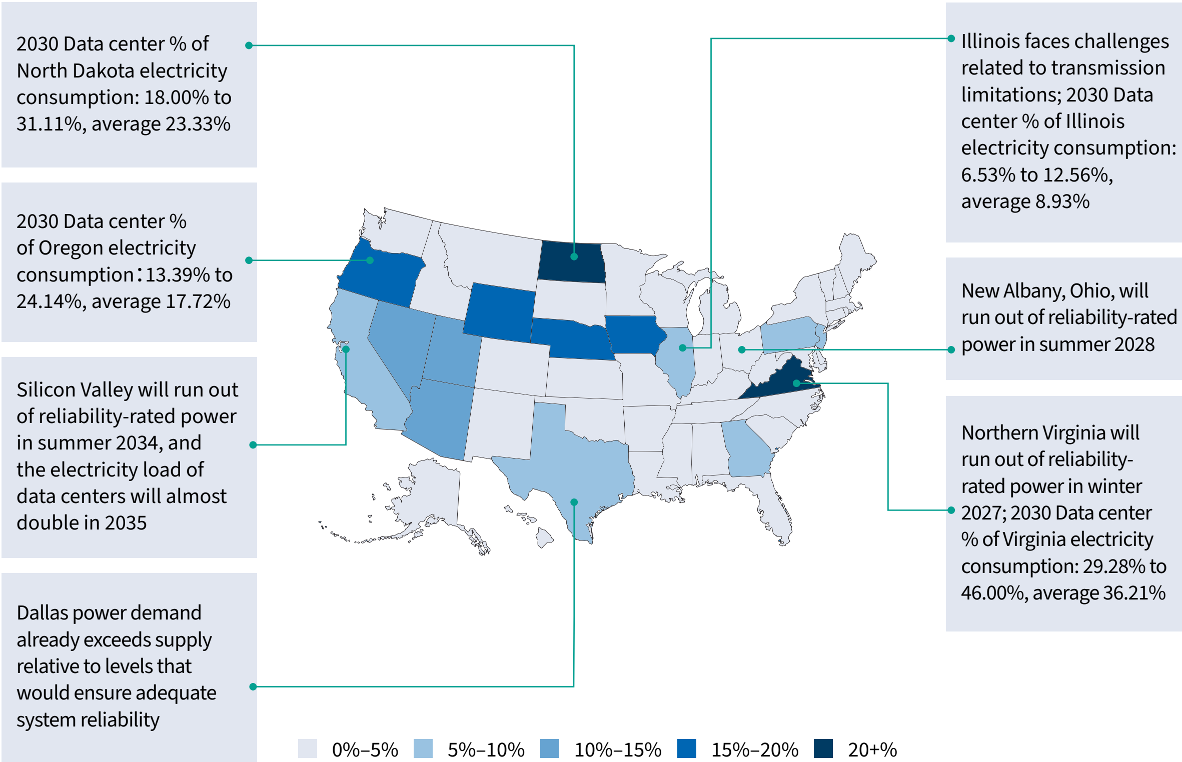
vii Data-center electricity consumption is not listed as a separate category in official electricity statistics. However, current and projected electricity consumption figures are estimated by various institutions. Although different organizations use different statistical criteria and estimation methods, there is a consensus that data-center electricity consumption will continue to grow in the future.

viii According to International Data Corporation, a hyperscale data center contains at least 5,000 servers and requires at least 10,000 square feet of space.

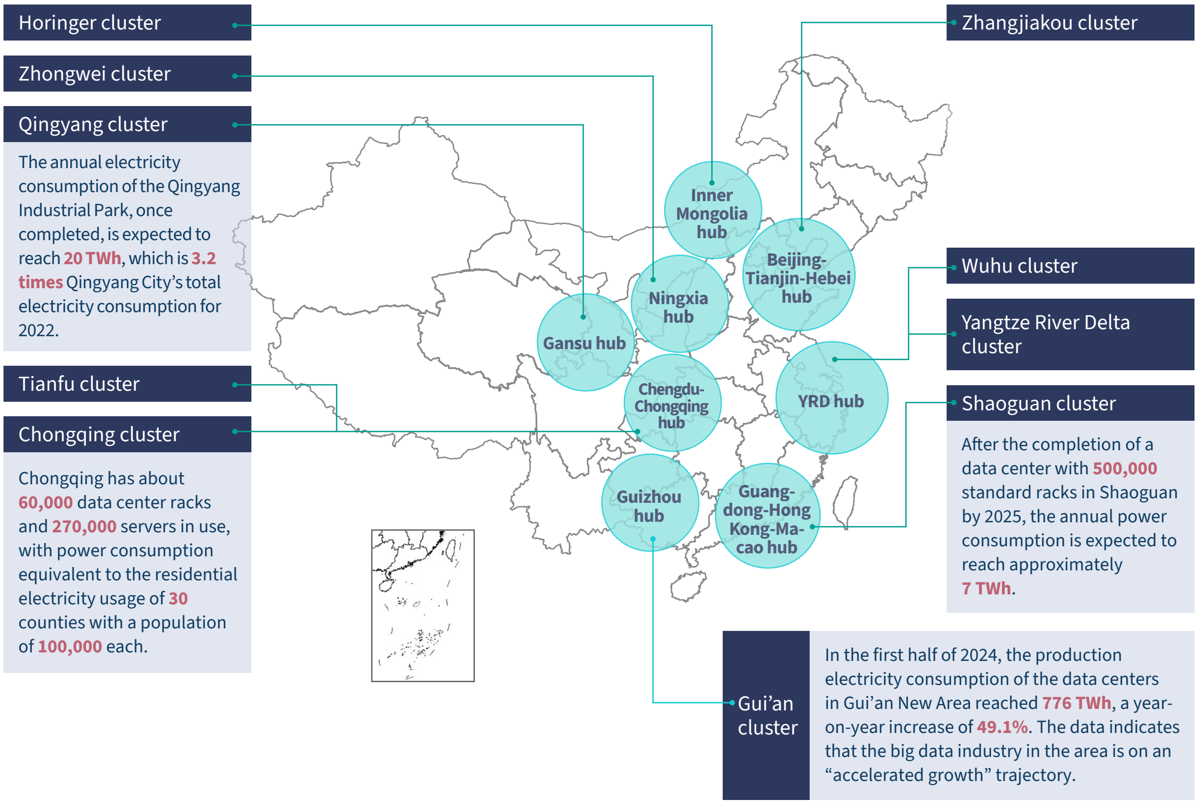
Exhibit 5 **2030 projected data center share of state electricity consumption in the United States and examples of potential local power system challenges**



Note: 2030 data center % in state electricity consumption is the average of four scenarios in the EPRI report.
RMI Graphic. Source: TD Securities, *Data Centers Part II: Power Constraints — The Path Forward*, **https://www.tdsecurities.com/ca/en/data-centers-2-power-constraints**; Data Center Dynamics, "PG&E: 3.5GW of Data Center Capacity in California's Connection Pipeline over Next Five Years," **https://www.datacenterdynamics.com/en/news/pge-35gw-of-data-center-capacity-in-connection-pipeline-over-next-five-years/**; and EPRI, *Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption*, **https://www.wpr.org/wp-content/uploads/2024/06/3002028905_Powering-Intelligence_-Analyzing-Artificial-Intelligence-and-Data-Center-Energy-Consumption.pdf**

In China, new electricity demand from data centers will increasingly concentrate in key hub cities. The central government has developed a top-level design for the national computing power layout, establishing 8 national computing hubs and 10 national data-center clusters in the hubs. In principle, no new large or extra-large data centers will be constructed outside of these hubs.[16] By 2025, it is expected that approximately 60% of new computing power will be concentrated in these hubs. Electricity consumption in these clusters has already shown significant growth (see Exhibit 6). For instance, data-center electricity consumption in Zhangjiakou rose from 6.8% of the city's total electricity consumption in 2019 to 20.1% in 2023. The annual electricity consumption of the Qingyang Data Center Industrial Park is projected to reach 3.2 times the city's 2022 total electricity consumption.[17] This booming demand puts massive pressure on local grid expansion and power plant build-out.

Exhibit 6 **Eight national computing hubs and ten national data-center clusters in China's East-to-West Computing Resource Transfer Project**

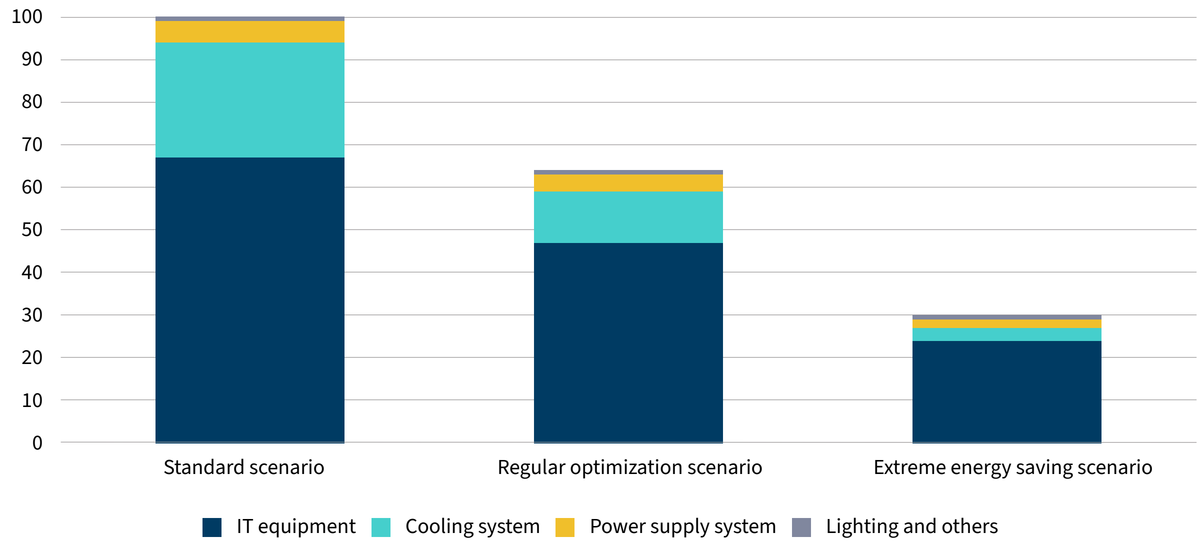


RMI Graphic. Source: National Development and Reform Commission (NDRC), *Understanding the "East-to-West Computing Resource Transfer Project,"* **https://gbdy.ndrc.gov.cn/gbdyzcjd/202202/t20220217_1315798.html**; and public sources, including Economic and Technical Research Institute of the State Grid Jibei Electric Power Company, Shaoguan Toutiao WeChat Official Account, State Grid Qingyang Electric Power Company WeChat Official Account, Smart Chongqing WeChat Official Account, and Guizhou Gui'an New District Management Committee WeChat Official Account

Energy-efficiency potential of data centers remains underexploited

The energy consumption of data centers — comprising IT equipment, cooling systems, and power distribution systems — holds significant potential for energy-efficiency improvements. Data-center energy-saving technologies can be divided into two categories: IT equipment energy savings and auxiliary equipment energy savings. These technologies work together to improve overall efficiency and help data centers reduce their energy consumption. As shown in Exhibit 7, under a regular optimization scenario, implementing IT equipment efficiency measures, such as virtualization and storage upgrades, can reduce data-center energy consumption by approximately 20%. In addition, optimizing cooling systems, including internal airflow improvements, can further reduce energy consumption by around 15%, resulting in a total energy reduction of about 35%. In an extreme energy saving scenario, where both IT and auxiliary systems adopt the most advanced energy-efficient technologies, total energy consumption could be reduced by up to 70%.[18]

Exhibit 7 **Potential for energy-efficiency improvements in data centers**

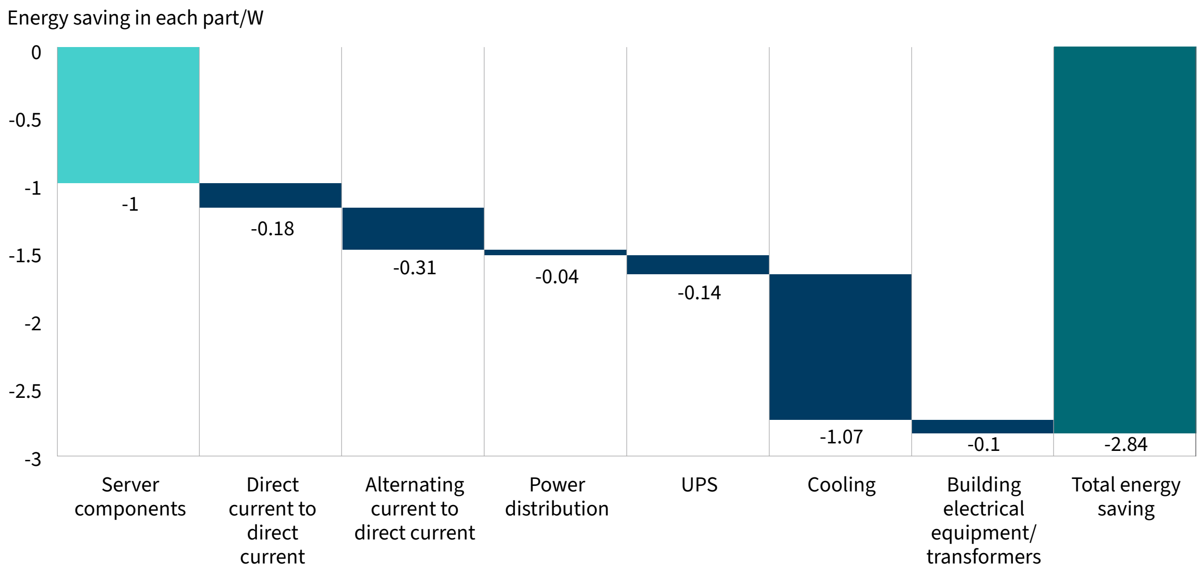


Note: In the standard scenario, total data-center energy consumption is set at 100.
RMI Graphic. Source: H. Zhu et al., "*Future Data Center Energy-Conservation and Emission-Reduction Technologies in the Context of Smart and Low-Carbon City Construction,*" **https://www.sciencedirect.com/science/article/abs/pii/S2210670722006266**

Improving the energy efficiency of existing data centers is also an urgent issue. Despite the average PUE of data centers in China being 1.48 in 2023, many small and medium-sized data centers were built earlier and typically have higher PUE values, some exceeding 1.8 or even 2.0. Large and extra-large data centers benefit from economies of scale, allowing them to more efficiently allocate and use resources such as power, cooling, and space, resulting in lower overall operational efficiency. However, despite their lower PUE, the massive size of extra-large data centers means that total energy consumption remains a significant issue and more advanced energy-efficiency optimization measures can be implemented.

Although energy-saving technologies for data centers are relatively mature, the main obstacle to wider adoption is that energy-efficiency evaluation metrics and measures are still insufficiently integrated into data-center construction standards. Currently, PUE is the predominant metric used to assess energy efficiency, but it has limitations. PUE is only a ratio and does not reflect changes in total energy consumption. It focuses solely on the energy efficiency of auxiliary systems (cooling, power distribution, lighting, etc.), overlooking the energy-saving potential of the IT equipment, itself. For instance, IT equipment typically has low utilization rates — server utilization is often only 5%–15%, and even in idle states, servers consume 30%–40% of their maximum power,[19] leading to significant energy waste. This issue is not captured by PUE. In fact, improving energy efficiency at the IT equipment level can have a "cascading effect" throughout the entire data center, reducing the energy consumption of power distribution and cooling systems (see Exhibit 8).

Exhibit 8 **Energy-efficiency cascade effect of IT equipment optimization**

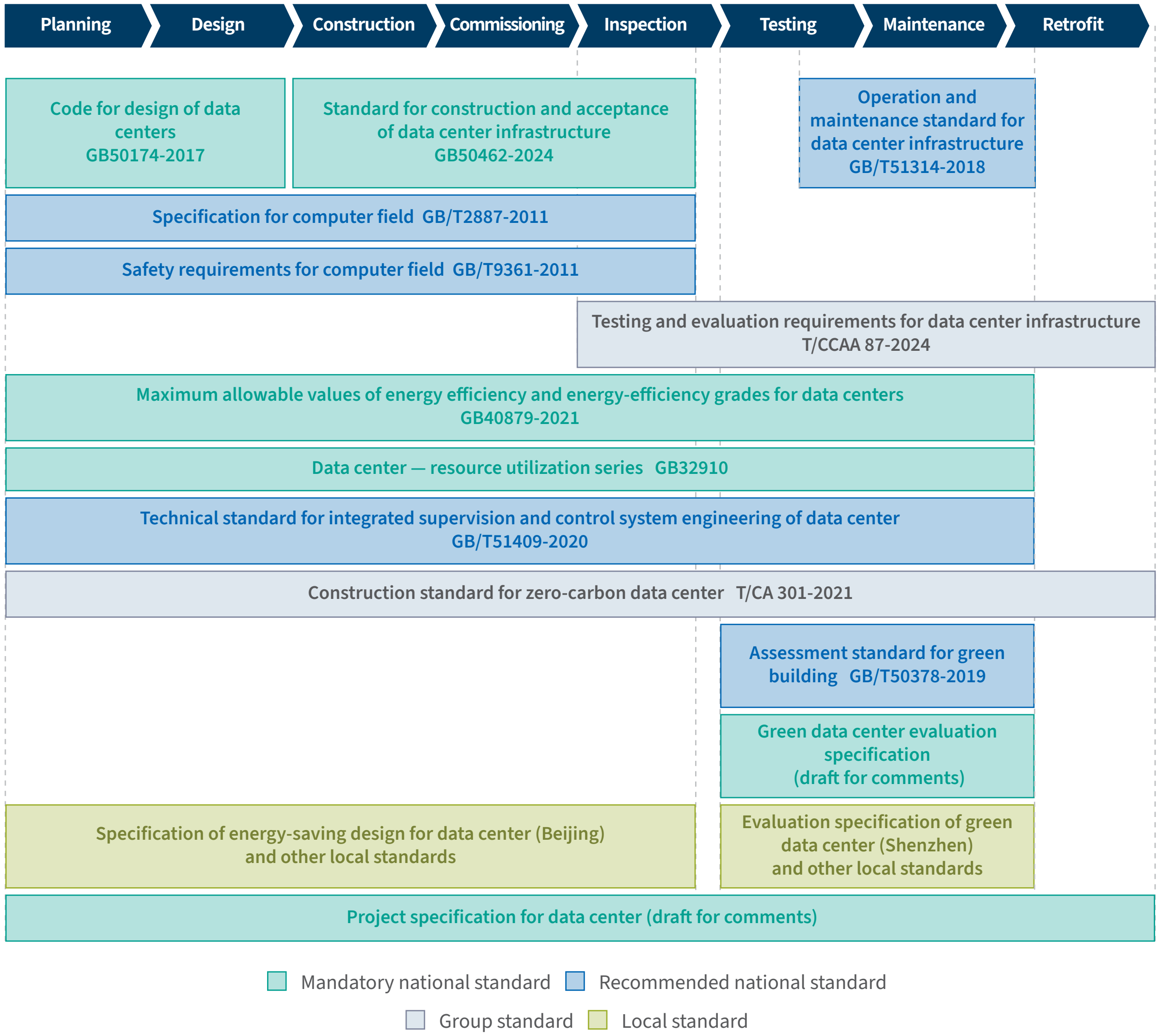


RMI Graphic. Source: Vertiv, *Discussion on PUE in Data Centers — Understanding the "BUG" in PUE and How to Address It*, **https://mp.weixin.qq.com/s/okEL4ErxDSN99bN6c6e9wQ**

Besides, there is room for improvement in the construction and management standards of data centers regarding the guidance of energy-efficiency measures. The Code for Design of Data Centers references the Design Standard for Energy Efficiency of Public Buildings for thermal insulation design of building envelopes. However, there are fundamental differences between the energy-efficiency requirements of data centers and public buildings. Whereas public buildings are primarily focused on providing a comfortable environment for people, data centers are designed to serve IT equipment. IT equipment has high power consumption and heat generation, requiring continuous heat dissipation to the outside environment. Therefore, energy-efficiency requirements for the building envelopes of data centers must consider their unique thermal environment characteristics.

Although China's data-center standard system already covers the full life cycle of data centers, including planning, construction, commissioning, and retrofit (see Exhibit 9), these standards have not yet fully and systematically reflected energy-efficiency and carbon-reduction requirements throughout the entire life cycle of data centers. Additionally, comprehensive energy-efficiency guidelines have not been developed for data centers of varying sizes and business types.

Exhibit 9 **Illustration of China's data-center standards system**



RMI Graphic. Source: RMI analysis

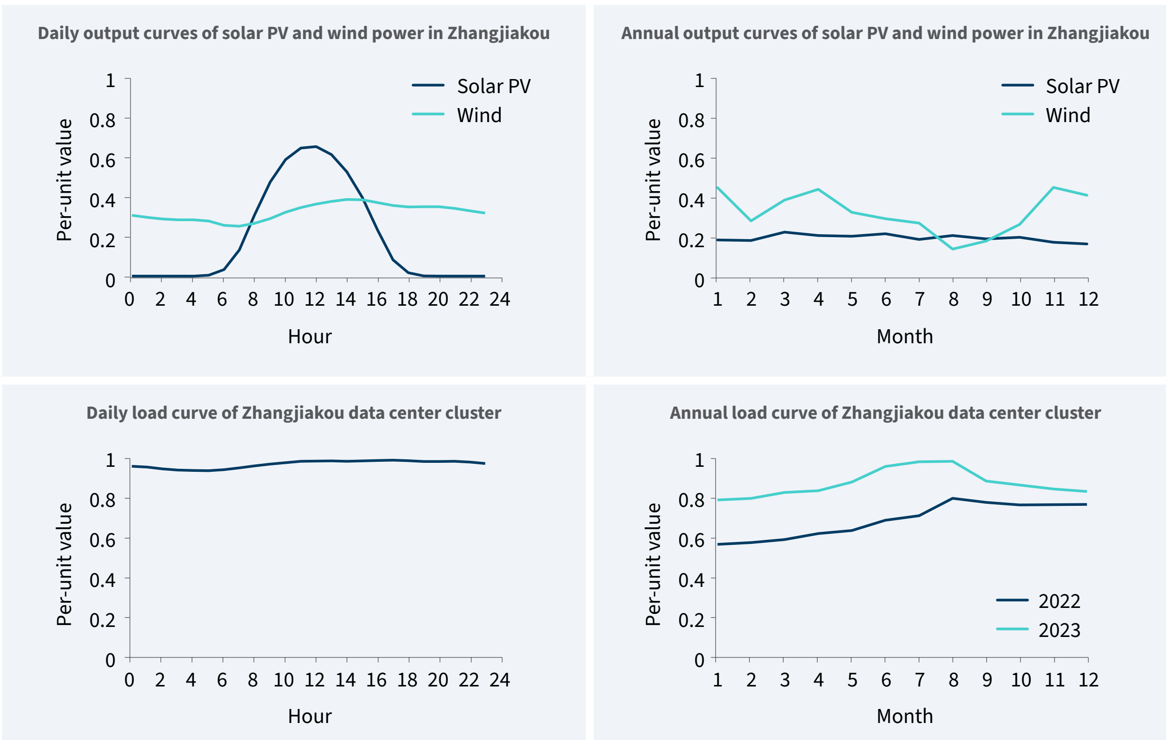
Temporal and spatial mismatch between computing demand and green power poses challenges for decarbonizing data centers

Meeting the energy demands of data centers with low- and zero-carbon electricity (referred to as "green power") is crucial for further reducing carbon emissions. However, from a physical standpoint, there is a temporal and spatial mismatch between data-center load and green power resources.

From a temporal perspective, the variability of renewable energy makes it challenging to meet the data-center requirement for a 24/7 stable power supply. Data centers require high power stability, with load profiles characterized by low intraday fluctuations and higher loads in summer. In contrast, renewable energy sources such as wind and solar exhibit high intraday fluctuations and strong seasonal uncertainties, leading to a mismatch between the timing of data-center electricity demand and renewable energy generation.

Exhibit 10 showcases an example of the Zhangjiakou data-center cluster in China. As early as 2022, the share of renewable energy installed capacity in Hebei, Gansu, and Ningxia — provinces with national computing hubs — exceeded 50% and is continuing to rise. In the future, the temporal mismatch between renewable energy generation and data-center demand will become increasingly pronounced, highlighting the importance of enhancing coordination between data centers and power systems in planning and operation.

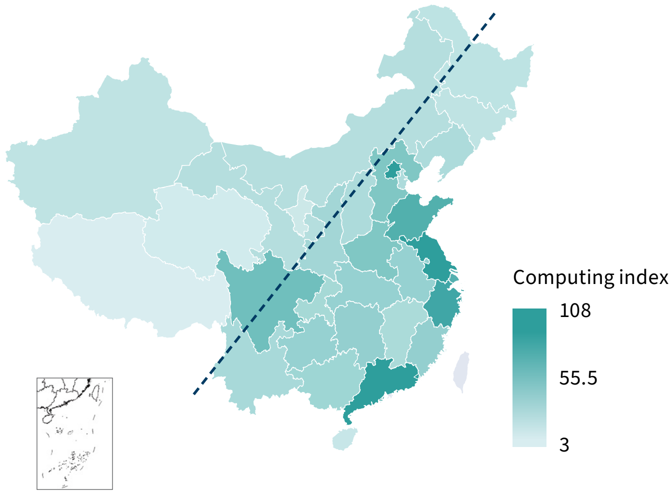
Exhibit 10 **Daily and seasonal mismatch between data-center load and renewables generation in Zhangjiakou data-center cluster**



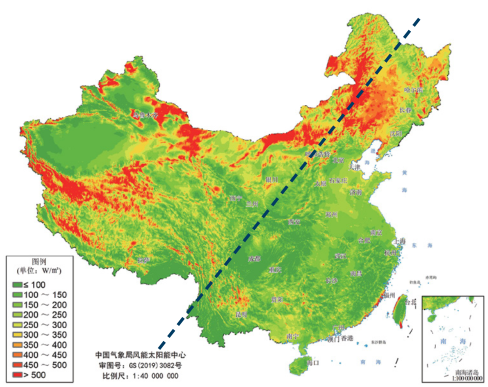
RMI Graphic. Source: Economic and Technical Research Institute of the State Grid Jibei Electric Power Company, Yue Hao, *Analysis of the Impact of the Rapid Growth in Intelligent Computing Power on Power Supply and Demand*, North China Electric Power University, **https://mp.weixin.qq.com/s/w05pYBIQRzfWRmTx2KyycA**; and Renewables Ninja, **https://www.renewables.ninja/**

From a spatial perspective, there is a mismatch between the distribution of data centers and green power resources. In China, historical data-center planning is demand-oriented, primarily concentrated in the eastern coastal regions. However, renewable energy resources such as wind, solar, and hydropower are abundant in the central and western regions, creating a clear spatial resource mismatch. To address this challenge, China has introduced the East-to-West Computing Resource Transfer Project, which promotes the migration of high-latency services — such as AI model training, machine learning, video rendering, offline analysis, and storage backup — from East to West China to coordinate the development of computing power and green energy.[20] However, challenges remain in implementation. Although data-center hubs and clusters in the western regions generally are near large renewable energy bases, existing renewable energy bases often already have long-distance transmission plans because early-stage planning coordination is insufficient, meaning local data centers may not guarantee enough green power.

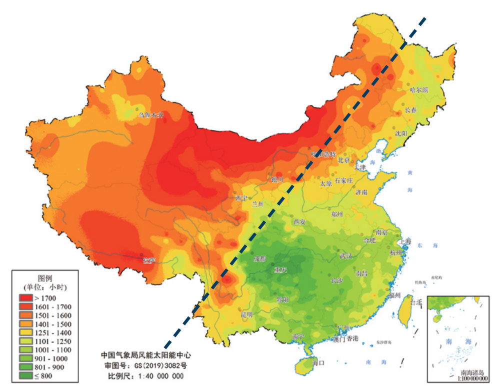
Exhibit 11 **Computing index by province and distribution of wind and solar PV resources in China**



National distribution map of the annual average wind power density at 100-meter height onshore



Distribution map of annual total solar irradiation for the best-slope fixed PV



Note: The China Computing Power Development Index is an evaluation metric used to assess the level of computing power development in China. The index, updated to version 2.0, is built on relevant indicators across five dimensions: computing power scale, industry, technology, environment, and applications. For more details, refer to the *White Paper on China's Computing Power Development Index* (2023) by CAICT.

RMI Graphic. Source: CAICT, *White Paper on China's Computing Power Development Index* (2023), **http://www.caict.ac.cn/english/research/whitepapers/202311/P020231103309012315580.pdf**; and China Institute of Water Resources and Hydropower Research, China Meteorological Administration, *Annual Bulletin on Wind and Solar Energy Resources in China 2023*, **https://www.cma.gov.cn/zfxxgk/gknr/qxbg/202402/t20240222_6082082.html**

Coordinated support of policies and market mechanisms is needed to drive carbon reduction in data centers

First, there is a lack of binding carbon-emissions regulations and disclosure mechanisms specific to data centers and related services and products, such as computing power, which weakens motivation for emissions reduction. Globally, sustainability disclosure requirements for data centers are shifting from voluntary to mandatory; however, China does not yet mandate carbon-emissions data disclosure for data centers or computing services. This includes:

- Organizational carbon disclosures for carbon markets: Most nationwide carbon markets only incorporate entities' Scope 1 emissions, but the carbon emissions of data centers are primarily Scope 2 emissions.

- Corporate environmental, social, and governance (ESG) disclosures for investors and consumers: An increasing number of listed companies in China start corporate ESG disclosures, which are still voluntary, and standards for disclosure and carbon-emissions disclosure are yet to be unified.

- Product-level carbon accounting, which downstream companies increasingly need when procuring data-related services and products: Data centers produce services rather than physical goods — specifically, computing power or digital services — which makes defining product units and accounting boundaries challenging. Furthermore, downstream companies do not yet explicitly require carbon-footprint data for the digital services they purchase from data centers.

Second, despite potential inclusion in carbon markets and disclosure requirements from downstream users, data centers and computing power services still lack a standardized carbon accounting methodology. Two main challenges must be addressed in developing this methodology.

- The carbon accounting methodology should cover various data-center operations, including on-premises data centers, colocation operations, and public cloud operations.[ix] A comprehensive approach that clearly defines accounting boundaries and considers data centers' contributions to decarbonizing other sectors is critical for accurate data-center carbon accounting. Although the Uptime Institute has proposed emissions scope guidelines for different data-center types (see Exhibit 12), a unified methodology has yet to be established in China or internationally.

- China's domestic carbon-emissions database, which significantly influences accounting outcomes, is still under development. Foreign databases cannot accurately represent the carbon footprint of production activities in China, and international recognition of green certificates for renewable power remains limited, creating uncertainty about their applicability in emissions offsetting. These factors could significantly affect the accuracy and credibility of carbon accounting, an issue also faced by data centers worldwide.

ix An on-premises data center is owned and operated by an organization to house its own IT infrastructure. Colocation data centers are designed for multiple organizations to locate their IT infrastructure in the same facility.

Exhibit 12 **Emissions accounting scope allocation by data-center operational control type**

	Emissions accounting scope	
	IT–related emissions	Facility infrastructure–related emissions
IT operator owns data center		
IT operator	2	2
IT operator at a colocation facility		
IT operator	2	3
Colocation operator	3	2
IT operator on a public cloud		
IT operator (cloud customer)	3	3
Cloud operator	2	2
Public cloud in a colocation facility		
IT operator (cloud customer)	3	3
Colocation operator	3	2
Cloud operator	2	3

Note: IT operators are entities (such as businesses, government agencies, etc.) that require computing power or digital services. Colocation providers are companies that offer data-center space and infrastructure, allowing other companies to place their IT equipment within the data-center facility while providing power, cooling, and security services. Cloud service providers are companies that deliver cloud computing services and manage the underlying cloud infrastructure, virtualization, and network resources. IT-related emissions are carbon emissions from energy consumption by IT equipment, while infrastructure-related emissions are carbon emissions from energy consumption by data-center systems such as cooling, lighting, and ventilation.

RMI Graphic. Source: Uptime Institute, *Accounting for Digital Infrastructure GHG Emissions*, **https://journal.uptimeinstitute.com/accounting-for-digital-infrastructure-ghg-emissions/**

Third, data-center decarbonization lacks adequate financial support. Significant capital is required for energy-saving investments in new data centers and efficiency upgrades in existing ones, especially older facilities where high upgrade costs present an even greater challenge.[21] Targeted financial support could effectively accelerate the adoption of energy-efficiency and carbon-reduction technologies in data centers. However, many deep decarbonization technologies for data centers remain costly, and various carbon-reduction technologies have yet to be included in catalogs of green bond supported projects.[22]

Comprehensive Transformation Pathways for Decoupling Data-Center Boom with Emission Surge

Integrating multiple factors in data-center site selection and layout planning

Data centers can achieve sustainable development by optimizing resource allocation, reducing costs, and minimizing environmental impact through systematic and strategic planning while meeting business needs. Specifically, data-center site selection should comprehensively consider critical factors, including computing power demand, power supply, cooling, heat recovery, land and policy, and network infrastructure to ensure technical feasibility, economic viability, energy saving, and carbon reduction.

- **Computing power demand:** Site selection for data centers is directly influenced by the requirements of application scenarios, with latency requirements dictating the physical proximity to users. For scenarios needing low latency and high operational performance, such as financial trading, autonomous driving, and the Internet of Things, edge data centers are commonly used to reduce latency and enhance performance.[x] Proximity to end-users can also lower bandwidth costs, reduce the likelihood of network congestion, and decrease energy consumption and the carbon footprint associated with data transmission. For scenarios that do not require low latency, such as non-real-time data analytics or data hosting, it may be viable to establish data centers in more remote areas.

- **Green power resources:** Data-center site selection should consider the availability of green power to reduce the carbon footprint and energy costs. Beyond sourcing green power, data centers should employ dual or multiple power supply paths and combine various clean-energy sources to ensure a reliable and stable power supply. Strategies for acquiring green power in site selection include: (1) locating data centers in areas with ample wind, solar, hydro, or nuclear power sources, where they can obtain green power from the grid or connect directly to green power sources; and (2) in regions with scarce local green power resources, data centers can acquire green power through trading to overcome geographical limitations.

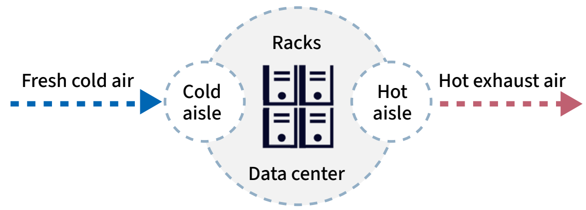
- **Natural cooling resources:** Using natural cooling resources is an effective energy-saving strategy for data centers. As shown in Exhibit 13, application options include: (1) selecting cold or temperate climate zones to use low-temperature outdoor air for direct or indirect cooling of data centers; (2) opting for arid regions to employ evaporative cooling technologies; and (3) locating near natural water sources, such as rivers or lakes, to adopt water-cooling systems. When planning new data centers, it is also essential to consider long-term climate trends and the potential for geological hazards. Measures such as intelligent control systems, phase-change energy storage materials, and seasonal thermal storage can help maintain the effectiveness and safety of cooling strategies.

x An edge data center is the data center closer to end users or devices that collect and transmit data, or wherever data is generated.

Exhibit 13 **Illustration of natural cooling resources utilization in data centers**

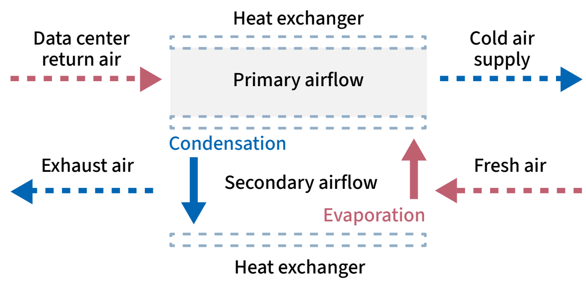
Direct natural-air cooling
Based on the temperature difference between cold air outdoors and indoor air, outdoor air is directly or partially introduced to replace air conditioning for the data center

- High air-quality requirements
- Low energy consumption and high energy saving rate



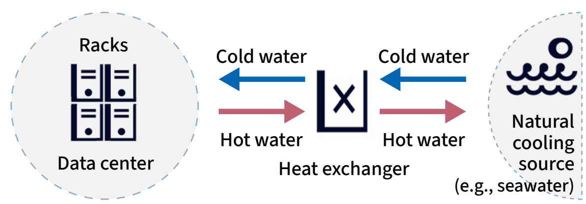
Indirect evaporative cooling
Use air cooled by direct evaporative cooling to cool the return air through a heat exchanger

- High reliability with simple structure
- Fully utilizes natural cooling sources, providing cooling on demand



Natural water cooling
Introduces natural outdoor, low-temperature water sources (such as seawater, lakes, rivers, etc.) into the data center for cooling

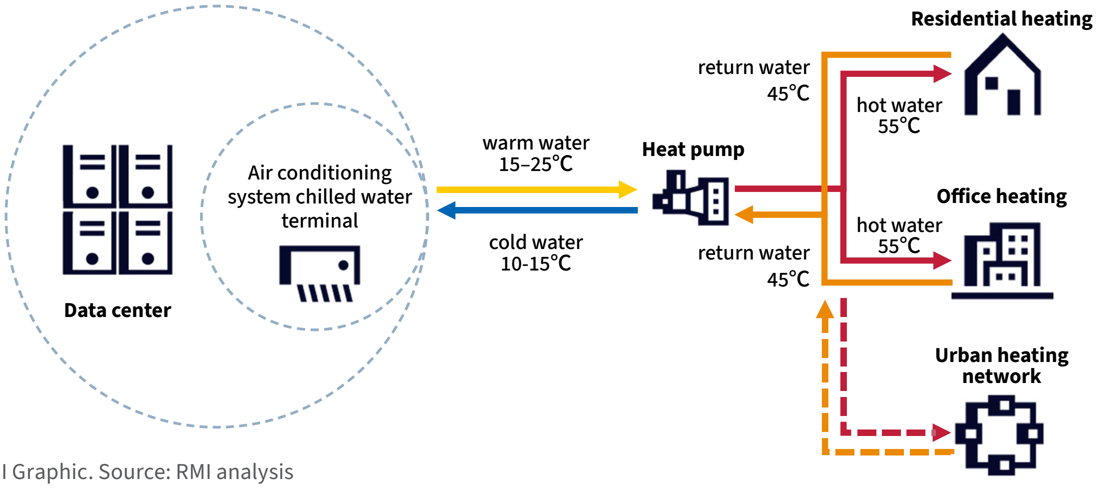
- High technical requirements: thermal flow, seabed currents, water temperature changes, water impurities, and turbidity
- Special material technology: prevents corrosion by seawater



RMI Graphic. Source: RMI analysis

- **Heat recovery:** Heat recovery from data centers is an effective strategy to improve energy utilization efficiency (see Exhibit 14). Using absorption cooling, heat pump systems, thermal storage, and integration with district heating systems, waste heat from data centers can be converted into thermal energy or electricity, enabling energy reuse. Waste heat is mostly used for heating and domestic hot water in two forms: (1) for data centers in industrial or office parks, site planning can consider the heating needs of various buildings, especially for heating office spaces and providing hot water for employee dormitories; and (2) for stand-alone data centers, waste heat can be transferred to buildings at urban heating networks through direct heat exchange or heat pumps. Additionally, if data centers within a park have excess waste heat after meeting internal heating needs, this surplus heat can also be connected to urban heating networks, further expanding the scope of heat recovery.

Exhibit 14 **Illustration of data-center heat recovery**



RMI Graphic. Source: RMI analysis

- **Land prices and policy factors:** Land costs, local incentive policies, recruitment challenges, government approval processes, and broader macroeconomic policies are key factors in data-center planning. Land costs vary by region, and some local governments may offer favorable land prices to attract investment. Additionally, different regions may provide incentives such as tax breaks and financial subsidies. Data-center operations depend on skilled technical personnel, so the availability of local talent and recruitment ease are also important factors; areas with higher education institutions and research resources may offer advantages. Data-center construction requires government approval, and some regions may impose strict limitations on energy consumption and carbon emissions.

- **Network infrastructure:** Bandwidth resource planning is crucial for new data centers. Given the growing bandwidth demands of data centers, site selection should consider proximity to high-speed fiber networks and the scalability of network infrastructure to support current data transmission needs as well as future growth. High-performance network equipment and advanced networking technologies are also essential for enhancing network performance. For services requiring real-time data processing, data centers should ideally be near major network-provider nodes or internet exchange points. For AI data centers, special attention should be given to fiber network capacity and scalability. Additionally, data-center planning should consider data transmission security to minimize risks of business disruption.

To achieve optimal data-center location, site selection should follow four main principles (see Exhibit 15):

Demand-oriented: The site should be close to areas with high computing demand to minimize latency and improve service quality. This requires a thorough analysis of network latency needs, the level of digital industry development, and regional informatization.

Cost-oriented: Site selection should comprehensively consider power costs, land prices, and labor costs to minimize operational expenses.

Green-oriented: Priority should be given to regions with abundant renewable energy resources and favorable climate conditions to promote sustainable energy use and eliminate environmental impact.

Security-oriented: Data-center locations must ensure both physical and network security, considering geological stability and low disaster risk to safeguard data and service integrity.

In addition to these principles, site selection for data centers should also consider policy, transportation, and other factors. Through scientifically planned layouts, a balance can be achieved between economic and environmental benefits.

Exhibit 15 **Principles for optimal data-center site selection and layout**

	Demand-oriented	Cost-oriented	Green-oriented	Security-oriented
Computing power demand	• Based on the latency requirements of different business scenarios, determine the physical distance from users.	• Reduce bandwidth costs by being close to end-users. • Shorten data transmission distance to reduce data-center energy consumption.		
Green power resources		• Fully utilize green electricity resources in regions with abundant supply to reduce power costs.	• Physically locate close to green power resources to increase green power consumption. • Ensure the accessibility of cross-province and cross-regional green power transactions.	• Select dual or multiple power supplies and complementary green electricity to ensure safe and stable data-center power supply.
Natural cooling resources		• Fully utilize natural cooling sources to replace electric cooling systems. • Store cooling energy at night or when temperatures are lower for daytime use.	• Fully utilize natural cooling sources to replace electric cooling systems.	• Reduce dependence on electric cooling systems. • Ensure a stable operating environment, such as stable temperature and humidity.
Heat recovery		• Convert waste heat into economically valuable energy. • Some regions offer tax incentives or subsidies for waste heat utilization.	• Improve overall energy utilization efficiency, reducing energy consumption and carbon emissions.	
Land prices and policy factors		• Ensure reasonable land and labor costs to reduce operating expenses. • Utilize incentives such as tax deductions and subsidies provided by local governments.		
Network infrastructure	• Focus on the local network resources to match the needs for high-performance, low-latency, and high frequency, real-time interaction.	• Possess flexible scalability to quickly expand bandwidth and add nodes, reducing long-term investment risk.		• Use redundant network equipment and path design to reduce risks. • Use advanced technology to increase bandwidth, ensuring real-time transmission.

RMI Graphic. Source: RMI analysis

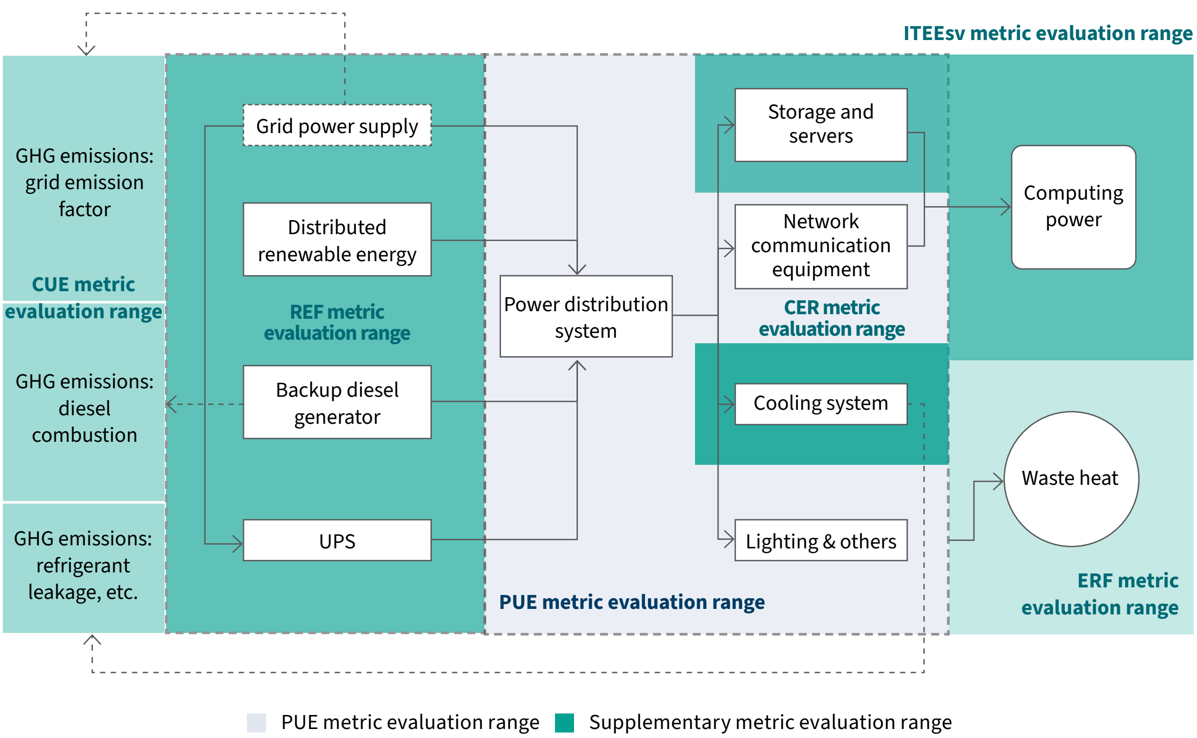
Enhancing energy efficiency in new and existing data centers

Refine energy and carbon assessment metrics and standards to guide the construction of new data centers

Given that PUE cannot fully measure the overall performance of data centers regarding energy efficiency and carbon emissions, a comprehensive, multidimensional energy-carbon assessment framework is needed. Exhibit 16 outlines recommended supplementary metrics for assessing data-center energy and carbon performance. These metrics cover nearly every aspect of data-center energy consumption, forming a comprehensive framework for energy and carbon assessments. Additionally, the energy-carbon metrics within data-center standards should account for regional variations — such as climate conditions, energy structure, and water resource availability — to set appropriate guiding and limiting values. This approach ensures that the assessment system is scientific, practical, and effective.

Exhibit 16 **Comprehensive energy-carbon assessment framework for data centers**

	Energy type	Cooling efficiency	Waste heat utilization	Carbon emissions	IT equipment efficiency
Main evaluation metric	Renewable energy factor (REF)	Cooling efficiency ratio (CER)	Energy reuse factor (ERF)	Carbon usage effectiveness (CUE)	IT energy efficiency of servers (ITEEsv)
Calculation formula	REF = amount of renewable energy used by data center ÷ total energy consumption of data center	CER = cooling output of data center's cooling system ÷ total energy consumption of cooling system	ERF = amount of energy reused from data center ÷ total energy consumption of data center	CUE = amount of CO_2 emissions from energy used by data center ÷ IT equipment energy consumption (kWh)	ITEESv = number of tasks processed by IT equipment servers ÷ server energy consumption



RMI Graphic. Source: RMI analysis

Integrating more comprehensive energy-saving and low-carbon technologies and management measures into data-center construction standards can optimize energy use and reduce carbon emissions from the outset.

- **Energy efficiency for non-IT infrastructure:** implementing green building design methods to reduce the energy demands of data centers and installing energy-efficient equipment. This includes optimizing the thermal performance of building envelopes, using passive cooling, employing efficient cooling and power distribution systems, and deploying intelligent management systems for real-time energy monitoring and optimization.

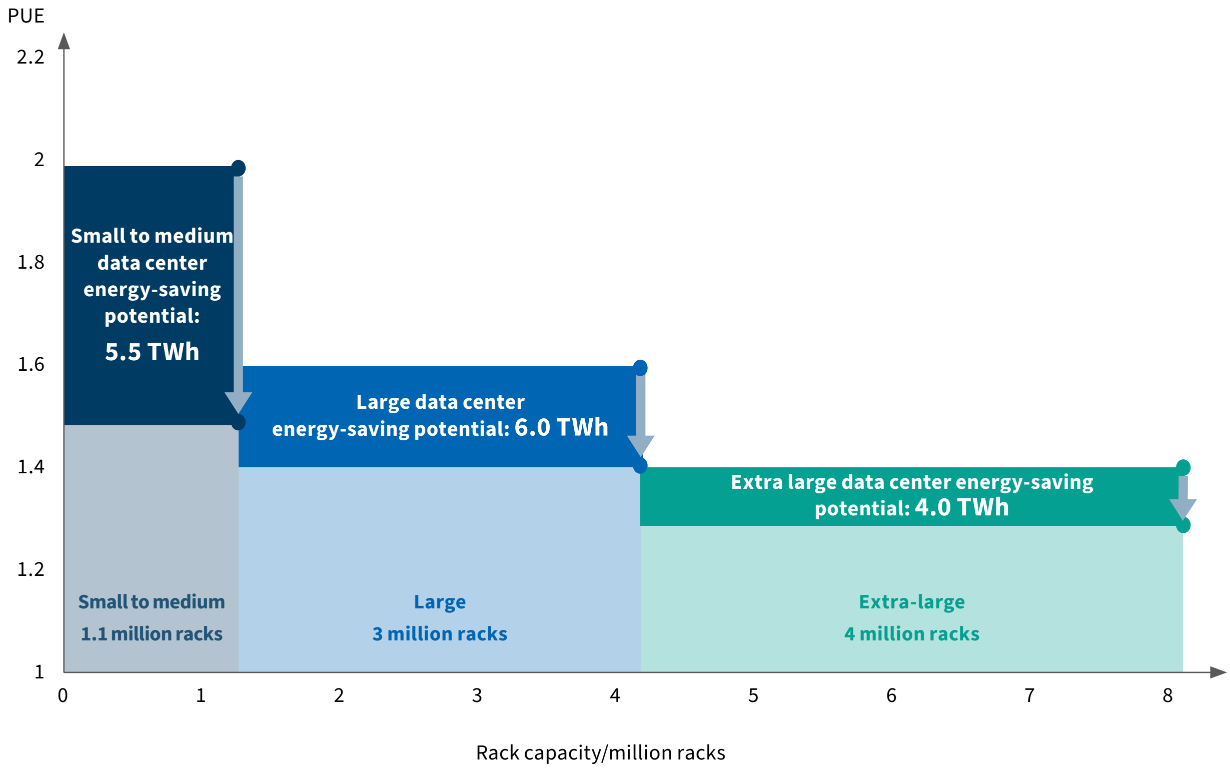
- **Energy efficiency in IT equipment and software systems**: improving computational efficiency by optimizing algorithms, enhancing server utilization through load balancing, and selecting high-efficiency servers, storage, and networking equipment to significantly boost the energy efficiency of the data center's IT systems.

- **Renewable energy utilization:** diversifying renewable power supply sources and coordinating computing with electricity will support the goal of carbon-neutral power. Additionally, attention should be given to procuring low-carbon IT equipment, using sustainable building materials, ensuring indoor environmental quality, and reducing the overall environmental impact of the building through life-cycle assessments.

Conduct comprehensive energy retrofits for low energy-efficiency data centers

To improve the energy efficiency of existing data centers, it is essential to develop tailored retrofit plans that address the specific conditions and needs of each data center. For outdated data centers with significant inefficiencies, considerations may include shutdown or consolidation measures.
For large and extra-large data centers, energy-saving retrofits should be implemented in stages and batches, focusing on operational management optimization, partial upgrades, and comprehensive system overhauls. According to RMI estimates, implementing energy-saving retrofits for existing data centers through classification in China — specifically aimed at improving the energy efficiency of non-IT equipment — can achieve energy savings rates of approximately 25% for small to medium-sized data centers, 13% for large data centers, and 7% for extra-large data centers. The total annual energy saving is estimated to reach 15.5 TWh (see Exhibit 17).

Exhibit 17 **Potential for classified energy-saving retrofits through classification in China's data centers**



RMI Graphic. Source: RMI analysis

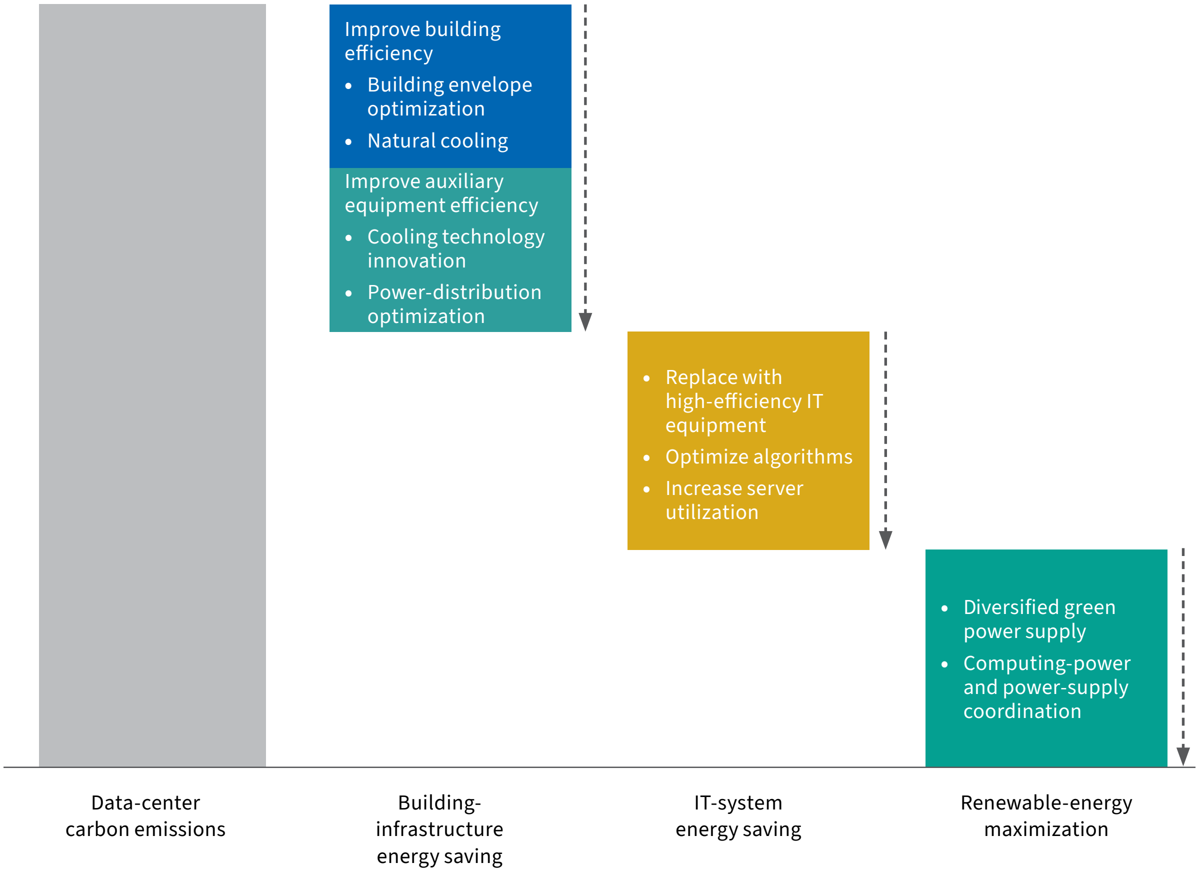
A thorough energy-saving and carbon-reduction retrofit in data centers focuses on three key aspects:

Improving energy efficiency in non-IT infrastructure: This includes improving building energy efficiency, such as optimizing the building envelope and using passive cooling. It also involves enhancing the efficiency of auxiliary systems, such as cooling and power distribution.

Improving energy efficiency in IT equipment and software systems: This involves replacing older IT equipment with more energy-efficient models and improving overall efficiency through algorithm optimization and increasing server utilization.

Increasing renewable energy utilization: This can be achieved by adopting diversified green power supply options and enhancing coordination between computing and electricity usage during operations. By reducing reliance on fossil fuels and maximizing the use of renewable energy, data centers can achieve the goal of low-carbon or even zero-carbon operation (see Exhibit 18).

Exhibit 18 **Pathways for energy-saving and carbon-reduction retrofits in data centers**



RMI Graphic. Source: RMI analysis

Energy-saving retrofits in data centers must address challenges such as data security risks, downtime risks, and cross-disciplinary coordination to ensure project success while minimizing operational impact. To reduce risks of data leakage and downtime, the retrofits should minimally affect the production process, making modular data centers a primary solution. Additionally, leveraging existing redundant resources in data centers and implementing retrofits in phased stages can further reduce these risks. To improve the efficiency of cross-disciplinary coordination, establishing a communication and coordination mechanism across specialties is essential. Moreover, enhancing data-center owners' understanding and evaluation of the economic benefits of energy-saving retrofits is key to promoting cost-effective energy-efficiency technologies. Using financial analysis tools, such as return on investment and total cost of ownership models, can provide owners with a clearer and more intuitive understanding of the economic benefits of energy-saving retrofits.

Ensuring scalable, grid-interactive, carbon-free use of energy at data centers

Select diverse green power supply options, including physical connections and market-based transactions

In the operation phase, maximizing the supply of green power is a key measure for achieving low-carbon energy use in data centers. Exhibit 19 presents four mainstream options for companies to secure green power. The first two options involve on-site distributed renewable energy projects, such as solar PV or wind power, for self-consumption or direct connection to off-site green power projects via dedicated electricity lines, both of which provide a physical connection between the power source and the data center. The latter two options use market-based transactions, such as green power trading or purchasing green electricity certificates, which remove geographical limitations. These two enable the transaction and certification of green power or its associated environmental attributes through contractual agreements between buyers and sellers or via third-party institutions.

Exhibit 19 **Comparison of four green power supply options for data centers**

	Option	Scale	Preparation	Economy	Maturity
Location-based	On-site distributed renewable energy	★☆☆☆	★★☆☆	★★★★	★★★★
	Direct physical connection to green power	★★☆☆	★☆☆☆	★★★☆	★☆☆☆
Market-based	Green power trading	★★★☆	★★★☆	★★☆☆	★★☆☆
	Green electricity certificate	★★★★	★★★★	★☆☆☆	★★★☆

Note: The rating is based on the overall global market situation, and specific countries or regions may vary. Starting from 1 to 4 stars, the more stars indicate the following: larger scale (better able to meet corporation needs), shorter preparation time required by the corporation (more convenient), higher cost-effectiveness (less additional cost for the corporation or even potential benefits), and greater maturity of the mechanism (lower risk for the corporation).
RMI Graphic. Source: RMI analysis

Data-center operators should select a combination of supply options based on such factors as electricity consumption scale, project stage, risk tolerance, economic benefits, and environmental disclosure requirements to continually increase the share of green power in their energy mix.

- **On-site distributed renewable energy:** Because of its high cost-effectiveness and ease of installation, distributed renewable energy is often a top choice for companies. However, the scale of green power supply is constrained by the availability of roof and land resources. In general, a portion of the data center's roof area is occupied by cooling systems, leaving limited space for rooftop solar installations. It is estimated that rooftop solar generation can cover less than 1% of a data center's electricity needs.[xi]

- **Direct physical connection to green power:** This option enables a large-scale green power supply and often reduces transmission and distribution costs, making it economically attractive. Currently, many examples rely on stable hydropower and nuclear power sources, although both have significant geographical constraints, limiting large-scale applications. Extensive wind and solar resources, however, are intermittent and variable, conflicting with data centers' need for stable power supply.

  In this case, grid power or dispatchable sources are often needed as backup generation. If grid power serves as a backup, data centers may need to negotiate reasonable reserve fees with the grid or explore new shared business models with the grid for transforming data centers from passive consumers to active flexible grid resources (discussed in the next section).[23] However, these arrangements may involve more complex planning and longer preparation times.

- **Green power trading and green electricity certificate:** These two options are currently the most common for achieving a green power supply among leading global data-center enterprises. The prerequisite for these methods is an in-place market trading mechanism in the country or region. This requires collaboration among the grid, power exchange, and government entities to facilitate the trading, certification, and verification of green power or its associated environmental attributes. Moreover, it should ensure the uniqueness, authority, and traceability of environmental attributes, gaining recognition in domestic and international carbon regulatory frameworks and major international initiatives like RE100 and SBTi.

  The mainstream green electricity certificates include International Renewable Energy Certificates (IREC, global), Tradable Instrument for Global Renewables (TIGR, global), Green Electricity Certificates (GEC, China), and Renewable Energy Guarantees of Origin (GO, EU). Power purchase agreements (PPAs) and other green power procurement options have operated in Europe and the United States for years, adding 36.1 gigawatts (GW) of renewable capacity in Europe and 77.6 GW of zero-carbon capacity in the United States from 2014 to 2023.[24,xii] In China, the green electricity certificate market, established in 2017, provides a sufficient supply, with 1.8 billion certificates issued as of August 2024.[25] Green power trading began in September 2021 and has grown rapidly, with transactions of 8.7, 18.1, and 69.7 TWh in 2021, 2022, and 2023, respectively, representing an average annual growth rate of 283%.[26] In 2023, eight data center–related companies ranked among the top 100 green power (including green electricity certificates) consumers in China.[27]

xi For instance, China Mobile's Dabailou Data Center in Daxing District, Beijing, has approximately 4,700 racks and 3,000 square meters of rooftop solar panels, with an annual solar power generation capacity of 400,000 kWh kilowatt-hours (kWh). Assuming an annual power consumption of 10,000 kWh per rack and an average annual PUE of 1.3, the annual rooftop solar generation accounts for approximately 0.65% of the data center's total annual electricity consumption.

xii In Europe, the statistical scope includes only the contribution from PPAs, whereas in the United States, the figures also account for contributions from additional green power procurement options, such as green tariffs, tax equity investments, and direct investments (project ownership).

Considering international trends in environmental disclosure, companies should increasingly focus on the temporal and spatial matching of procured green power with data-center load. Under the EU RED III framework, the Association of Issuing Bodies plans to enhance the geographic and temporal granularity of GO in 2024 to reflect more precise location, generation time, and technology type of renewable energy.[28] In its *2024 Reporting Guidance*, RE100 also introduces an option for companies to declare granular time and location matching strategies (24/7 procurement), identifying it as a fourth impact metric in its market progress report and indicating a potential future reporting framework for granular matching.[29]

Promote harmonized coordination between data center and power systems

Harmonized coordination between data centers and power systems can create a win-win effect, facilitating both grid decarbonization and low-carbon energy use in data centers. With increasing renewables penetration, the power system is facing uncertainties on both the supply and demand sides, underscoring the need for more flexible and dispatchable resources to maintain balance. Data centers, as large electricity consumers with growing demand, have the potential to be a significant source of demand-side flexibility.

From the perspective of the grid, flexible data-center loads can ease grid balancing pressures, support greater integration of renewables, and lower the grid emissions factor. Over the long term, they can also reduce investments in peaking power plants and delay expansions in transmission and distribution capacity. From the perspective of the data center, in liberalized power-market regions, electricity prices tend to be lower during periods of high renewable generation, incentivizing data centers to shift loads in response to price signals, thus reducing operational costs while achieving low-carbon power supply.

The capability of computing workloads to shift across time and space lays a crucial foundation for addressing the temporal and spatial mismatch between data-center demand and green power supply. Exhibit 20 summarizes the primary sources of temporal and spatial flexibility in data centers and their characteristics for grid-load interaction. The largest portion of data-center load comes from the IT system, which can be further segmented into computing load and server load. The former reflects the dynamic load for data processing tasks, while the latter represents the base load required by core equipment to support these tasks. Computing workloads can be classified as offline or online based on their sensitivity to processing timeliness.

Offline workloads typically consist of complex data processing tasks with long processing times and can tolerate some delay, which provides temporal load flexibility from minutes to hours influenced by server availability and task priority. Online workloads, comprising real-time tasks, are highly sensitive to latency. Generally, the workload scheduling system maintains redundancy for critical online workloads on remote servers, enabling rapid redirection of operational commands from one data center to another geographically, which provides spatial load flexibility.

Leveraging this operational flexibility, data centers can become valuable dispatchable resources on the demand side of the power system, not only providing grid services such as hour-level load shifting and minute-level frequency regulation but also participating in economic dispatch, unit commitment, and system planning processes to achieve coordinated scheduling of data centers and power systems.[30]

Moreover, the cooling, backup power, and other supporting systems offer additional flexibility for load-grid interaction. For example, adjusting cooling equipment and cold thermal storage systems, using the thermal inertia of data-center facilities and cooling networks, and optimizing the operation of distributed energy storage can also enable demand responses to grid signals from the second to hour level, achieving coordinated operation across multiple energy sources, including electricity, heat, and cooling.

Exhibit 20 **Primary sources of temporal and spatial demand-side flexibility in data centers**

Source	Main equipment	Load share	Adjustment method	Temporal flexibility					Spatial flexibility
				Second level	Minute level	Hour level	Day level	≥ Days	
IT system load	Storage and servers	~50%	Online workload scheduling						✓
			Offline workload scheduling	✓	✓	✓	✓	✓	
			Server power management	✓	✓				
Cooling system load	Air conditioning, cooling network	~30%	Temperature control, using thermal inertia	✓	✓	✓			
Backup power system	Diesel generators	N/A	On/off, output control		✓	✓	✓	✓	
	Energy storage system	N/A	Charging and discharging strategy optimization	✓	✓	✓			

RMI Graphic. Source: North China Electric Power University, Cao Yujie et al., *Coordination and Optimization of Data Centers and Power Systems Under the Energy Internet Background (Part II): Opportunities and Challenges, Proceedings of the Chinese Society for Electrical Engineering*

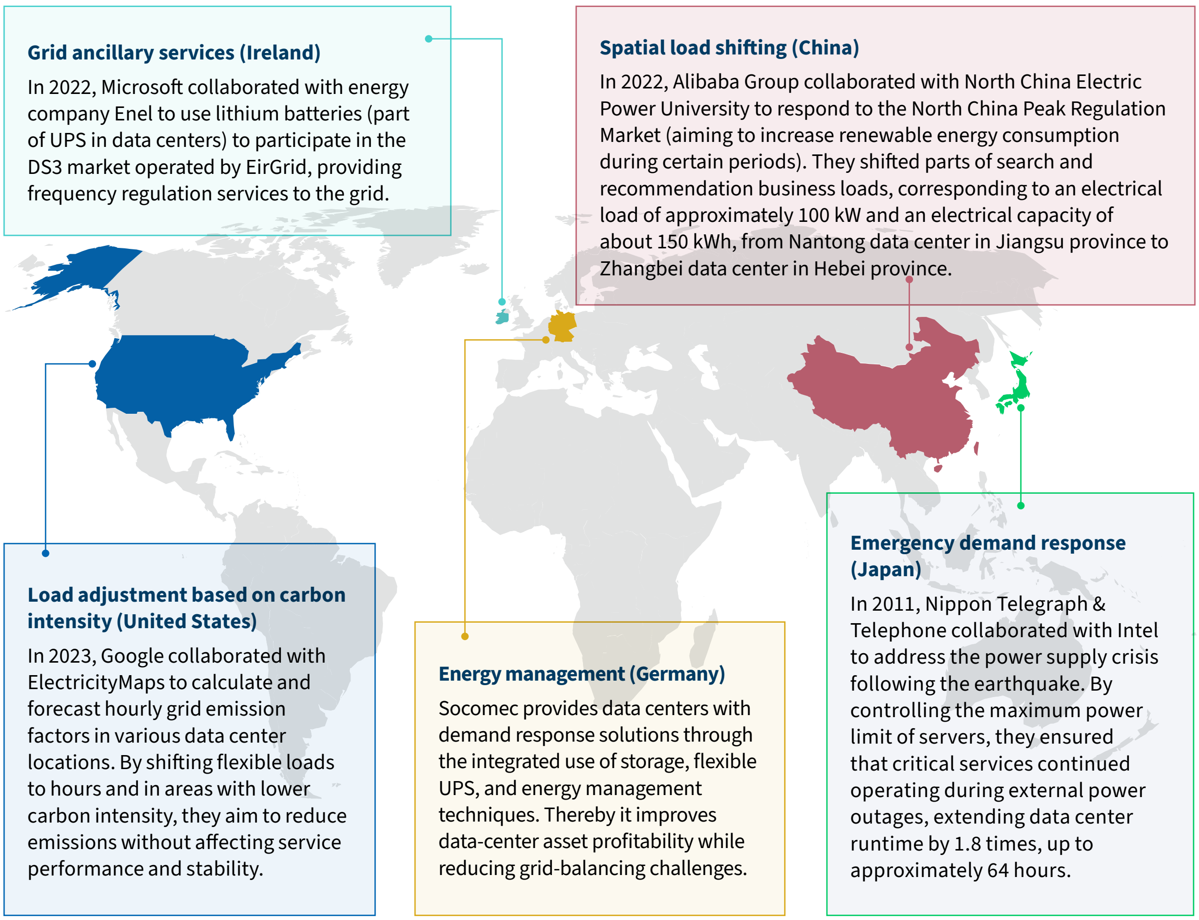
From a practical perspective, the coordinated scheduling of data centers and power systems exists on two levels: (1) intra-facility flexible scheduling of workloads and energy systems within individual data centers; and (2) regional-level coordination across multiple geographically distributed data centers. Exhibit 21 showcases global examples of interactions between data centers and power systems at different levels and of various types.

- **Intra-facility level coordination:** The first step is to establish an efficient and low-carbon energy supply system within the data center. This includes optimizing internal power distribution, improving cooling efficiency, and introducing distributed renewable energy. Next, data-center operators need to leverage the demand-side flexibility of data centers and align load profiles with power and carbon market signals. This is achieved by scheduling the computing workloads with loose logical coupling as flexible resources.[xiii] This approach can increase the consumption of green power and further reduce energy costs and carbon emissions without having an impact on business logic.

xiii Coupling is the degree of interdependence between software modules. Loose logical coupling means that components are weakly associated with each other, and thus changes in one component do not greatly affect the existence or performance of another component.

- **Regional-level coordination:** Characterized by scheduling multiple data centers and optimizing cross-regional data-center loads and power systems, regional-level coordination involves dynamically scheduling workloads and power consumption across multiple geographically distributed data centers. The scheduling system requires high flexibility and adaptability, especially in response to load variations and renewable energy intermittency. Regional-level coordination is often closely integrated with electricity markets, participating in mechanisms such as demand response, frequency regulation, and spot markets to optimize energy costs, while correlating computational costs and market prices. Furthermore, this coordination can respond to carbon signals such as dynamic time- and location-specific grid emissions factors, precisely reducing carbon emissions associated with data-center electricity consumption.

Exhibit 21 **Global examples of interactions between data centers and power systems**



RMI Graphic. Source: Alibaba, "Supporting Green and Low-Carbon Development: Alibaba and North China Electric Power University Release Multiple Results from the Data Center Computing Power and Electricity Coordination Project," **https://developer.aliyun.com/article/1135139**; ElectricityMaps, "Discover How Google Is Reaching Its Sustainability Goals With Electricity Maps," **https://www.electricitymaps.com/client-stories/google**; Microsoft, "Microsoft Datacenter Batteries to Support Growth of Renewables on the Power Grid," **https://news.microsoft.com/source/features/sustainability/ireland-wind-farm-datacenter-ups/**; German Energy Agency, *Sino-German Data Center Flexibility Study — Current Status and Best Practices*; and Intel, "Dynamically Controlling Server Power Consumption and Reducing Data Center Peak Usage by 16 to 18 Percent," **https://www.intel.co.id/content/dam/www/public/us/en/documents/articles/ntt-data-case-study.pdf**

Leveraging policy and market mechanisms to support carbon reduction in data centers

First, it is essential to improve carbon-emissions policies and disclosure mechanisms for data centers and their products (e.g., data-related services) to enhance carbon management in data centers.

- Policy development could begin with mandating carbon disclosure for publicly listed companies and major internet enterprises. Given the high market concentration in the data-center sector, mandatory disclosure by leading companies would significantly reduce emissions while setting an example and offering guidance for small and medium-sized data centers, promoting industry-wide carbon transparency.

- Downstream companies and the public sector can encourage upstream data centers to disclose and manage their emissions by setting carbon requirements for computing power and digital services. Private companies might specify emissions limits in contracts with colocation or cloud providers, while the government and public sector could integrate carbon metrics into procurement standards.

- Incorporating carbon metrics into green data-center certifications can strengthen their role in promoting energy efficiency and carbon reduction. Current certifications, such as China's National Green Data Center Evaluation Index System, primarily address energy efficiency without emphasizing carbon emissions. Adding carbon criteria would encourage data-center operators to improve carbon management and provide clearer guidance for downstream purchasers. Establishing a streamlined application, certification, and approval process could also encourage wider adoption of green certification.

Second, establishing a carbon accounting system for data centers is fundamental for carbon management.

- Carbon accounting for data centers should focus on defining measurement methods for Scope 3 emissions. It should also consider various types of operations (on-premises, colocation, public services), clarifying carbon accounting boundaries and scopes for different entities and ownership structures.

- Data-center operators are encouraged to adopt data-center infrastructure management platforms to standardize the collection, processing, and reporting of energy and carbon data, enhancing the comprehensiveness and transparency of data-center energy and carbon data.

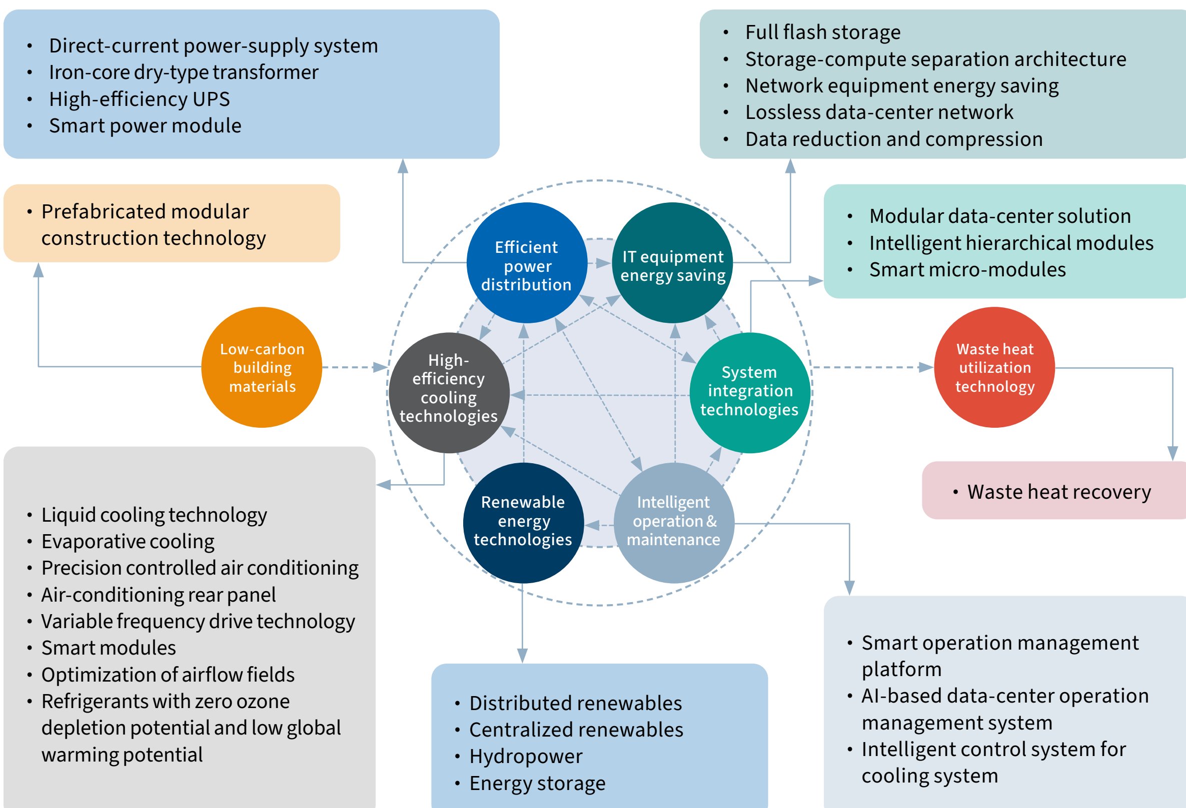
- International alignment and benchmarking of carbon accounting standards are also necessary. With the rapid growth of global internet usage and the introduction of climate-related tariffs, data-center carbon standards must be compatible internationally to address cross-border digital services and emissions. China's system should align with global standards and build a domestically recognized carbon-emissions database with international credibility, supporting the global integration of China's data-center industry.

Furthermore, strengthening the use of green financial tools in the data-center sector is crucial. A more market-driven and specialized green finance model and regulatory framework are needed to provide greater incentives for the deployment of energy-efficiency and carbon-reduction technologies in data centers.

- Innovative green financial tools should be developed to offer diversified funding for implementing green technologies in data centers. Green bonds and sustainability-linked loans are currently the two most widely applied green finance instruments for data-center projects. Additionally, energy-performance contracting models can be explored in data-center retrofit projects, involving third parties like energy service companies to address the high initial investment required for upgrading existing data centers.

- Expanding the green finance taxonomy to include data center–specific technologies would provide clearer guidance for financial support. Prioritizing technologies that improve energy efficiency across subsystems and adopting low-carbon solutions (see Exhibit 22) could simplify project eligibility for green financing, supporting financial institutions, corporations, and listed companies in issuing green bonds. This expanded taxonomy could also guide local governments in designing incentive mechanisms for green bonds and related policies. Finally, including life-cycle carbon-reduction technologies, like prefabricated modular construction, will further help achieve minimized carbon emissions.

Exhibit 22 **Summary of low-carbon technologies for data centers**



RMI Graphic. Source: Department of Energy Conservation and Comprehensive Utilization, PRC Ministry of Industry and Information Technology, *Guide to Energy-Saving Technology Applications in the Information Sector*, **https://www.miit.gov.cn/jgsj/jns/nyjy/art/2022/art_fbb57e69a8b148cfa263953a71b53e2e.html**

Powering the Future: Suggested Actions for Decarbonizing Data Centers

Planning and site selection — optimizing data-center location and layout by balancing multiple factors

- Ensure high availability of green power: Prioritize the construction of data centers in regions rich in green power resources, such as wind, solar, hydro, and nuclear. Use local clean grids, direct physical connections, or microgrids to source green power locally. Where green power resources are limited, consider regions with well-established interprovincial and interregional green power trading markets to supply green power through market mechanisms. Employ dual or multiple power supply paths and combine complementary energy sources to ensure a stable power supply.

- Make full use of natural cooling sources: Select sites with cold or temperate climates to use cool outdoor air or sites near natural water sources such as rivers, lakes, and seas for natural water-cooling systems. Combine these natural cooling technologies with intelligent control systems for automated adjustments to enhance cooling efficiency. Build a reliable cooling system by integrating natural and traditional cooling sources to ensure the stable operation of data centers.

- Explore waste heat utilization: When planning data centers within a park, consider heat demand from surrounding buildings to achieve precise connection and efficient allocation of waste heat. In addition to using waste heat nearby, integrate waste heat into district heating systems through technologies such as heat pumps, thermal storage, and long-distance heat transmission. Use incentive measures such as tax reductions and subsidies offered by national and local governments.

New construction and retrofits — leveraging standards to improve energy efficiency and carbon reduction in new and existing data centers

- Establish a multidimensional energy and carbon assessment framework: Beyond PUE, introduce indicators such as the renewable energy utilization rate, cooling efficiency, energy reuse rate, carbon utilization rate, and server efficiency of IT equipment to build a comprehensive multidimensional energy and carbon assessment framework. Set guidance and constraint values for energy and carbon indicators based on the local climate and energy structure.

- Refine energy-efficiency standards for data centers and promote carbon-reduction technologies: Incorporate green building design principles into standards by using natural cooling and optimizing building envelopes. Provide guidelines for adopting energy-saving technologies such as efficient cooling, electrical equipment, IT equipment, waste heat recovery, and intelligent energy management systems. Promote using renewable energy, including solar PV, wind power, and storage systems.

- Accelerate low-efficiency data-center retrofits: Develop tailored energy-saving retrofit plans based on the size and age of data centers. For older, low-efficiency small and medium-sized data centers, consider options for shutdown or consolidation. For large and extra-large data centers, implement selective and system-wide retrofits. Prioritize modular upgrades to minimize disruption to operations. Establish a cross-disciplinary mechanism to ensure cooperation on energy-efficiency retrofits. Regularly conduct energy-efficiency evaluations to enhance awareness of the economic benefits associated with these measures.

Operations management — developing clean, low-carbon, and grid-friendly data-center power consumption models

- Select diversified green power supply options: Data-center operators should select a combination of on-site distributed renewable energy, direct physical connection to green power, green power trading, and green electricity certificate trading, based on factors such as their electricity demand, project phase, risk preferences, economic benefits, and environmental disclosure requirements to maximize green power consumption.

- Improve green power and green electricity certificate trading mechanisms: Government, grid operators, and trading centers should collaborate to establish a stable market mechanism for green electricity certificates and green power trading, ensuring the uniqueness, authority, and traceability of environmental attributes to enhance recognition domestically and internationally. In regions with limited green power supply, improve cross-regional green power trading mechanisms to increase transaction frequency, scale, and transmission capacity.

- Explore optimal computing power and electricity coordination models: Companies should assign skilled personnel to manage energy supply, computational scheduling, and cooling systems comprehensively, identifying and independently controlling flexible resources loosely coupled with real-time business logic. Furthermore, spatial resource sharing and optimal allocation across data centers are essential. Sufficient pricing signals from electricity markets are crucial to incentivize demand-side flexibility participation in spot markets, ancillary services, and demand response mechanisms, supporting facility-level and regional-level coordination and aligning computational and electricity prices.

- Scale up green data-center and electricity-computational synergy pilot projects: Data-center operators should partner with local renewable energy companies and grid operators to establish full green-power, direct-supply practices in data centers. Initial trials could prioritize centralized or distributed renewable-rich regions and national computing hubs, exploring zero-carbon power alternatives such as green hydroge/ammonia fuel cells, and small modular reactors. Develop commercial models for electricity-computational synergy and share operational experiences to promote coordination nationwide.

Support mechanisms — ensuring green, high-quality development of data centers through policy and market synergies

- Improve carbon-emissions policies and disclosure mechanisms for data centers and products: Establish mandatory carbon disclosure requirements for listed companies and large enterprises in the data-center sector. Encourage energy efficiency and carbon reduction through green procurement practices. Downstream companies with digital-service demand can set carbon-reduction requirements for upstream data centers, while government and public sectors can integrate carbon criteria into procurement standards. Include carbon-emissions indicators in sustainable data-center certification systems.

- Establish a unified carbon accounting system for data centers: Develop carbon accounting standards for data centers, with particular attention to Scope 3 emissions. Define emissions boundaries for different entities and ownership structures. Encourage the use of digital tools like a data-center infrastructure management platform to standardize data collection and processing, enhancing data transparency; prioritize international alignment and mutual recognition when developing data-center carbon accounting standards.

- Apply green financial tools to support data-center energy efficiency and carbon reduction: Encourage financial institutions and companies to develop innovative green financial tools suited for data-center projects, providing diversified funding for energy-saving and carbon-reduction technologies in green data centers. Include technologies such as liquid cooling, high-efficiency system integration, and intelligent operations in the green finance taxonomy to guide green finance in supporting data-center energy efficiency and carbon reduction.

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