Turning Data Centers into Grid and Regional Assets: Considerations and Recommendations for the Federal Government, State Policymakers, and Utility Regulators

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Key takeaways

- Data centers are competing with manufacturing facilities for electricity, potentially extending the use of fossil fuel power plants and derailing states' and companies' climate goals.
- Industrial electricity demand growth has not been accurately factored into current demand projections. Those demand projections are likely too low.
- Policymakers must address this dual challenge together rather than viewing industrial growth and data center growth as competing forces that require choosing one over the other.
- Some legislators are reexamining incentives for data centers because of the abovementioned competition and because communities are objecting to data centers' noise, water consumption, and impact on electricity costs.
- A promising solution to electricity adequacy concerns is to convert data centers into grid and regional assets, with flexible demand that is powered by carbon-free electricity.
- RTOs and ISOs (regional transmission organizations and independent system operators), utilities, and data center developers and operators must join in this coordinated effort. Successful implementation of these recommendations also needs buy-in and support from utilities, information and communications technology companies, local governments, and communities.
- Three key steps the above actors need to take immediately are (1) fill data and knowledge gaps in AI data center design and operation, (2) improve AI data centers' energy efficiency and integration with regional infrastructure and the grid, and (3) develop policies that transform demand-side strategies for all customers.

Data centers are driving massive growth in electricity demand—just as U.S. manufacturing is surging

Over the last two years, America's demand for electric power has surged thanks to the resurgence of U.S. manufacturing and the emergence of—and demand for—artificial intelligence (AI) and generative AI (GenAI) that rely on power-hungry data centers. The manufacturing surge is substantially driven by Biden administration policies—BIL, CHIPS, and IRA—prompting major investments in new manufacturing facilities powered by electricity. Together, new industrial loads plus new loads from data centers have reversed a long period of flat electricity demand since 2007. The emergence of these two substantial new electric loads is unprecedented, and policymakers must address this dual challenge rather than viewing industrial growth and data center growth as competing forces that require prioritizing one over the other.

This trend is especially challenging at a time when many U.S. states and private companies are setting ambitious goals to reduce or even eliminate carbon emissions in the near future. One study[1] projected that the combined expansion alone of traditional and AI data centers and chip foundries will increase electricity demand from 130 terawatt-hours (TWh) in 2023 to 307 TWh in 2030. This increase is higher than the projected growth in EV power demand, which is expected to rise from 18.3 TWh in 2023 to 131 TWh in 2030. In fact, it is equivalent to a projection of total demand growth of 175 TWh across the residential, commercial, and industrial sectors during the same period.

Industrial demand growth has not been fully captured in many demand growth projections because planning and constructing a new mega factory takes considerably longer than building a data center. However, this growth is on the horizon, fueled by new investments in clean energy manufacturing—currently driven by semiconductors, batteries, electric vehicles, wind, and solar—supported by both the private and public sectors.[2]

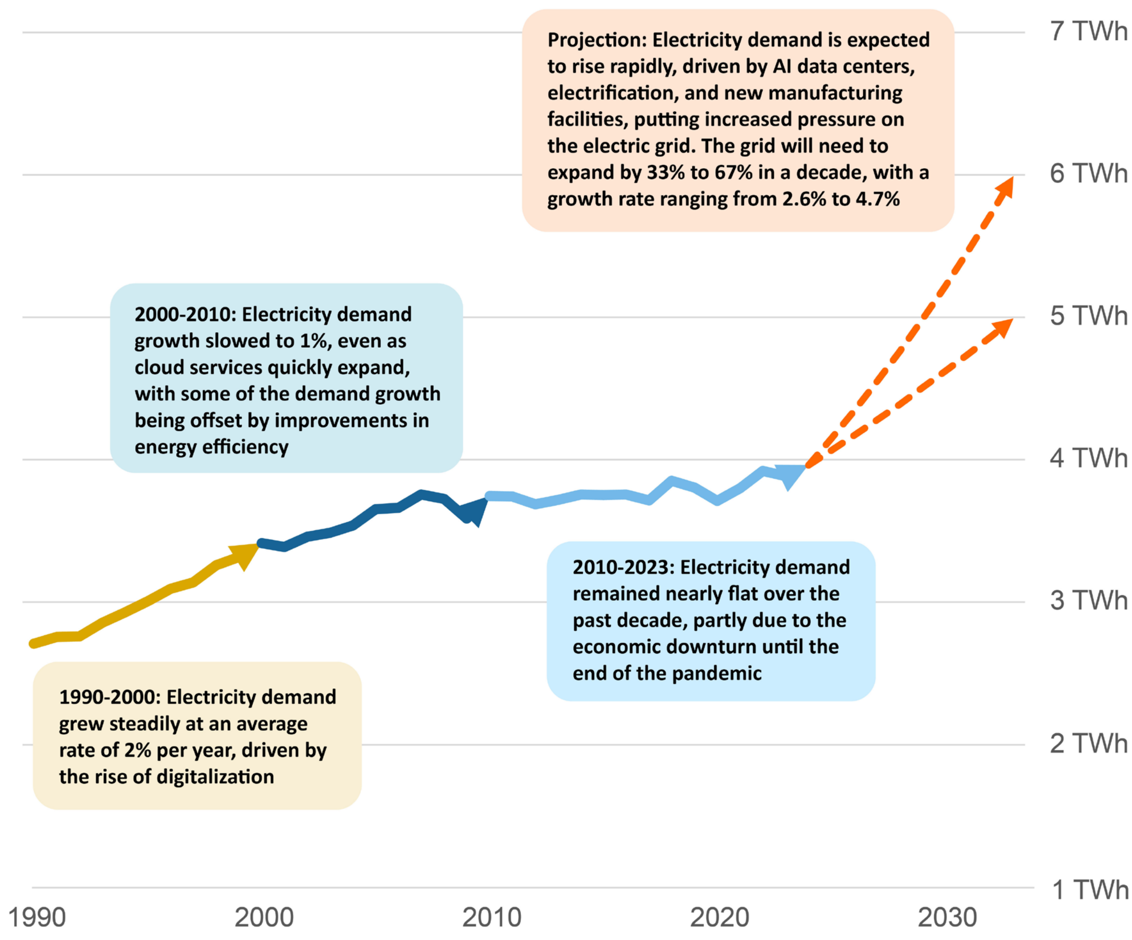

Figure 1. Industry and GenAI are competing for electricity, threatening states' carbon goals

Electrical load growth puts achieving carbon goals at risk

The transition to low-carbon electricity is a pivotal strategy to reduce industrial greenhouse gas emissions.[3] States' industrial economic development opportunities now face direct competition from the information and communications technology (ICT) industry's push to site new data centers. This trend has slowed the increase in the share of carbon-free electricity in the grid mix because utilities have chosen to meet these new loads through conventional means, such as extending the operating lives of fossil fuel power plants or constructing new gas-fired generation. This trend puts our country's climate and economic growth goals—and the goals of many companies—at risk.

Some GenAI data centers consume more energy than even the most energy-intensive facilities we are accustomed to and that the grid was built for. For example, traditional data centers, which can meet the computation requirements of machine learning but not GenAI, consume around 7.5 kilowatts (kW) per rack of servers. However, just *one* of the new servers essential for high-performance AI tasks requires over 10 kW.[4] Consequently, the power and heat density of a GenAI center is at least four times that of a comparable cloud-computing facility (e.g., those used by Amazon Web Services [AWS], Microsoft Azure, and Google Cloud) or a colocation data center (where businesses can rent space to house their servers). OpenAI CEO Sam Altman has suggested that the United States needs to commit to building multiple five-gigawatt (5,000 MW) data centers in various states to advance AI and compete with China.[5]

Rising electricity demand from artificial intelligence and the expansion of data centers have significantly increased scope-1 and scope-2 greenhouse gas emissions. This surge presents a challenge for tech giants like Google and Microsoft,[6] utilities such as Dominion Energy, and state and local governments, including Loudoun County in Virginia,[7] in achieving their clean energy and carbon neutrality goals. Reliance on renewable energy certificates and carbon offsets is insufficient to curb this growth. As a result, some companies may face tough decisions between pursuing business opportunities and upholding their carbon commitments, potentially risking public and constituent support. Rhodium Group's latest projections suggest that rapid load growth—combined with unanticipated headwinds in grid carbon-free electricity supply—could dramatically slow the rate of U.S. decarbonization.

Geographic considerations: uneven distribution of electric loads

The increase in demand is not uniform. Immediate shortfalls in electricity supply are particularly acute in the Southeast, Southwest, and Midwest, where manufacturing and data center construction are surging.[8]

These power-hungry locations are at the nodes of the fiber backbone (see the figure below). For example, in Ohio, GenAI competes with Intel's Chip Fabs and Cleveland Cliffs' Middletown direct reduction iron project. The Public Utility Commission of Ohio has new rules for connecting data centers that discourage their location through high interconnection charges. Other states are considering similar responses.

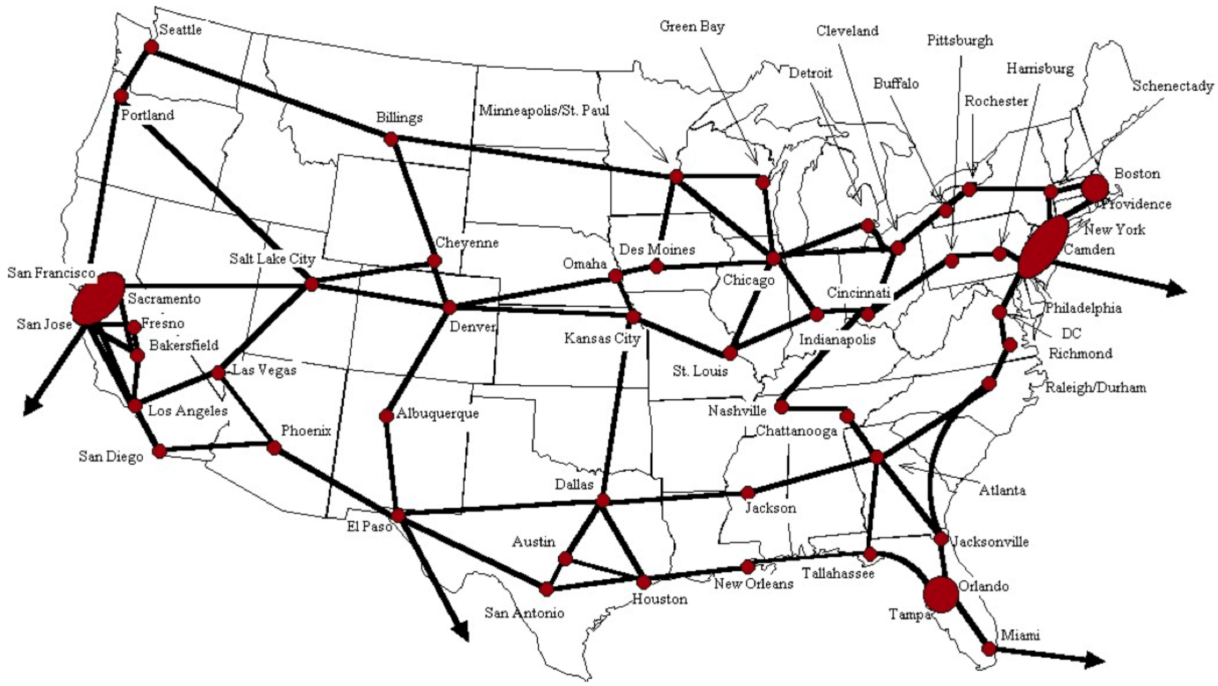

Figure 2. U.S. fiber backbone. Source: Brown, Elliott and Shipley 2001.[9]

Data centers can increase household energy bills and affect environmental quality; communities are starting to resist

AI data centers are currently being built near many communities, often without residents being informed. The data centers create noise, use large amounts of water, and can increase energy bills for nearby households. In Santa Clara, the heart of Silicon Valley, rising electric rates are driven by the municipal utility's significant spending on transmission lines and other infrastructure to meet the enormous power demand of over 50 data centers, which now account for 60% of the city's electricity consumption.[10] Data centers typically pay lower rates for electricity than residential customers.

A study on the environmental footprint of data centers in the U.S. estimated that in 2018 (two years before ChatGPT was publicly released), they consumed 5.13×10^8 cubic meters, or 135 billion U.S. gallons, of water,[11] equivalent to about 0.4% of the total annual water withdrawals in the United States. Less than 1% might not seem significant, but when data center water consumption is concentrated in a small region, it can account for a quarter of a town's annual water consumption, as revealed during a lengthy legal battle in Oregon.[12] Additionally, one-fifth of data centers draw water from moderately to highly stressed watersheds in the western United States.[13] The rapid growth of resource-intensive AI data centers will further exacerbate water scarcity in some regions. Growing concern that big tech companies have kept data center development secret to avoid community involvement is leading to calls for more transparency and regulation.[14]

Data centers generate limited long-term local jobs, although they bring tax revenue

Although data centers create construction jobs and drive demand for construction materials and IT equipment, they typically have relatively low long-term local employment. While headquarters, manufacturing, or shared service operations may have 200 to 1,000 jobs onsite, a typical data center usually employs significantly fewer people. One study estimates that the number of jobs at a typical data center can be between 5 and 30,[15] and another study states that a typical data center (with a capital expenditure of over $215 million) directly supports 157 local jobs.[16]

Data centers have been a significant source of tax revenue, making them attractive to state and local policymakers. For example, the data center industry is estimated to bring $1.2 billion in tax revenue into the Virginia economy annually, including $1 billion to local municipalities and $174 million to the state.[17] However, this revenue boost has not been adequately assessed in the context of increasing electricity demand and its broader impact. While more comprehensive studies on the indirect and induced jobs created by data centers, as well as comparisons with other economic development options, are needed, some states' legislators, such as in South Carolina, Georgia, and Virginia, are reexamining incentives for data centers, since they may lead to higher utility costs for residents, limited job creation, and other adverse environmental effects.[18]

Just as clean manufacturing facilities compete with data centers for electricity from the grid, they create some of the same problems for communities—noise and water pollution and higher electricity bills for all customers. As this competition intensifies, the sector that can turn its facilities into grid and regional *assets* may face less opposition to new development and take the lead in sustainable growth.

A promising solution is to transform data centers into grid and regional assets with flexible demand powered with carbon-free electricity.[19] These centers can reduce energy consumption during grid strain, ramp up usage during renewable energy surpluses, and even store excess electricity to feed back into the grid, improving grid reliability and resilience.

Grid asset traditionally refers to physical components that make up grid infrastructure, including equipment for generation, transmission, distribution, metering, and communication. The transition to a modern and smart grid has expanded the definition to include customer-side solutions (e.g., smart appliances, EV charging stations) and control technologies (e.g., distribution management and automation systems, advanced analysis and visualization software).

Regional asset refers to any resource, capability, or infrastructure within a defined geographical area that can be leveraged to enhance the efficiency, effectiveness, and reliability of local utility systems and services. A region can be a district, city, county, or even a larger area, depending on structure and distribution of the utility infrastructure.

For example, Enel X[20] has developed a way for data centers to participate in grid services by using their uninterruptible power supplies (UPS), backup generators, and battery storage as part of a virtual power plant. Verrus aims to build new data centers that segregate critical and non-critical loads, powered by microgrids that utilize batteries and flexible data center loads to reduce energy costs and carbon footprints.[21] While new technologies like these show promise, using data centers as grid assets is still an emerging field.

States that can lead—by charting a path to data centers as grid and regional assets—will be best positioned to attract new technology companies and reap the rewards they bring, including jobs and economic growth. They will also maintain momentum toward meeting their carbon reduction goals.

Conventional efficiency measures and operational optimization are inadequate to manage GenAI data centers

Since the emergence of data centers in the late 1990s, continuous improvements in energy efficiency and operational optimization enabled by server virtualization have held down energy demand as processing and data communication volumes have increased exponentially.[22] Server virtualization is a technology and process that creates multiple virtual machines on a physical server, with each virtual machine operating independently. This allows multiple users to perform different tasks on the same server, maximizing its utilization and reducing total energy use (compared to running multiple servers at partial capacity) and associated carbon emissions. With these measures, data center energy use can be reduced by as much as 80%.[23]

Energy efficiency measures include efficient devices (chips, servers, processors, power supplies), efficient arrangement of server racks, efficient cooling systems, and data center energy management.

Data center is a general term that can refer to a range of facilities housing computer servers and networking equipment with very different power and market characteristics. These data centers can be grouped into four different market categories:

- Hyperscale cloud computing infrastructure operated by large technology companies (e.g., AWS, Google, Microsoft) hosts customers' software (from small businesses to large companies like Netflix). Large cloud service providers can use networks of data centers to route workloads to those with the best access to renewable energy at any given time, or they can help customers optimize their workloads to run during times of lower grid carbon intensity.
- Co-location services result in limited grid responsive behavior when they provide connectivity, power, cooling, and facilities for customer servers, but where the operators (e.g., Iron Mountain) have limited control of their customers' server utilization and energy use.
- Crypto mining seeks locations with cheap electricity rates to improve profitability. Many Bitcoin mining companies participate in formal demand response programs, where they agree to curtail operations when called upon by grid operators during peak events.
- Artificial intelligence (AI), an emerging category that typically uses arrays of graphic processing unit (GPU[24]) based servers to train large language models and respond to queries using these models (known as inference). While some AI workloads can be challenging to virtualize efficiently, advancements in GPU virtualization are improving flexibility. Training large models often results in high load factors (i.e., the ratio of average energy consumption to peak load over a specified time period), while inference workloads may have more variable load factors. How to fully utilize this flexibility has not been well explored.

However, the traditional data center energy efficiency and server optimization measures discussed above are only partially effective for handling the proliferation of current GenAI data centers. These new data centers create unprecedented electricity demand due to their much higher power density, increased cooling demand, constant high utilization (i.e., high load factors), different computational patterns (compared to traditional enterprise applications), and rapid scaling. Consider Dominion Electric, Virginia's largest utility. Dominion took 115 years to reach its current power delivery capacity. However, with the rapid growth of data centers in Virginia, Dominion is on track to double its system load within the next 15 years—a scale and speed of expansion that is unprecedented.[25] While the future trajectory of data center electricity demand remains uncertain, the current rapid pace of growth is creating immediate challenges, even though electric supply and infrastructure may eventually expand to meet future needs.

Data centers have the potential to lower emissions and cut electricity costs—if their owners have the right incentives

Instead of viewing AI data centers as a threat to the grid and local economic development because they compete with other job-creating industrial sectors and climate goals, it is possible to transform them into valuable grid and regional assets.

However, without proper incentives, data center owners, operators, and even their customers have little reason to pursue these opportunities, resulting in a failure to take advantage of data centers' full potential of demand flexibility. Realizing this potential relies on the collaborative efforts of technology developers and providers, utilities, and governments—all supported by corresponding industrial standards and regulatory frameworks.

As grid assets, AI data centers have the potential to adjust power consumption during peak demand periods, helping utilities avoid the use of expensive, high-emission peaking power plants. They can shift computational loads to times of lower electricity demand and prices, flattening the demand curve and increasing grid utilization. AI data centers can also increase energy use during renewable energy surpluses, balancing intermittent sources and reducing the need for costly energy storage solutions. Additionally, they can mobilize their resources (uninterruptible power supply, energy storage, and backup generation) to help prevent power outages, which are becoming an increasingly significant concern due to more frequent extreme weather events, aging infrastructure (much of the U.S. electric grid was built in the 1960s and 1970s,[26] and it will take decades to upgrade the whole grid), and growing power demand.

By providing ancillary services (i.e., crucial functions that help maintain a reliable and stable electricity system) and improving utilization of grid infrastructure (i.e., minimizing or deferring required transmission and distribution buildouts), AI data centers could help lower grid emissions (as less renewable energy is curtailed and fewer peaking power plants are dispatched) and lower utility costs for all customers by avoiding or deferring the costs of grid expansions that are recovered from all ratepayers.

By using advanced controls, optimizing data center operations, and leveraging rapidly advancing AI for load forecasting, data center operators can also reduce data center energy consumption and integrate them with the local grid without sacrificing their computational capacity.

Recommendations for state policymakers and utility regulators

State policymakers and utility regulators can take three key steps to turn data centers into grid and regional assets and attract technology businesses to their regions. We discuss each in more detail below.

- Fill data and knowledge gaps in AI data center design and operation
- Improve AI data centers' energy efficiency and integration with communities and the grid
- Develop policies that transform demand-side strategies

First, fill data and knowledge gaps; encourage data sharing

We cannot manage what we cannot measure. Due to critical data gaps, energy analysts are not sufficiently equipped to provide robust answers to AI data center electricity growth questions.[27] Current data gaps make it impossible to predict data centers' potential value to the grid as assets. AI data centers differ from conventional data centers in three key ways that significantly affect their overall electricity consumption: they require more power, higher rack densities, and more cooling.

AI servers demand more power than traditional servers, primarily due to the inclusion of accelerators—such as graphic processing units or tensor processing units—essential for AI model training and inferencing. An important metric to measure data center energy use is IT rack density, which is the quantity of power consumed by a server rack. IT rack density continues to increase as cloud computing dominates, rising from an average of 4–5 kW/rack a decade ago to 8–10 kW/rack in recent years, with over 20% of data centers operating above 20 kW/rack.[28] AI data centers operate above 30 kW/rack, and emerging designs will require 100 kW/rack.[29]

These rising power demands require more cooling equipment and new cooling technologies and configurations to manage the high concentrations and amounts of waste heat generated. All this cooling will require even more energy. Air cooling, the dominant industry approach, is no longer viable in such power-dense environments.

We need to baseline, measure, and predict each AI data center's energy consumption and usage patterns to transform AI data centers from large energy consumers to active participants in the grid. A study[30] of 13 large global companies, including Amazon, Apple, Google, Meta, Microsoft, Oracle, and Tesla in the United States, found that while 10 disclosed their total company energy use, only 2 reported the total energy use of their data centers. Additionally, 7 companies reported their average power usage effectiveness—a data center energy efficiency metric—at the company level, but only 2 reported it at the individual data center level.

Data transparency and comprehensive data gathering are essential for integrating AI data centers with the power grid. This information will provide crucial insights into the design and operation of AI data centers, power dynamics in AI model training and inference, and spatial and temporal concentration of energy loads. These factors are critical because the location and timing of AI training and usage directly impact energy demand patterns.

To facilitate this transparency, federal policymakers can (1) encourage AI companies to voluntarily share non-sensitive data about their data center operations and energy usage, or (2) implement regulations that require reporting of key energy metrics related to AI data centers before they can be connected to the power grid. Establishing secure platforms for data sharing and creating mechanisms for companies to share aggregated or anonymized data can help address data privacy and intellectual property concerns.

While federally funded or led studies on key energy issues have provided valuable resources for industry and policymakers, a series of one-off reports on the ICT sector is insufficient. The federal government needs to continuously gather reliable data on energy use in the ICT sector. Given the growth of the sector and its deep integration with the economy, it should be treated as a distinct sector, rather than a subset of buildings or industrial energy use. The rising energy demand of data centers is a symptom of the broader challenges posed by ICT demand growth. Moreover, the products and services powered by the ICT sector serve as a grid-edge resource and support a distributed economic model, which requires systematic data gathering and analysis.

Having standards, protocols, and platforms at the national level is particularly crucial for companies operating nationwide, as consistency reduces their compliance costs. The adoption, implementation, and enforcement of these national standards will depend on state policymakers and, in some cases, local governments. Companies' participation in the development of these standards is also essential. Addressing state-specific challenges and local interests during standard development will ultimately lower barriers to adoption.

Second, improve AI data centers' energy efficiency and integration with the grid

We do not know to what extent AI data centers can further reduce and flex their energy use, as data center developers and operators currently lack incentives and policy support. The first step is collaborative research to investigate, assess, and demonstrate this potential by analyzing how AI workloads impact grid stability and identifying strategies for better integration.

The Secretary of Energy Advisory Board recently recommended 18 actions the federal government can take to meet growing power demands reliably and affordably.[31] The Board recommended that the Department of Energy start with three main steps: (1) fund and lead a series of studies on AI data centers' energy use patterns, (2) explore opportunities for demand flexibility in data centers, and (3) demonstrate these capabilities. While swift action from federal legislators and agencies is essential, state and utility policymakers should work with data center developers and operators in their states to develop creative local solutions because there is no one-size-fits-all approach. Regional considerations inspire creativity that turns limitations into strengths.

For instance, while processor manufacturers continue to improve chip efficiency, many GenAI system owners are exploring novel ways to cool the chips, such as liquid cooling to circulate coolant directly to heat-generating components or submerging components in non-conductive liquid. DG Matrix, a startup in the Research Triangle of North Carolina, offers ultra–high power density silicon-carbide power systems for GenAI data centers, achieving 2–5 times higher power density than conventional power supplies and performing at up to 98% efficiency.

There may be opportunities to enhance cooling system efficiency and reduce water consumption through ground-coupled or district energy systems. Meta and Google are exploring solutions that harness clean heat far below the earth's surface in the Rocky Mountains and Nevada, respectively, through partnering with startups like Sage and Fervo Energy.[32] Innovative cooling systems reduce electricity and water use and ambient noise from conventional direct air–cooling systems. Policymakers can set efficiency targets or provide incentives to encourage these innovations.

Additionally, co-locating data centers with controlled environment agriculture, industrial parks, and commercial and residential buildings with heating needs can lead to more efficient use of resources and energy. For example, Amazon's Tallaght data center in Dublin sends its waste heat to adjacent buildings (public schools, commercial buildings, and apartments) through the city's new district heating system, reducing 60% of carbon emissions from those buildings by replacing their individual onsite boilers.[33] Meta and Microsoft are planning similar district heating projects in Denmark and Finland, respectively. At the same time, Amazon's headquarters in Seattle has used excess heat from a data center in the Westin Building Exchange since 2019.

Although the political environment and infrastructure in the United States differ from those in European countries, we can still learn from their experiences and adopt proven technologies through global companies. As natural gas utilities face existential challenges under the pressure to decarbonize, district heating systems present an opportunity to grow new business revenues. The Jamestown Board of Utilities in New York is proposing a project to expand and retool their thermal heating system,[34] and "GeoNetworks" (neighborhood-wide networks of ground source heat pumps) are being piloted in New York and Massachusetts.[35]

However, such synergistic developments are unlikely to occur organically without policy interventions. To facilitate these integrations, policymakers can provide business incentives (e.g., financial or tax incentives to encourage companies to pursue co-location and resource sharing), regulatory support (e.g., streamlined permitting processes, prequalification of sites, and updated zoning laws to accommodate co-location of data centers and other buildings while requiring measures to control ambient noise), and necessary infrastructure upgrades (e.g., investments in power distribution and thermal energy transfer systems to support these integrations). For example, the Danish Government has made it easier for data centers to supply excess heat to district heating systems by allowing direct pricing agreements between heat suppliers and district heating companies.[36] Intentional and facilitated collaboration among data center operators, agricultural businesses, industrial park managers, local governments, and utility companies is also vital. These policy-driven initiatives can help overcome barriers to implementation and promote more sustainable and grid-integrated data center developments.

Third, develop policies to use demand-side strategies in coordination with energy generation and transmission

To meet the growing electricity demands of the ICT sector while advancing states' and companies' clean energy goals, building more clean electricity generation, transmission, and distribution will be essential. But the longer time horizons of these projects, combined with construction delays, require other tools to meet demand over the next several years.

According to Federal Energy Regulatory Commission (FERC) data, as of the end of 2022, over 10,000 active interconnection requests existed in interconnection queues throughout the United States, representing over 2,000 gigawatts of potential generation and storage capacity if those electricity generators are connected to the power grid.[37] Over the last two decades, the time from submitting an interconnection request to achieving commercial operations has roughly doubled.[38] At a recent FERC workshop,[39] FERC Chairman Phillips commented, "*We know right now that the average wait time is over five years for projects to get through the queue*."

In recent decades, demand-side actions, like energy efficiency and demand response programs for buildings and industrial facilities, have effectively helped meet demand growth and keep customer rates affordable. Demand-side measures have also come to the rescue when our country has faced energy crises over the past quarter century. We can draw upon these learnings for guidance to fully utilize demand-side strategies to meet the immediate load growth needs, allow time for more measured planning of other investments, and avoid unintended overbuilding.

Currently, several policy barriers discourage large loads, such as AI data centers, from participating in grid services. For example, in many utility territories, demand charges—a cost based on electricity usage in a very short period, such as 15 minutes or one hour—are imposed on retail consumers based on their highest power demand over a defined period (a month or even a year), regardless of when it occurs. This legacy rate structure from the 19th century was designed to differentiate customers with relatively stable loads over the month (such as industrial loads) from those who used lots of energy in a few hours but much less the rest of the month, which makes them more expensive to serve. However, this rate structure does not incentivize customers like AI data centers and modern industrial facilities to lower their energy consumption when the grid is congested and strained. Moreover, retail customers often lack access to low-cost or no-cost renewable electricity during periods of surplus, which misses the opportunity to leverage large energy consumers' ability to store excess energy behind the meter for the grid. As a result, drawing energy from the grid is likely more cost-effective for data center developers and owners than investing in local storage.

Technologies such as smart meters, load forecasting, real-time feedback, and dynamic controls have emerged to better align consumption with grid conditions and renewable energy availability. Policy reforms are needed to give retail customers greater access to variable pricing that reflects real-time grid conditions. Large consumers should have options to access wholesale markets or special tariffs that offer incentives to adjust their load based on grid conditions and emissions. Achieving these reforms will require collaboration among policymakers and utility regulators across energy generation, transmission, and distribution.

Recommendations for other key stakeholders

The combined challenges of meeting growing data center and clean manufacturing electricity demand require an integrated effort engaging all stakeholders—going beyond actions from policymakers and regulators.

What we need from data centers:

Collaborate with industry to increase chip efficiency and network efficiency; share knowledge of rapidly advancing AI technologies, which will undoubtedly have grid impacts; commit to working with utilities on managing the grid impact of their flexible loads. These actions are equally necessary for new manufacturing facilities experiencing significant demand growth.

What we need from utilities:

Work with data centers, clean manufacturers, and adjacent communities to ensure affordable, reliable electricity service for all customers while committing to working with customers to implement the latest technologies. These technologies should be deployed not only on the utilities' own networks but also at customer sites when expanding grid capacity.

What we need from RTOs/ISOs and their regulators:

Encourage robust planning; remove regulatory hurdles to implementation of innovative solutions; identify policy opportunities to create win-win scenarios that engage multiple customer groups.

Together, we can ensure just and reliable electric services while powering robust economic growth in the industrial and ICT sectors without sacrificing the environment.

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