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Electricity Demand Growth and Data Centers: A Guide for the Perplexed

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AUTHORS

Jonathan Koomey, Ph.D.
President
Koomey Analytics

Zachary Schmidt
Senior Researcher
Koomey Analytics

Tanya Das, Ph.D.
Director of AI and Energy Technology Policy
Bipartisan Policy Center

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Executive Summary

Reports of unprecedented and "explosive" growth in electricity demand from data centers—facilities that host websites, store data, stream media, mine cryptocurrency, and train artificial intelligence models—have appeared in many major news outlets. These headlines encapsulate two widely expressed concerns:

- First, that rising energy demand from data centers could further overburden aging power infrastructure.
- Second, that this new source of demand could jeopardize efforts to mitigate climate change.

Focusing on empirical data, this report explores the accuracy of narratives that data centers are behind exploding demand for energy. It finds no evidence that this is true on the national level in recent years—indeed, the data show no rapid growth of energy demand—but we did find regional variations. It also shows that utility forecasts in 2023 were much higher than forecasts from prior years, demonstrating that utilities expect demand for electricity to grow in the years ahead.

This report also explains the key drivers of load growth for data centers, focusing on growth in computing services and improvements in efficiency. Both these drivers are subject to deep uncertainty. The report puts data centers' projected growth into perspective, comparing it to load growth in a high electrification scenario. This comparison shows that even for an extremely high projection of data center electricity use, data centers are likely to be only one of several important contributors to load growth in the years ahead.

Authors' Note: During publication of this report, Chinese AI startup DeepSeek released a generative AI model that reportedly operates more efficiently and cost significantly less to develop than similar models from OpenAI, Google, and others. While the implications of this announcement are still being analyzed, this milestone underscores a key finding of this report: Innovations in AI systems including software, algorithms, and training methods could lead to substantial efficiency gains that reduce future electricity demand associated with AI technology compared to previous expectations.

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Introduction

Reports of unprecedented and "explosive" growth in electricity demand from data centers—facilities that host websites, store data, stream media, mine cryptocurrency, and train AI models—have appeared in many major news outlets [1, 2, 3, 4, 5, 6, 7, 8]. Sample headlines conveying a sense of alarm include "Amid explosive demand, America is running out of power" (*The Washington Post)*; "A New Surge in Power Use Is Threatening U.S. Climate Goals" (*The New York Times)*; and "Booming AI demand threatens global electricity supply" *(Financial Times).*

These headlines encapsulate two widely expressed concerns:

- First, that rising energy demand from data centers could further overburden aging power infrastructure.
- Second, that this new source of demand could jeopardize efforts to mitigate climate change.

Such concerns have been amplified in recent reports by influential management consulting and investment advising firms [9, 10, 11, 12, 13, 14, 15]. Together, they suggest that a power crisis could be looming, and that AI's electricity consumption could be a national issue [16].

This report examines recent forecasts of demand growth in the U.S. electricity sector and claims about the potential impact of AI-related power consumption. How important will data-center-driven growth be compared with other changing sources of demand, such as the addition of new industries or the electrification of home heating and transportation? If growing demand is a problem, is it a national, regional, or local one?

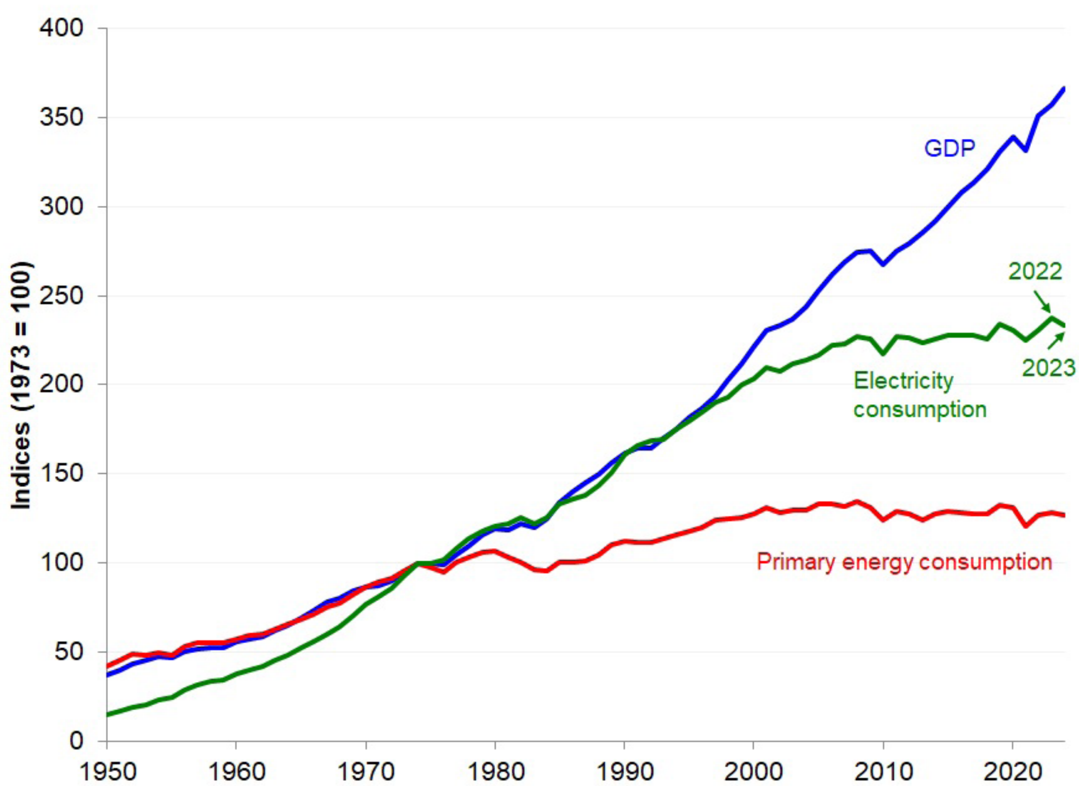
The goal of this report is not to dismiss concerns about grid resilience, or to downplay the challenges of reconciling expected growth in electricity demand with simultaneous efforts to decarbonize the power sector, but to bring empirical data to bear on questions about the role of data centers (particularly AI data centers) in load growth. Such a critical analysis is long overdue, both to improve policymaking and to develop effective strategies for managing rapidly evolving demands on the U.S. electricity grid.

Understanding U.S. electricity sector load growth: A look at the data

Changes in the composition and geographic distribution of different industries and economic activities have always influenced U.S. electricity consumption, as have a host of other hard-to-predict factors, from technological developments and behavioral changes to short-term weather variations. This section explores the evidence for recent electricity load growth in the United States, starting with national-level data, followed by an assessment of trends in two states that are projecting higher than average load growth.

Analysis of national U.S. electricity demand shows that there is no evidence for explosive demand growth in recent years, in the annual, monthly, or sectoral data (see Appendix A for details), although some states have seen demand growth. For example, national electricity use was lower in 2023 than in 2022, as shown in **Figure 1**, as was the commercial sector's electricity demand.

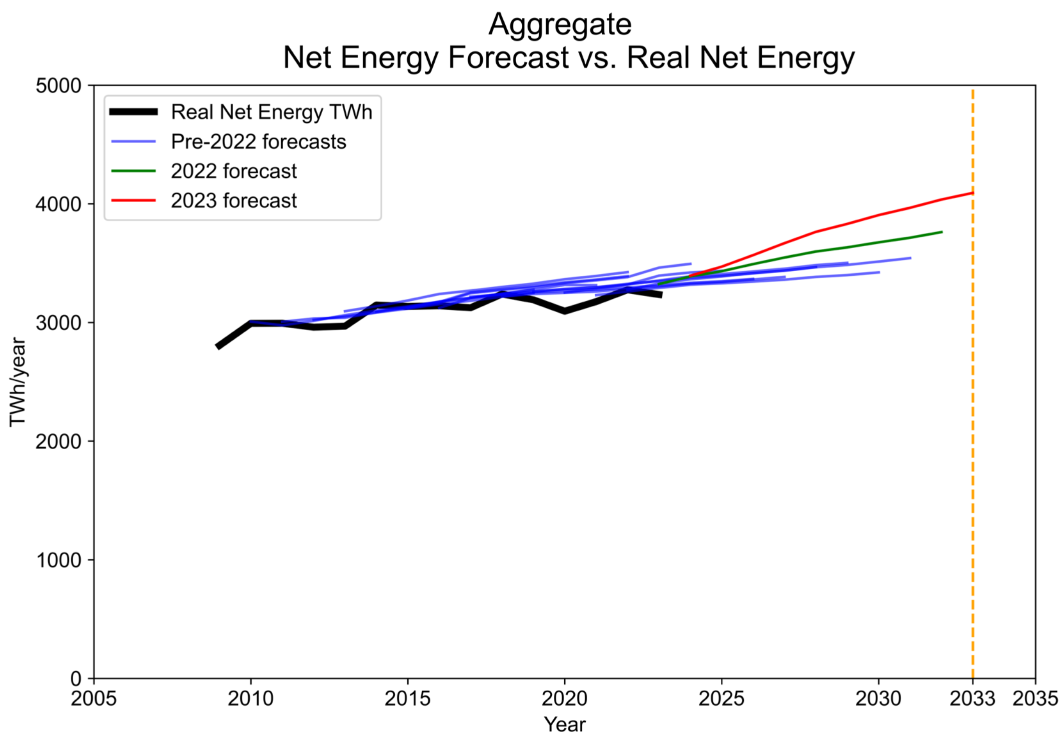
Figure 1. Historical U.S. electricity use, primary energy use, and economic output (GDP)



Source: https://www.eia.gov/opendata/

To understand the relationship between historical electricity use trends and projections, we used data from the Federal Energy Regulatory Commission's Form 714, which compiles utility sector forecasts and historical generation every year for many utilities and most balancing authorities. Although no exhaustive database of forecasts covers the whole U.S., we compiled data for 14 utilities and balancing authorities representing about three-quarters of U.S. generation in 2023 (see Appendix B for a complete list). **Figure 2** shows the results.

Figure 2. Aggregate electricity generation (actual and projected) for a large sample of U.S. utilities



Source: https://www.ferc.gov/industries-data/electric/general-information/electric-industry-forms/form-no-714-annual-electric/overview

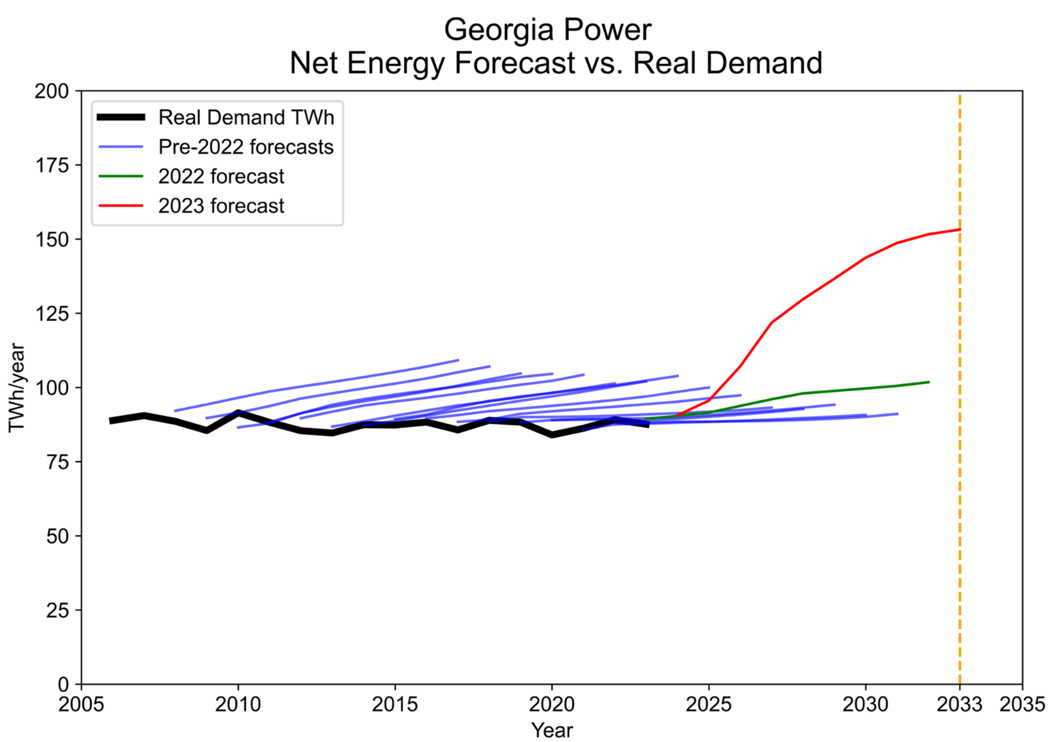
Figure 2 shows actual electricity generation rising slowly from 2009-2023, projections typically exceeding actual generation, and then significantly higher projected growth in the 2023 forecast—about 26% growth through 2033 (roughly 2.4% a year).

Utilities generate forecasts as part of their planning processes. In many states, the forecasts are incorporated into what are called "Integrated Resource Plans" in which options for meeting the projected demand are compared to each other. Those comparisons help the utility choose among those options to minimize costs, maintain or improve reliability, and achieve other goals, such as reducing emissions [17]. Uncertainty is almost always inherent in these forecasts [18, 19, 20, 21], but creating them is necessary so that utilities have a baseline against which to measure alternative scenarios.

Although there is no strong evidence for explosive electricity demand growth in the United States in recent years, these data may not tell the whole story. Looking beyond figures showing little load growth nationally, individual states and utilities are experiencing substantial load growth. For example, recent news stories about potential energy impacts of data centers have often focused on two states, Georgia and Virginia, which have seen growth in data center electricity use, Georgia more recently than Virginia.

Figure 3 shows Georgia Power's forecasts of future demand, compared with actual net generation going back to 2006, using data from the utility's Form 714 filings. The figure shows a large increase in Georgia Power's 2023 forecast (indicated by a red line) relative to its pre-2022 forecasts (indicated by blue lines) and its 2022 forecast (indicated by a green line). The 2023 projection shows growth of about 75% in total electricity generation by 2033.

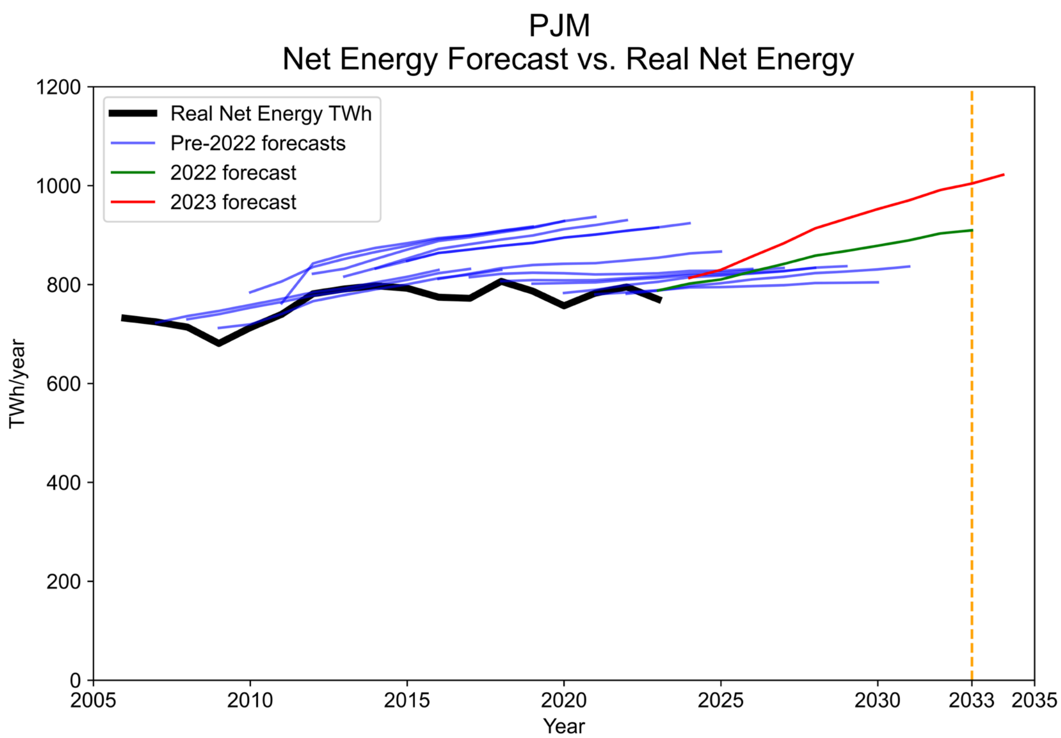
Figure 3. Actual generation and 2006-2023 projections for Georgia Power



Source: https://www.ferc.gov/industries-data/electric/general-information/electric-industry-forms/form-no-714-annual-electric/overview

A similar pattern emerges from forecasts for the PJM Interconnection, which includes the state of Virginia, as shown in **Figure 4**. The 2023 forecast represents a substantial departure from past forecasts, showing a roughly 30% increase in demand by 2033 in the 2023 forecast.

Figure 4. Actual generation and 2006-2023 projections for PJM

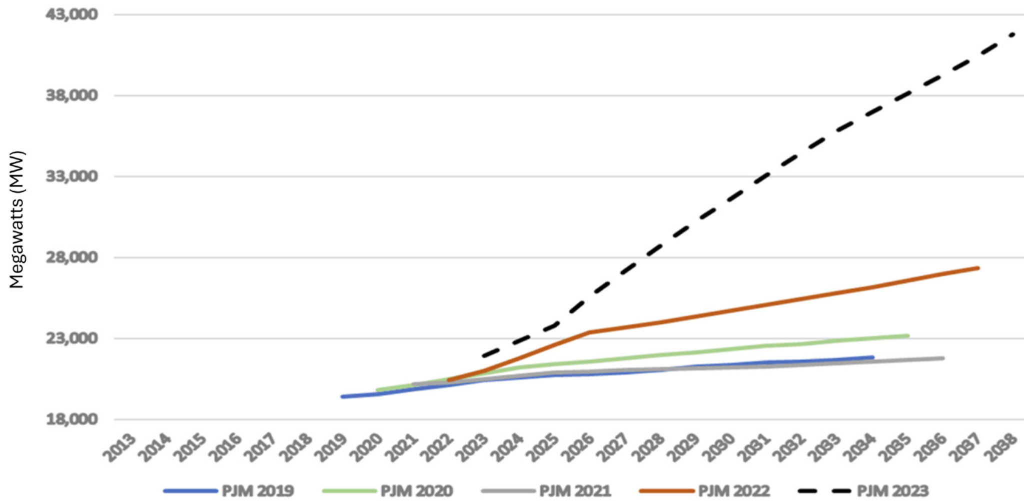


Source: https://www.ferc.gov/industries-data/electric/general-information/electric-industry-forms/form-no-714-annual-electric/overview

The 2023 forecast for the eastern Virginia portion of PJM anticipates one of the largest peak load increases for any utility in that region [22]. **Figure 5** shows the projected load increase for the DOM Zone in Virginia—the service territory of Dominion Energy, which covers much of the eastern part of the state—indicating a more than 50% increase in peak load projected to 2033 compared with 2023 [23].

Northern Virginia has the largest data center market in the world, with 70% of the world's internet traffic originating in or passing through Loudoun County [25].

Figure 5. Peak demand growth (MW) in DOM Zone



Source: https://rga.lis.virginia.gov/Published/2023/RD214

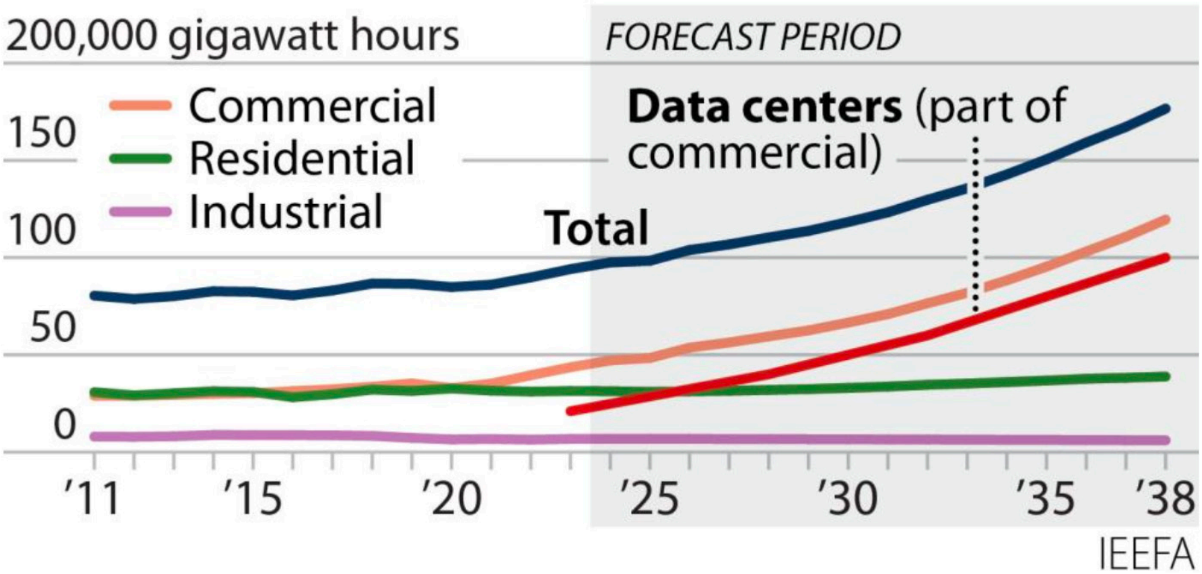
Dominion Energy has serviced and assessed data center load growth in its service territory for over a decade. In particular, Loudoun County, VA, contains 80% of Dominion's data center electricity demand [24]. Northern Virginia has the largest data center market in the world, with 70% of the world's internet traffic originating in or passing through Loudoun County [25].

Load growth from data centers in context

Load growth due to data centers in a specific region can be difficult to predict. Data center developers consider multiple states as possible locations for data centers, and they query multiple utilities simultaneously for electricity rates and incentives prior to making a final selection. Therefore, counting data center project proposals to forecast load growth can result in the overestimation of data centers likely to be built in a specific service territory. Only national or regional level tracking of these projects can give an accurate picture, but such tracking currently does not exist, at least in a publicly available form.

Figure 6 shows the sources of new load growth in Dominion Energy Virginia. In this case, the majority of projected load growth is driven by the commercial sector, and specifically by anticipated growth in data center demand [26]. Industrial and residential electricity sales, in contrast, are expected to be flat.

Figure 6. Electricity sales growth projected by sector for Dominion Energy Virginia



Source: https://ieefa.org/resources/dominion-virginias-improbable-integrated-resource-plan

Another contributing factor to the uncertainty of projecting data center demand growth is the availability of land and new transmission capacity needed to support new data centers. Easy expansion of data centers in Virginia has depended on cheap land, low power prices, and public support—conditions that prevailed until relatively recently. There is evidence that data center buildout is entering a new and more contentious phase with siting issues and growing public opposition [26]. Thus, expectations that growth will continue for the next 14 years as rapidly as it has in the past are uncertain.

Currently, utilities are collecting better data, tightening criteria about how to "count" projects in the pipeline, and assigning probabilities to projects at different stages of development [27, 28, 29, 30]. These changes are welcome and should help reduce uncertainty in forecasts going forward.

Electrification is also important to load growth

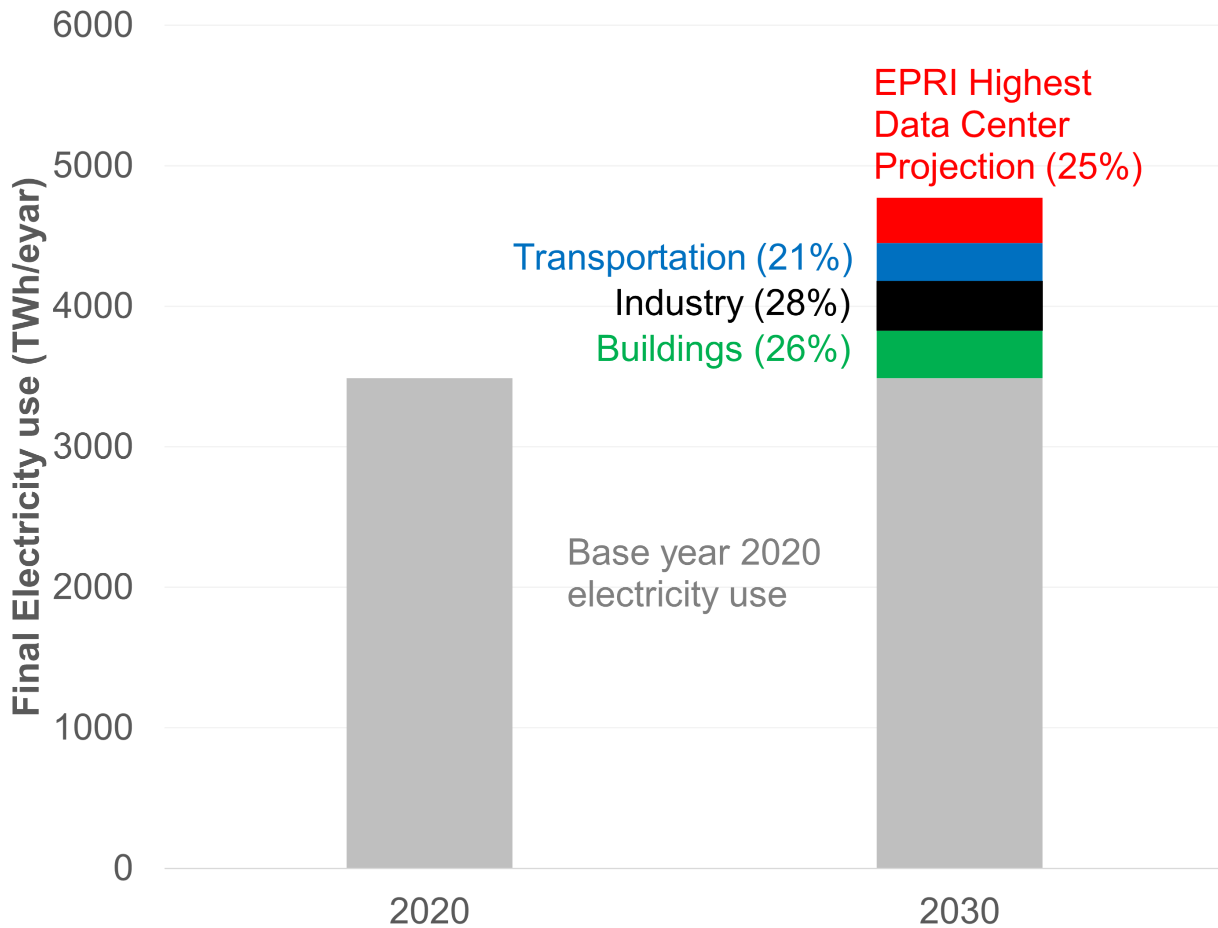
Data centers are only one potential source of load growth in coming decades. Others include shifts in industrial investments and electrification of vehicles, heat, and industrial processes [12, 31, 32]. Demand for air conditioning is also increasing as the world warms [33]. Due to the rapidly changing nature of the U.S. commercial sector, policymakers must consider these factors when deciding how to address electricity load growth.

Figure 7 shows U.S. electricity use in 2020 and projected use in 2030, highlighting projected load growth by sector for 2020-2030. The projections for buildings, industry, and transportation are part of a high electrification scenario compiled in the *Fifth National Climate Assessment* for the United States [34].

This scenario exercise was completed before recent concerns about electricity growth from data centers became salient—and before the onshoring effects from the Inflation Reduction Act became evident—so it is fair to infer that AI-driven scenarios of data centers' load growth were not included in the projections. We add on top of that bar (in red) the highest projections, by the Electric Power Research Institute (EPRI), of data center load growth to 2030 [35] for comparison.

This comparison shows that data centers would still only account for 25% of expected growth over 2020-2030. This comparison is admittedly a bounding one, given that the EPRI projections are at the high end of recent forecasts, but it does demonstrate that other sources of potential load growth are likely to be substantial compared with growth in data centers' electricity use. Total data center electricity use would be about 8% of U.S. electricity use in 2030 based on EPRI's projection, up from about 2% in 2020. The EPRI estimate for 2020 is comparable in percentage terms to estimates in [16] but higher than estimates for the world, which are around 1% [36].

Figure 7. U.S. electricity use (2020), compared with projected growth in electricity use by sector to 2030 in a high electrification scenario; top bar (red) is data center growth from EPRI's highest data center growth scenario



Understanding the potential for load growth from computing

The growth of two major factors will determine the impact of new computing applications on electricity demand:

- Service demand, as determined by the quantity of computations being performed.
- Computing efficiency, as determined by the amount of energy required to perform each computation.

As segments of the computing industry grow rapidly, an additional third factor may come into play in the form of *limits on industrial production capacity* to supply AI chips and servers, to expand the infrastructure needed to build new data centers (such as backup power generators), and to modernize the electricity grid. These three drivers are interdependent, and their trajectory in coming years is difficult to predict.

Consider future demand for AI compute: The industry's current growth projections are aggressive, but whether they materialize depends on businesses realizing positive economic returns from AI investments and on whether users' concerns about accuracy and reliability can be adequately addressed [37, 38, 39]. The industry's growth trajectory could also be affected by new technologies that can deliver similar services but without some of the risks and liabilities associated with current AI models.

Historically, as demand for computing services has increased, the efficiency of meeting that demand has also increased rapidly, offsetting some or all of the growth in demand for computing services [40]. In the early stage of the AI boom, efficiency was not top of mind, and companies bought all the AI equipment that was available, regardless of efficiency. As constraints in deploying AI manifested, the industry rightly began to focus on efficiency as one path to alleviating those constraints [41]. This pattern matches what happened from 2000-2005 when electricity used by data centers in the United States and globally roughly doubled [42], and the industry then focused on improving efficiency. This effort led to slower growth in data centers' electricity use in 2010 and little growth from 2010-2018 [43].

Growth in the ability to meet service demand can also be uncertain because of supply chain constraints in producing and deploying AI servers and supporting equipment. In the first phase of the recent AI boom, people bought as many AI servers as the industry could produce, causing shortages that could persist if demand continues to grow rapidly. There are also constraints on the physical systems—such as backup power generators for data centers—that may hamper the speed of AI deployment. If service demand growth moderates, these issues become less pressing. When growth in new technologies is rapid, it can affect the rate at which these technologies can be deployed.

Progress in computing efficiency in the future

How much potential is there to improve computing efficiency in the future? Most people know about progress in shrinking transistors [44, 45] in the form of "Moore's law." These changes resulted in rapid and consistent improvements in performance and efficiency from the first microprocessor in 1971 until the early 2000s, when real physical and economic limits started to slow things down [46]. During the modern era, these changes and others led to a doubling of computing energy efficiency at peak output every 1.6 years or so [40] through the year 2000. After 2000, this rate of improvement slowed to a doubling every 2.6 years [47].

Making smaller transistors is not the only way to improve efficiency. When it became harder to shrink transistors in the early 2000s, the industry had to rely on continued innovation in other areas. Charles E. Leiserson et al. [48] identified ways the industry could continue to push performance and efficiency forward at rapid rates, including changes to hardware architecture, using better software, improving algorithms, and adopting special purpose computing (including co-design of hardware and software).

The potential for these technologies to improve efficiency is vast. Leiserson and his co-authors cited an example of matrix multiplication that could be improved by a factor of 60,000 using these techniques. Other back-of-the-envelope calculations show that current technology is far from the ultimate physical limits for computing. Companies might need to rethink computing technology from first principles as they approach these limits in coming decades [49].

Some people have pointed to the "Jevons paradox" [50] to argue that improvements in the energy efficiency of computing always lead to a corresponding increase in energy use that swamps the efficiency gains. This claim reflects a misunderstanding about a complex phenomenon. As computing devices become more powerful, their costs per compute cycle drop rapidly. Lower costs can drive increased adoption, but whether that increased adoption fully or partially offsets efficiency improvements depends on the net benefits the new technology brings, as well as the offsetting effect of retiring the older technologies displaced by the new one. A technology that brings benefits greater than its costs will be adopted much faster than one whose benefits only slightly exceed its costs. But energy is only one cost of computing, albeit a significant one in some cases. It is not generally true that a change in energy efficiency must drive increases in energy or computing consumption.

Of course, new technology with significant net benefits will be adopted rapidly, and consumption of the inputs that allows that new technology to be adopted will also increase. This story, however, is not primarily about energy efficiency. It is about technological change driving down costs of new technology, which increases adoption, while displacing old ways of accomplishing the same task.

For AI systems, the question of efficiency is complicated. Historically, models have improved their performance with scale [51, 52], so that the bigger, more powerful models trained on more data outperformed earlier "best in class" models. AI researchers plowed all efficiency gains back into increasing aggregate performance, so electricity use increased, and that trend held for the most recent explosion of interest in AI [53].

For the most part, costs and benefits did not factor into these experiments, except in the narrow sense that the companies building the big models presumably kept to the budgets they set for those projects. However, business value (i.e., net benefits) will drive the next phase of AI deployment. Whether continuing to scale models to ever larger sizes will be the best approach to generate business value is an open question that will ultimately be answered in the marketplace, depending on people's willingness to pay for AI compute services and the cost to deliver those services. That open question is one of the main sources of deep uncertainty for AI service demand in the future.

Conclusion

It is incumbent on utilities, regulators, policymakers, and investors to investigate claims of rapid new electricity demand growth and to ensure that expectations are based on the latest and most accurate data and models. Although data centers' electricity use appears to be growing again, exactly how that growth will play out in coming years is deeply uncertain, both because growth in the use of AI is uncertain and because progress in efficiency is uncertain. It is likely, however, that other sources of demand growth, such as the onshoring of industry and the electrification of transportation, heating, and industry, will be bigger drivers of total demand growth than data centers in the medium to longer term.

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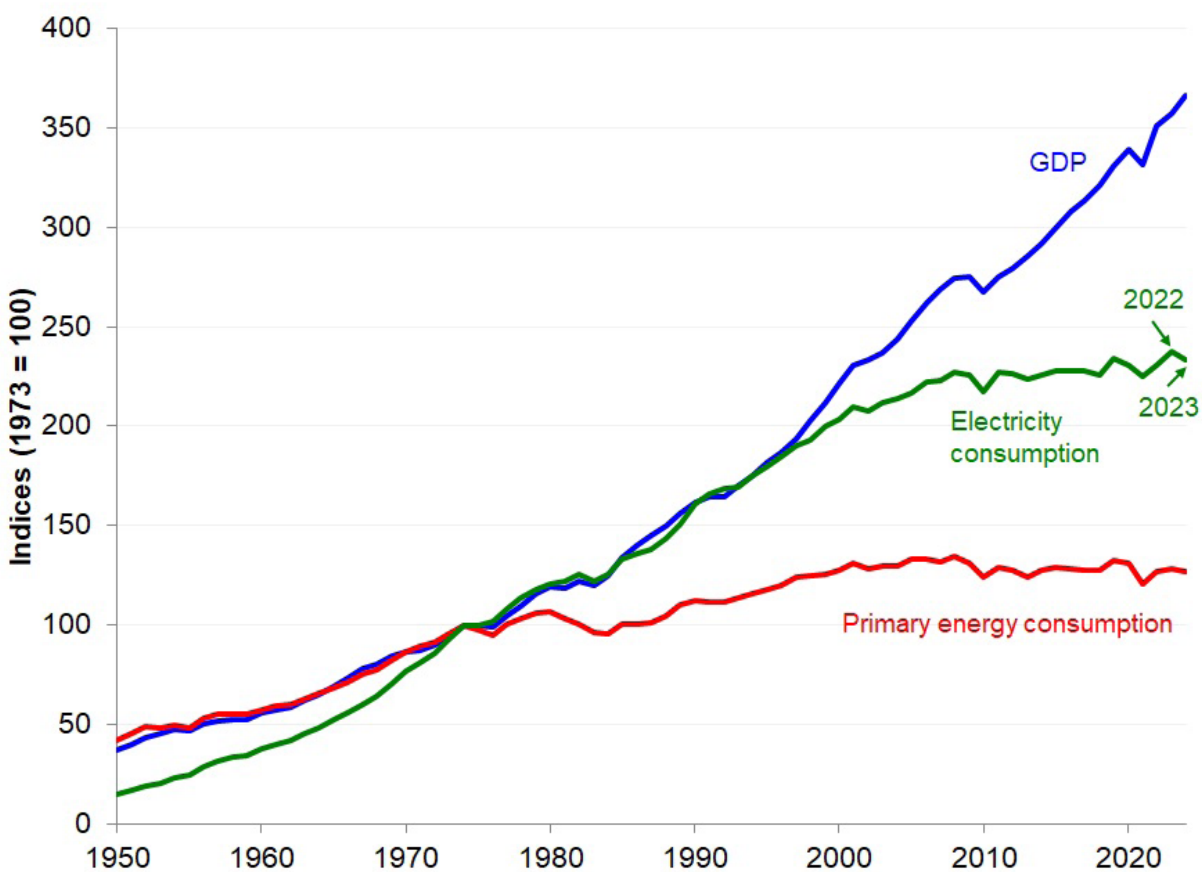
Appendix A: Details on U.S. electricity demand growth

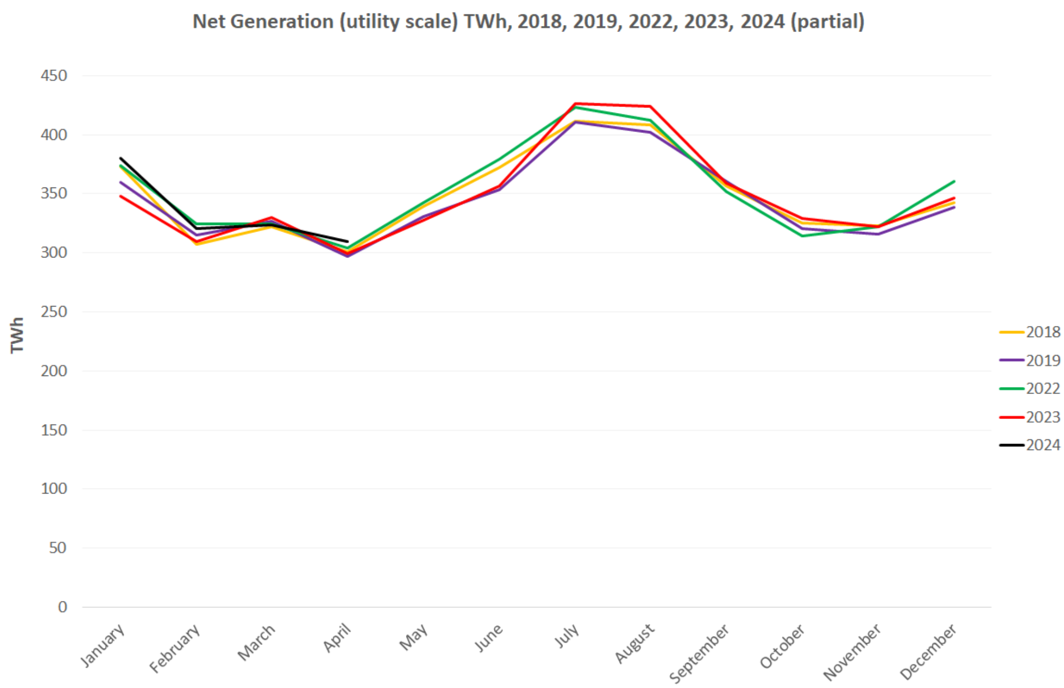
Figure A-1, which relies on data from the U.S. Energy Information Administration (EIA), shows that electricity consumption grew more rapidly than GDP (and more rapidly than primary energy consumption) between 1950-1973 (https://www.eia.gov/opendata/). Between 1973-2000, the growth in electricity demand tracked GDP growth, while primary energy consumption began to level off. Beginning in the early 2000s, electricity consumption, including primary energy consumption, was increasingly decoupled from GDP growth, and aggregate demand grew only slowly, increasing at a rate of about 0.3% per year from 2014-2023. In 2023, electricity consumption was down slightly compared with 2022.

Figure A-1. Historical U.S. electricity use, primary energy use, and economic output (GDP)



What about more recent trends? **Figure A-2** shows U.S. net electricity generation by month for 2018, 2019, 2022, 2023, and the first part of 2024, also from EIA (data from 2020 and 2021 are anomalous because of the COVID-19 pandemic and are not included). Monthly data are more subject to weather variations, but the figure does not show significant demand growth at the national level over the past few years.

Figure A-2. Monthly U.S. net generation for selected years



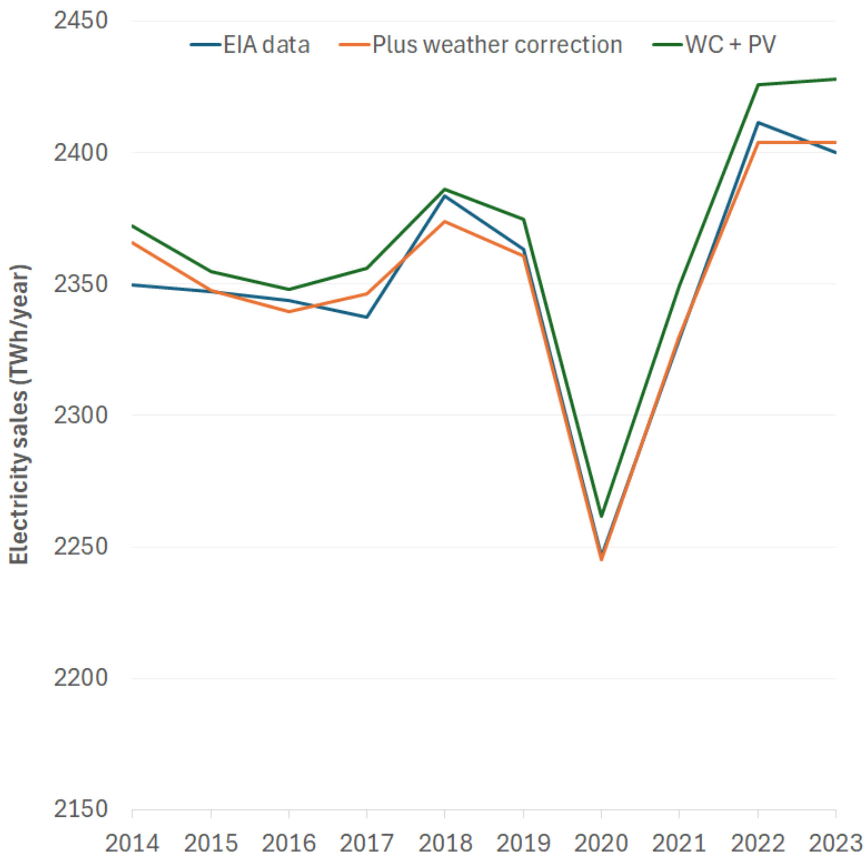
EIA also collects data on monthly electricity sales by sector. If data centers were adding significant new load, one would expect to see growth in the commercial and industrial sectors in recent years. Commercial sales were lower in 2023 compared with 2022, whereas industrial sales increased slightly between 2022-2023. Combined, commercial and industrial sector electricity sales declined slightly from 2022-2023.

Two additional factors could affect electricity sales data as they are currently reported: weather variations and "behind the meter" electricity generation from solar photovoltaics (this generation is not counted in either retail electricity sales or net generation statistics).

Heating and cooling loads in the residential and commercial sectors are temperature sensitive, and year-to-year (as well as month-to-month) weather variations can have a measurable effect on electricity use. **Figure A-3** shows EIA data for the sum of annual commercial and industrial sales from 2014-2023 (blue line) with commercial adjusted for the average weather in that period (orange line), which smooths out yearly weather variations. The results do not change much, but adjusting for weather produces a smaller reduction in electricity sales between 2023 and 2022.

Adding EIA estimates of behind-the-meter solar generation slightly increases total electricity consumption figures for the residential, commercial, and industrial sectors in 2014 and subsequent years (the green line in **Figure A-3** shows the combined effect of this adjustment for commercial and industrial customers). Total consumption increases slightly, but the shape of the curve does not change much.

Figure A-3. EIA electricity sales for the sum of commercial and industrial sectors, corrected for weather and behind-the-meter solar generation



Appendix B: Utilities and balancing authorities included in aggregate forecast tallies in Figure 2

Arizona Public Service Company

Bonneville Power Administration

California Independent System Operator

Duke Energy Carolinas

ERCOT

Florida Power & Light Company

Georgia Power

ISO New England

MISO

NYISO

PJM

Puget Sound Energy

Southwest Power Pool

Tennessee Valley Authority

Appendix C: Understanding recent estimates of data center electricity use

Most estimates of data centers' electricity use have been conducted at the global level, with some regional disaggregation. **Figure C-1** summarizes the most important global estimates for data centers in recent years. These data only include compute data centers and exclude network providers and cryptocurrency. AI data centers are implicitly included within the category of compute data centers, and are sometimes explicitly identified, but have been relatively small until recently.

The peer reviewed estimates are those by Koomey [42], Masanet et al. [43], and Malmodin et al. [36]. These are shown as circles of different colors. From 2000-2005, data centers' electricity use doubled, then growth moderated to 2010 and significantly slowed down in the decade after that. By 2018, data centers used a little under 1% of the world's electricity.

The second group of data is from two organizations with some topic knowledge that produced nonpeer-reviewed estimates for 2021 from iMasons [54, 55] and for 2022 from the International Energy Agency (IEA) 2024a and 2024b [56, 57]. iMasons is an industry group of the world's top data center designers, builders, and operators. IEA is a government-sponsored institution that tracks energy consumption and production trends globally and regionally. These data points are colored squares.

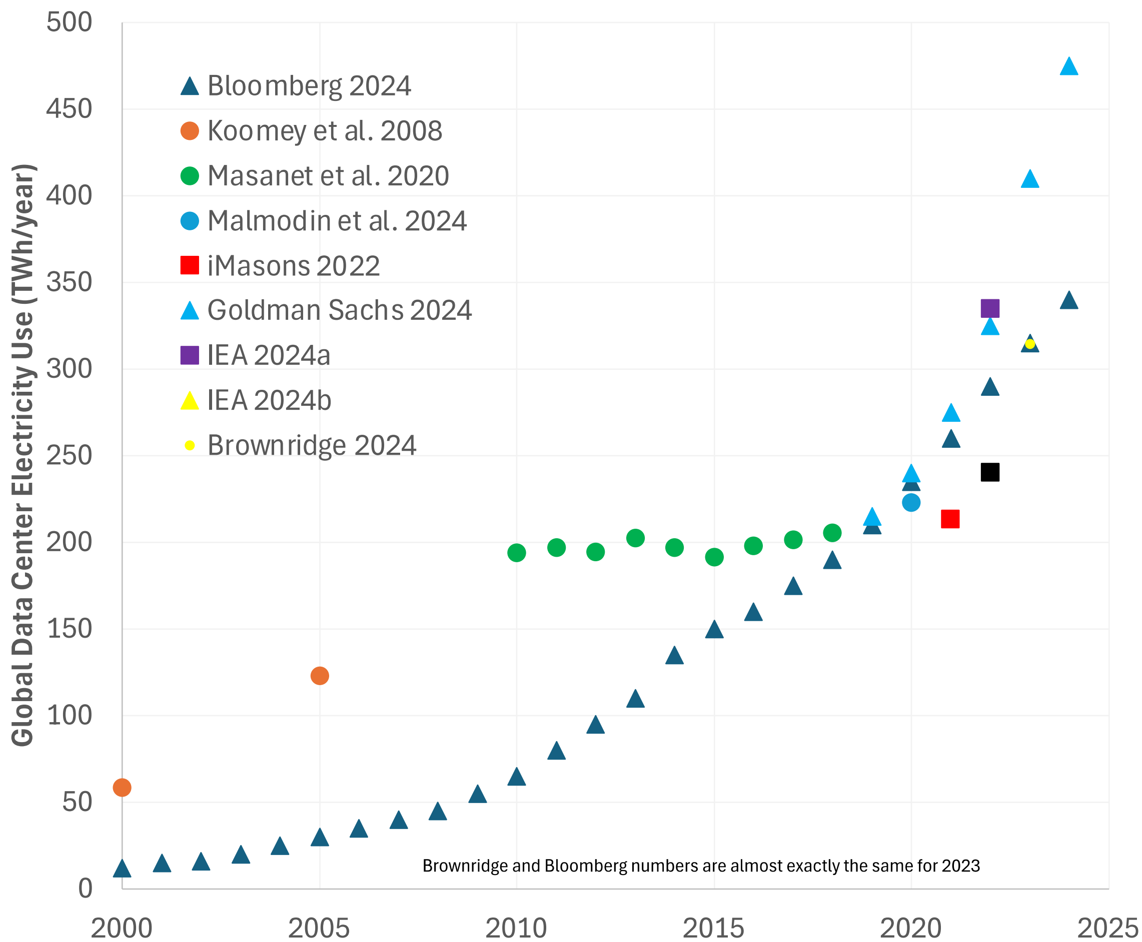
The iMasons estimate for 2021 is close to the 2020 data point from Malmodin et al. The IEA 2024a estimate for 2022 is about 50% higher than Malmodin's 2020 data point. Unfortunately, the IEA report does not give enough information to determine how it arrived at this figure. It could indicate substantial recent growth, or it could be anomalous; nobody knows yet.

In October 2024, IEA released its World Energy Outlook [57], which gave a range of 240 to 340 TWh/year for total compute data center electricity use in 2022 (p. 186). The top end of that range corresponds to the earlier IEA estimate, while the bottom end is closer to iMasons' and Malmodin's estimates. This report also does not give enough detail to determine how it arrived at these figures.

The other three estimates are from Bloomberg [58], Goldman Sachs [11], and Brownridge [13]. These data points are colored triangles. The three firms are analysis shops that are ostensibly credible, but some of these estimates should give one pause. The Bloomberg numbers pre-2020 are particularly concerning, given how low these estimates are compared with the peer-reviewed analysis. The estimates for all three of these sources post-2020 are in the same ballpark as the IEA 2024a number, but given the lack of transparency for the data and methods for these estimates, it is impossible to know how accurate they are.

As time passes, more data will become available to determine whether the projected short-term growth post-2020 is a real phenomenon. Credible analysis always lags events in this space, which is often frustrating to policymakers.

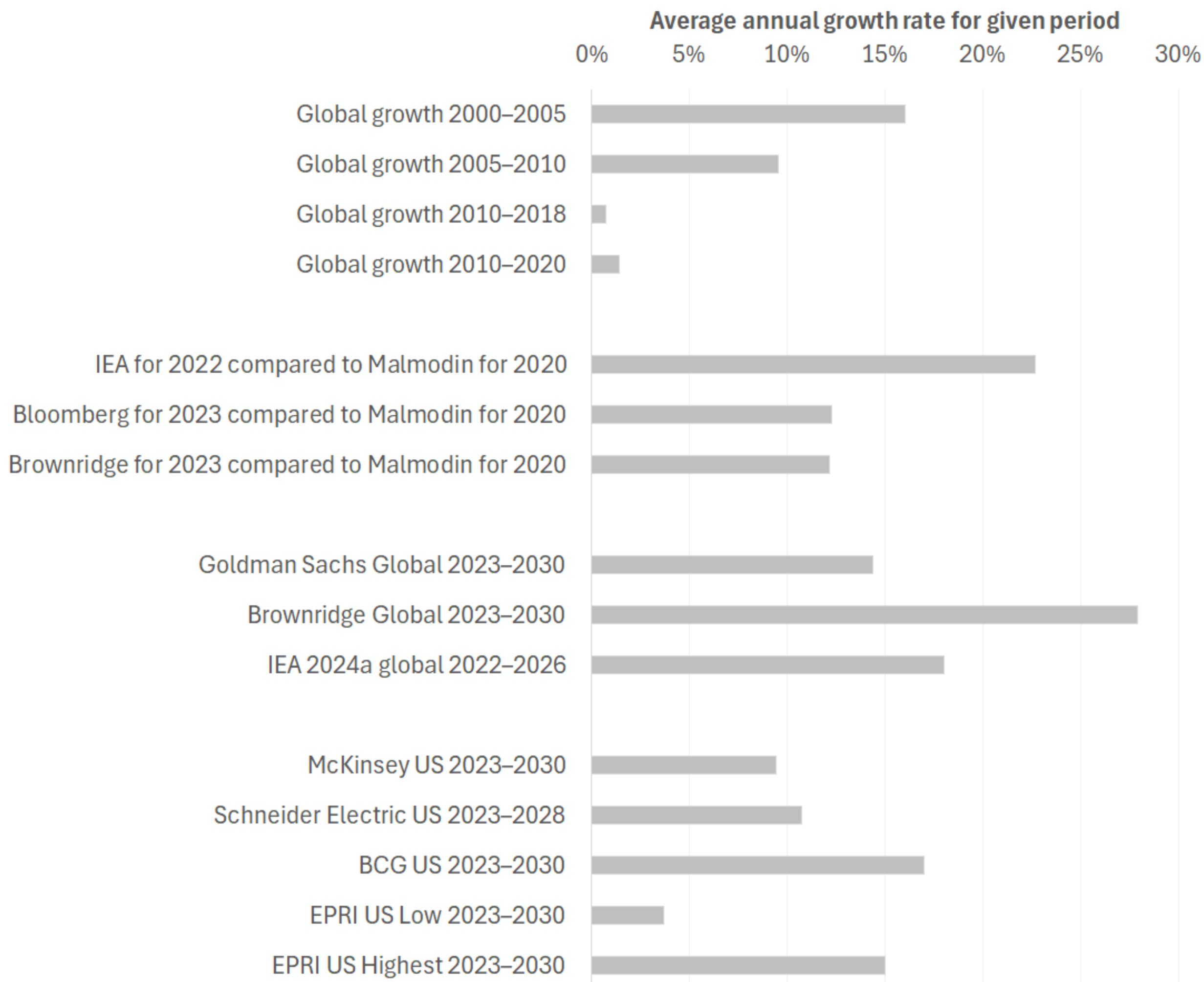
Figure C-1. Estimates of global data center electricity use for historical years



There are also a variety of projections that have been published over the past two years, and it is interesting to compare their projected growth rates to historical developments. **Figure C-2** shows average annual growth rates for a variety of time periods from different sources. At the top are growth rates for different periods from the peer-reviewed data. Growth from 2000-2005 was about 16% per year, and from 2005-2010 was about 9% per year. That growth slowed drastically after 2010.

The graph also shows growth rates from 2020-2022 or 2023 for IEA, Bloomberg, and Brownridge (the 2020 data point comes from Malmodin in all cases). The implied growth rate for the IEA 2024a data is over 20% per year, which would be remarkable if true. The Bloomberg and Brownridge growth rates are about 12% per year, which are rapid but not without historical precedent.

Figure C-2. Growth rates in projected global and U.S. data center electricity use



The Goldman Sachs global projections from 2023-2030 show growth of just under 15% per year; the Brownridge global projections over the same period show growth of 28% per year; and the IEA projection from 2022-2026 shows growth of 18% per year. The latter two projections exceed the growth rates in the 2000-2005 period, for an industry that is now much bigger than it was then.

For U.S. data centers' growth, figure C-2 also shows projections from McKinsey [9], Schneider Electric [59], Boston Consulting Group (BCG) [10], and the Electric Power Research institute (EPRI) [35], which gives a range of estimates. BCG and the EPRI high case show growth rates comparable to 2000-2005, while the McKinsey and Schneider electric cases show growth comparable to 2005-2010.

Which, if any, of these projections are credible? Comparisons to historical data can be suggestive, but they are not conclusive. If the benefits of AI are as compelling as many think, the growth in service demand for AI could indeed be unprecedented, driving absolute electricity use upward at rapid rates. At the same time, an initial period of rapid growth could lead the industry to invest heavily in improving efficiency, just as it did after the big growth spurt in the early 2000s.

There are some things we can say with confidence. Projections of computing's electricity use more than a few years out are no better than guesswork. Growth rates in electricity use equal to or greater than those prevailing in the 2000-2005 period (for an industry that was much smaller then) are unlikely to prevail for very long and are worthy of careful scrutiny. As the uncertainty range for these data is huge, caution and humility are the order of the day.

Bipartisan Policy Center

1225 Eye Street NW, Suite 1000
Washington, D.C. 20005

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