

AI for the Grid

Opportunities, Risks, and Safeguards

By Joseph Majkut and Leslie Abrahams

Abstract

Artificial Intelligence (AI) is now a major force in the U.S. economy. The rapid expansion of data centers in the United States has emphasized the challenges facing the U.S. electricity sector, which is struggling to meet growing demand while maintaining low costs, improving system resilience, and reducing emissions. Given AI's role in the economy, its application to energy is inevitable.

While attention has focused on the challenges of meeting data center demand, there is also opportunity for applications of AI in the electricity sector. Newly available AI tools will enable grid operators, utilities, and consumers to reduce costs and improve performance. At the same time these tools unlock new opportunities for grid reliability, efficiency, and growth, they introduce novel sources of risk to this critical infrastructure that will need to be managed. Policymakers can help by prioritizing immediately useful and scalable grid applications of AI while moderating risk and emphasizing safety, transparency, and broadly distributed benefits.

Introduction

As hyperscalers and AI companies rapidly expand their computing resources to train better models and provide services to users, AI's impact on energy is attracting scrutiny. The coming fleet of data centers will feature some of the largest individual sources of electricity demand and while there is **substantial uncertainty** about exactly how much electricity data centers will consume, growth toward 10 percent of U.S. electricity within this decade is a reasonable estimate. Such growth has raised questions about how the United States can adequately supply electricity to power this technology while maintaining grid security, affordability, and progress toward environmental goals.

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Powering AI will surely impact electricity demand, and it is increasingly likely that AI itself will transform electricity grid operations. Modern AI tools can process large amounts of data, explore and optimize solutions to complex problems, and be used by centralized and decentralized decisionmakers to find local and global optima. AI should therefore be particularly helpful in the electricity sector, which is replete with data and clear performance metrics (e.g., price, reliability, revenue, and efficiency). These interventions would be welcomed and timely for the sector, which is now challenged with meeting multiple imperatives and has emerged as a priority issue for policymakers on both sides of the aisle.

Grid Applications of AI

There have been some excellent and in-depth reviews of AI applications to the electricity sector, which have informed and inspired this analysis. In particular, a recent [systematic review](#) of papers documenting how AI and machine learning tools can be applied to energy systems found dozens of examples where AI was providing documented improvements over existing practices and key insights for how they can be classified in terms of specific AI technologies and maturity, as well as issues for

Table 1: Opportunities for Impactful AI Contributions to Key Electricity Sector Challenges

Category	Implementation	Benefits
Reliability	Load forecasting	Short- and long-term forecasts improve real-time balancing and reserve scheduling, reducing stress that leads to blackouts. AI captures nonlinear drivers (e.g., weather, holidays, and behavior) and enables localized predictions, lowering costs and errors.
	Event prediction, detection, and response	Faster anomaly detection, fault localization, self-healing grid operations, and enhanced situational awareness allows operators to better prepare for and recover from extreme events and cyber attacks.
Efficiency	Real-time decisionmaking	Better forecasts of variable renewable energy (VRE) and load and improved commitment and dispatch decisions lead to lower dispatch costs for thermal generation and higher utilization of renewables.
	Dynamic line rating	Unlocking additional transmission capacity reduces congestion costs and defers costly grid upgrades and expansion.
Growth	Faster interconnection	AI-enabled grid modeling and optimization tools shorten interconnection study timelines, accelerating new generation and large load connections without compromising reliability.
	Virtual power plants (VPPs)	VPPs can rapidly scale using existing distributed generation, home batteries, and smart appliances. VPPs are effective at reducing peak demand, which allows for more rapid new load interconnection.

Source: Authors' analysis.

public policy. Additionally, the Department of Energy published a comprehensive [report](#) highlighting AI applications to modernize the grid, and the International Energy Agency published an in-depth [study](#) of both the energy demands of AI and its potential applications within energy.

RELIABILITY AND GRID STABILITY

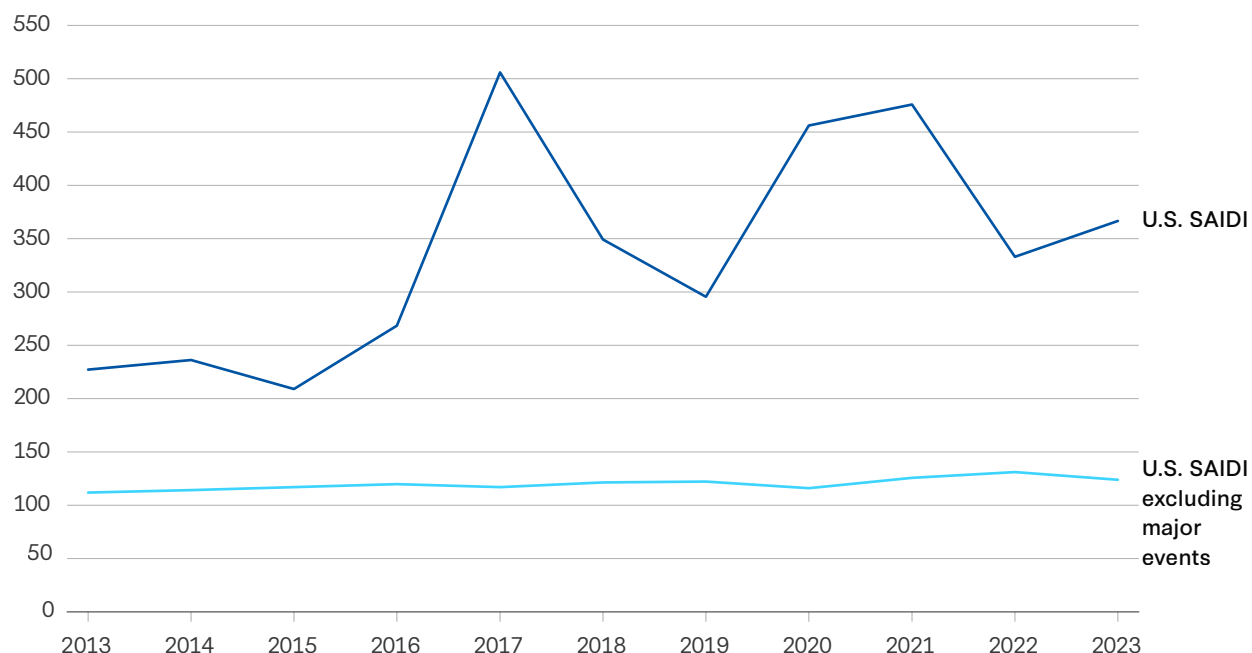
Grid operators continuously manage the real-time condition of the electric grid. They need timely, actionable information to dispatch resources, meet demand, and maintain service. Grid stability is a core component of reliability based on the real-time physics of the power system; it is the ability of the power system to maintain steady voltage and frequency within safe limits, even when the grid faces sudden changes like a large generator outage, unexpected demand spike, or fluctuating renewable supply. Instability can lead to cascading failures and widespread blackouts.

For the last decade, service interruptions have increased on the U.S. grid (see Figure 1). Although growth in system outages is particularly driven by extreme events, regulators caution that system stress is becoming less the exception and more the rule. New pressures are coming from aging infrastructure, growing complexity, higher demand, integrating intermittent renewables, and retirements of dispatchable resources. Grid regulators are warning of increasing risk to grid reliability.

“Uncertainty in energy sufficiency is increasing as the types of resources change, leaving fewer resources that can be dispatched . . . and greater exposure to constraints in fuel supplies,

Figure 1: Service Outages Increased Over the Last Decade

System Average Interruption Duration Index, minutes



Note: Reliability of the U.S. grid has been falling for the past decade, as illustrated by the U.S. System Average Interruption Duration Index, which is the average total minutes the typical customer was without power that year. When removing outages due to extreme events, service interruption has increased by an average of 1.2 minutes per year since 2013.

Source: “Annual Electric Power Industry Report, Form EIA-861 detailed data files,” U.S. Energy Information Administration, August 5, 2025, <https://www.eia.gov/electricity/data/eia861/>.

reservoir levels, or battery discharge capabilities.”—*National Electricity Reliability Corporation, 2024 Long-Term Reliability Assessment*

On the reliability front, AI tools can help translate large volumes of live and forecast data into decisions that keep the system stable and restore service quickly after outages. This is especially valuable as intermittent renewables play a larger role in the power system, because AI tools can improve forecasting of both weather and renewables generation and connect those forecasts to decision tools for planning and operating the grid.

- **Load Forecasting:** Grid operators are practiced in balancing load, which requires predicting both the amount of generation and demand. Improved short-term forecasting, predicting load from minutes to hours ahead, helps operators better balance supply and demand in real time. Longer-term forecasting, predicting sharp spikes in demand from hours to days ahead, allows operators to schedule reserves and avoid system stress that could trigger rolling blackouts.

AI improves forecasting through advanced pattern recognition, incorporating complex nonlinear relationships between demand and factors such as weather, holidays, economic activity, and human behavior. Unlike traditional methods, its computational power can enable predictions at more granular levels, such as for individual neighborhoods or even individual buildings.

- **Event Prediction, Detection, and Response:** AI, with its ability to identify subtle shifts in large and noisy datasets, can be a **powerful** tool in detecting and diagnosing anomalies, and improving situational awareness for operators to respond to various natural and human-caused disruptions. AI-driven high-resolution weather models are also effective in predicting impact from extreme events. These precision forecasts help utilities reduce vulnerabilities such as by cutting down tree limbs from near affected distribution lines and pre-positioning crews ahead of storms to reduce customer down time.

EFFICIENCY

The U.S. Energy Information Agency projects U.S. electricity prices will increase **13 percent** between 2022 and 2025, creating pressure on household budgets and political leaders. Managing cost increases is becoming a more salient priority, at the same time more investments are needed to expand the system. Extracting more capacity from existing infrastructure is less expensive than building new, is the fastest way to accommodate more demand, and will be an important part of managing energy costs in this new era.

“Optimize existing grid resources as much as possible. This involves implementing strategies to enhance the efficiency and performance of the transmission system. The United States must explore solutions like advanced grid management technologies and upgrades to power lines that can increase the amount of electricity transmitted along existing routes.” - The White House, **America’s AI Action Plan Pillar II: Building America’s AI Infrastructure**

Operational efficiency is achieved through maximizing the use of existing generation and the transmission system. AI and advanced analytics help address these challenges by enabling more accurate forecasts of variable renewables and demand and optimizing transmission lines. These tools unlock latent capacity on the grid, help defer upgrades, reduce reliance on expensive standby generators, and increase low-cost renewable use—all reducing expenses for ratepayers.

- **Real-Time Decisionmaking:** Variable renewable energy is weather-dependent and non-dispatchable. As its share grows, hour-to-hour uncertainty in solar and wind output to the grid increases. Control rooms therefore need better short-term forecasts for both VRE generation and load, plus decision support tools that can turn those forecasts into decisions around commitment, dispatch, and curtailment to more efficiently use all available resources.

AI tools are advancing weather prediction, where deep-learning models can emulate numerical weather prediction and downscaling to deliver high-resolution, probabilistic solar and wind forecasts at low computational cost. Advanced methods now produce fine-grained weather fields and associated estimates of VRE generation. These can improve recommendations for how operators commit and dispatch reserve generation. These tools lower dispatch costs for thermal generation and improve utilization and revenue certainty across the generation fleet.

- **Transmission Optimization:** The transmission system moves power between service areas to help meet demand but can reach limits when the capacity of transmission lines is unable to meet demand imbalances. Frequent transmission congestion adds up to over **\$20 billion** a year in the United States, as operators are forced to use expensive standby generation instead of low-cost power for well-supplied regions. While demand imbalances are part of overall grid management, transmission capacity is affected by environmental conditions. Hot, stagnant weather reduces line capacity and worsens congestion, while cool or windy conditions raise capacity and ease congestion. As with many other parts of the power system, operators have traditionally used static and conservative ratings for transmission lines, which result in unused capacity and increased costs.

AI tools are producing dynamic, weather-aware line ratings that allow operators to raise limits when conditions permit or lower them when necessary. Using high-resolution weather data, paired with models of how weather affects line capacity, these methods reduce the need to assume static ratings by enabling: (1) hyper-local wind and weather information at the span level to improve capacity estimates, (2) probabilistic ratings so operators can assess risk, and (3) system-wide scalability without ubiquitous line-mounted sensors, allowing dispatch to mitigate congestion across the system rather than shifting congestion.

ACCELERATING GROWTH

If the power system cannot expand to meet growing demand, it will stall economic growth by slowing investment in energy intensive sectors and increasing electricity prices. After decades of flat demand, forecasters anticipate increasing electricity load; CSIS [analysis](#) forecasts data center electricity demand alone to increase from 4 gigawatts (GW) to 84 GW by 2030. Expanding the power system to meet that peak demand, while also backfilling for retiring plants, will be critical in the coming decades.

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In the electricity sector, planning horizons for some types of infrastructure spans decades. Energy infrastructure siting and permitting are laden by lengthy and convoluted processes that create risk and uncertainty for developers and investors. AI tools can address these bottlenecks by accelerating interconnection studies and enabling integration of rapidly scalable VPPs.

- **Interconnection:** Utilities, regulators, and grid operators coordinate to ensure that grid infrastructure and generation can affordably and reliably meet future demand. This process involves multiple institutions doing complex modeling and manual assessments of future reliability, a method unfit for rapid expansion of the grid. In recent years, the median time from interconnection request to commercial operation has stretched to about **5 years**. More than **2.6 terawatts** (TW) of proposed projects were waiting in interconnection queues at the end of 2023, enough generation to power more than 145 million customers nationwide. As uncertainty about future demand and technology is rising, new tools are necessary to manage this interconnection process.

AI can accelerate planning and interconnection without sacrificing reliability standards. High performance computing and optimization routines for grid models shorten runtimes, enabling more scenarios at higher spatial and temporal resolution, and improved weather modeling gives greater confidence in generation forecasts for wind and solar. Foundation models, such as large language models, can automatically screen and validate large documents and public filings, reducing the time it takes to review applications.

- **Virtual Power Plants:** VPPs are software-based aggregations of distributed energy resources that are digitally managed to collaborate in the electricity market and grid operations. VPPs aggregate rooftop solar generation, electric vehicles, smart thermostats, and even industrial loads. The complexity and scale involved in coordinating thousands or millions of small, distributed devices in real time can only be unlocked through recent advances in AI.

Individualized agents can be calibrated to individual preferences about temperature control, vehicle charging, or home battery settings. The Department of Energy (DOE) projects VPPs could meet **10-20 percent** of peak load by 2030, allowing substantial growth in load without sacrificing reliability. Importantly, VPPs are flexible, scalable, and do not face the siting and permitting delays born by utility scale physical infrastructure.

Data Center Demand Flexibility

The data centers that will enable AI will themselves be large electricity consumers. Adding these large loads to an already strained grid could create problems without an adequate supply of electricity. Grid planners and regulators have previously sought to power datacenters with all-new generation to ensure grid stability at peak demand.

Now facing long delays to access power, data center developers are building out their ability to offer demand flexibility, becoming a tool for grid stability rather than being a strain on the system. Shifting loads to different times or different data center locations can avoid stress on the existing grid, defer investments in new generation and transmission infrastructure, and better align demand with intermittent wind and solar generation. According to **Norris and coauthors**, flexibility could allow up to 100 GW of data centers to connect to the grid with minimal additional generation.

Industry is beginning to experiment with real-world applications of this flexibility. The Electric Power Research Institute's Data Center Flexible Load is providing a testbed for companies at three sites to experiment with flexibility solutions and report their results to build trust and accountability with regulators and grid operators. These developments **promise** an industry-led approach to developing the AI industry and grid improvements simultaneously.

Managing AI Induced Grid Vulnerabilities

As these applications demonstrate, AI has the potential to mitigate immediate challenges facing today's electricity grid. However, implementing these tools requires careful attention to the inevitable new risks that arise from deploying new technologies. Because the electricity sector is so critical, complex, and sensitive, appropriate measures must be put in place to ensure these benefits are safely realized.

The key challenge for policy makers is to strike a balance between encouraging AI adoption where it most enhances reliability, efficiency, and growth while safeguarding critical infrastructure with appropriate governance and oversight mechanisms. Implementation at scale will need appropriate safeguards for maintaining cybersecurity.

Risks from AI integration with the grid span the value chain. In the case of real-time decision support, AI systems are considered black boxes, making it difficult to verify and validate tool outputs before implementing system-wide changes. Faulty or poorly trained models could amplify, rather than reduce, reliability concerns. Similarly, because AI systems themselves are so complex, pairing them with the already complicated grid architecture could lead to new failure modes. Existing literature has

sought to highlight these risks and recommend mitigation measures. For example, the DOE Office of Cybersecurity, Energy, and Emergency Response **wrote a report** on the potential risks of expanding the use of AI in critical energy infrastructure.

Due to the criticality of the grid, electricity planners, regulators, utilities, and operators are historically risk adverse. Integrating AI solutions at scale—especially those informing real-time and automated operational responses—will be a slow process without policymakers supporting clear objectives, industry working together to iterate and learn quickly, and appropriate safeguards in place for consumers and the grid.

Effective risk mitigation will be essential for building confidence in AI applications on the grid. Protecting customer privacy through data anonymization can reduce exposure to misuse of sensitive information, such as household occupancy patterns. Establishing clear industry standards will give utilities and regulators a shared foundation for evaluating tools, while maintaining human oversight in critical decisions can ensure accountability. Robust testing environments, digital twinning, and regulatory sandboxes will allow new applications to be trialed safely before widespread deployment, and system redundancies can provide additional safeguards to preserve reliability if AI-enabled systems fail. Together, these measures can help translate technical innovation into trustworthy practice.

Key Observations and Policy Recommendations

America's AI Action Plan identifies the “limited and slow adoption of AI” as a key bottleneck to realizing its potential economywide impacts, citing “distrust or lack of understanding of the technology, a complex regulatory landscape, and a lack of clear governance and risk mitigation standards.” These barriers are evident in electricity, where AI tools show clear promise but remain at the pilot stage.

Although AI offers significant opportunities for improving reliability, cutting costs, and permitting growth, adoption has been uneven. A Federation of American Scientists **report** identified 12 high-value AI applications for the grid, yet even the most technically mature are not applied at scale in the United States. Surveys from the International Energy Agency confirm this globally: Grid operators **reported** using AI for asset management and planning (70 percent) or grid development (54 percent), while fewer than one-quarter (23 percent) reported deploying AI in daily operations such as load forecasting. Operators expressed skepticism about relying on AI for critical decisions, preferring advisory roles for software and maintaining traditional standards.

To realize the benefits of AI in energy, the United States must balance the try-first experimentalism preferred in the digital economy with the stringent safety and reliability demands of the power system. Achieving this balance will require political leadership from the federal government to prioritize strategic projects, support near-term demonstrations, and promote best practices through standards and information sharing.

Some immediate policy recommendations are as follows:

1. **Develop standards to capture reliability benefits of AI.** The AI Action Plan calls for a coordinated federal approach to domain-specific efforts led by the National Institute of Standards and Technology (NIST). In doing so, NIST could lead in adapting its **AI Risk Management Framework**—a voluntary framework that guides the safe and trustworthy design, deployment,

and use of AI—to grid applications for load forecasting, fault detection, and other operational matters. Working with the DOE, the Federal Energy Regulatory Commission (FERC), and industry, NIST could define standards that would give operators and their regulators a shared basis for validating AI's performance and reliability, building confidence in the tools that are developed so that they can be widely adopted. The DOE and states could use those standards in supporting grid enhancement projects and implementation initiatives with grants and loans.

2. **Allow FERC to incorporate AI into grid planning and expansion.** Prolonged interconnection processes are stalling the development of new generation. Demonstrations have shown how they can be sped up with AI tools for document management and simulations of the power grid. Defining how these tools can be used by grid planners is a key task for regulators and thus should be a FERC-led process. The Federation of American Scientists [recommends](#) that a FERC-DOE-RTO working group convene to “clarify the regulatory pathway for AI use cases in grid planning,” a proposal which would bring the right parties into the process and provide clarity on how AI-enabled tools can inform long-term investment and expansion decisions.
3. **Define priority regions for demonstration projects.** The DOE has existing authority to support grid enhancements and projects that would implement AI in applications such as dynamic line ratings. With substantial expertise in grid flows and data center development, the DOE can define priority areas where congestion is exacerbating electricity rates and limiting growth. Deploying AI-assisted tools such as dynamic line ratings and distributed energy resource management in high-impact contexts will build confidence, generate replicable models, and demonstrate the value of federal leadership.
4. **Support demand flexibility, large and small.** The AI Action plan cites data center flexibility as a key tool for improving grid efficiency and accommodating new demand. Federal support should extend this principle to encourage distributed participation through virtual power plants and other distributed resources. Expanding demand-side options will give utilities and regulators more tools to deploy during periods of peak load, and consumers access to the benefits of a more dynamic grid.

Economy-Wide Energy Effects

This paper has thus far focused on what AI can do in support of the electricity sector and highlighted several areas where AI tools can address the challenges that sector faces today. Resolving these issues through the application of AI and broader reforms to the energy sector will be important for a thriving economy in the future. But AI can and will affect energy use more broadly.

AI tools will help deliver efficiencies across energy intensive sectors of the economy, where firms adopt practices to reduce costs and increase output. In its AI and Energy [report](#), the International Energy Agency estimated energy savings across key subsectors by 2035 that could be achieved with AI applications (See Table 2). Based on [projected](#) 2035 U.S. demand, AI applications could save nearly

Table 2: IEA Forecasted AI Induced Energy Savings Across Energy Intensive Sectors by 2035

Sector	Subsector	2035 AI energy savings (%)	2035 demand: reference case scenario (PJ)
Industry	Iron and Steel	2.9	1,160
Industry	Cement	3.8	500
Industry	Chemicals	2	10,440
Industry	Aluminum	4	260
Industry	Paper	2.2	1,860
Industry	Other	8	13,650
Transportation	Light commercial vehicles	6.3	8,160
Transportation	Heavy duty trucks	3	3,670
Transportation	Cars	3	4,460
Transportation	Buses	6	1,690
Transportation	Aviation	3.8	3,120
Transportation	Shipping	3.7	940
Transportation	Rail	7.4	530
Buildings	Residential	0.8	4,780
Buildings	Non-residential	3.9	1,760

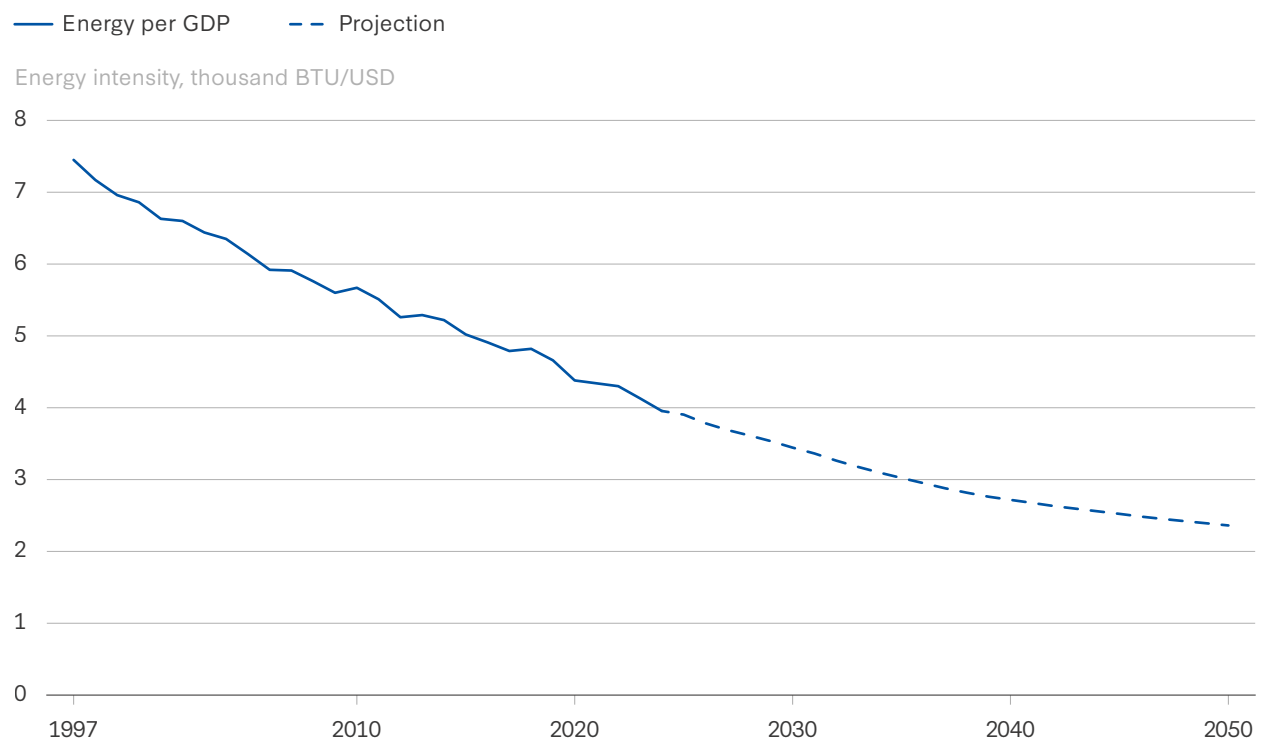
Source: Davide D'Ambrosio et al., *Energy and AI* (Paris : International Energy Agency, April 2025) <https://www.iea.org/reports/energy-and-ai>; and "Net Zero America: Potential Pathways, Infrastructure, and Impacts," Princeton University, <https://netzeroamerica.princeton.edu/?explorer=year&state=national&table=2020&limit=200>.

2,500 petajoules (PJ) of energy for the U.S. if fully realized. This translates to approximately 4.5 percent of 2035 demand in the three most energy intensive sectors.

Applications for AI thus create opportunities to make industry, transportation, and buildings more productive in terms of total energy usage (not just electricity). And since these sectors have traditionally been labeled hard to abate because they are difficult to electrify, AI-driven energy reduction could provide another pathway towards marginal decarbonization.

Finding energy efficiencies will help make the economy more productive (or less intense) per unit of energy consumed. An economy that is less energy intense has distinct advantages because it implies lower input costs, less exposure to energy price volatility, lower emissions, and a stronger competitive position. In the United States, energy intensity of the economy has fallen by about 2.2

Figure 2: U.S. Energy Consumption per GDP (Past and Forecast)



Note: Historical and forecasted energy intensity of U.S. GDP show ongoing improvements, driven by energy efficiency and increases in the size of the digital economy. Forecasts expected increased energy productivity before widescale deployment of AI.

Source: U.S. Energy Information Administration, *Annual Energy Outlook 2025* (Washington, DC: U.S. Energy Information Administration, April 2025), <https://www.eia.gov/outlooks/aeo/>.

percentage points per year (see Figure 2). This represents both higher energy efficiency and growth in less-energy-intensive parts of the economy. Looking forward, this trend is expected to continue and perhaps accelerate, partially due to AI applications helping to increase energy efficiency and shifting investment concentrating energy use in higher value add sectors.

Whether AI can provide tools to accelerate larger increases energy productivity of the economy, in the same way economists expect it to increase labor productivity, is an important question beyond AI's own energy consumption or applications to the grid.

Conclusion

AI tools are uniquely positioned to address problems in energy, a sector replete with data, complex optimization problems, and multiple layers of governance. The tools already under development will enhance efficiencies, save companies and consumers money, and help realize new business models and technologies. However, without appropriate safeguards and regulatory oversight, the same AI solutions that could enhance grid operations could unleash new vulnerabilities to this critical infrastructure. The question facing policymakers is how those tools might be utilized to solve immediate problems facing society, and how those can be prioritized and accelerated while moderating the degree of additional risk.

The United States has adopted a strong stance toward winning the AI race, recognizing the economic and security stakes of being at the front of the line in this new technology. The country is now rushing to enable that victory by increasing the availability of electricity for datacenters through vigorous investment, accelerated permitting for individual projects, and infrastructure strategies. As that is done, applying AI solutions to the energy sector could help reduce friction in expanding and operating an increasingly complex grid. Reliable and affordable electricity at the scale necessary to meet the needs of innovative industries of the future is key to U.S. economic security and competitiveness. AI is a driver of challenges to the grid but should also be seen as a tool that can be leveraged to enhance the grid and allow the electricity sector to rise to the challenge. ■

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