13

IMPACT SERIES

AI revolution: Meeting massive AI infrastructure demands

Barclays Research explores the global race for pre-eminence in Artificial Intelligence – and the strains on resources, and likely geostrategic tensions, that may result.

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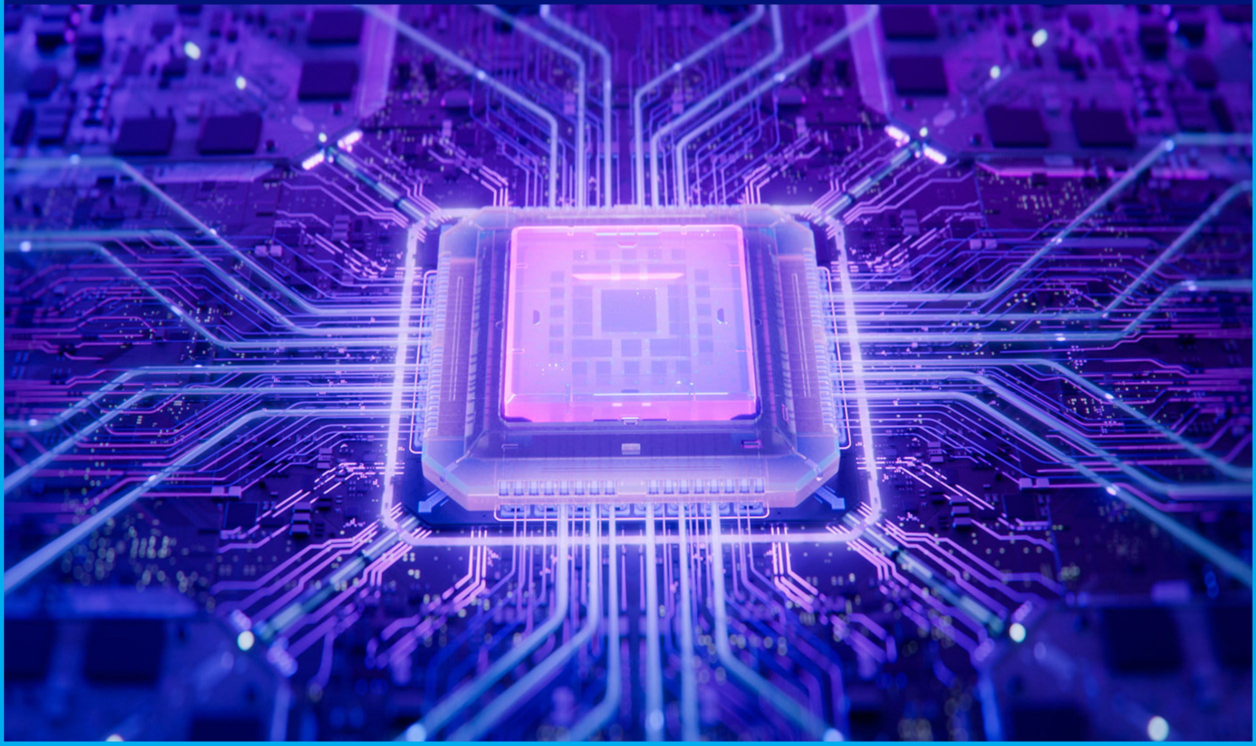
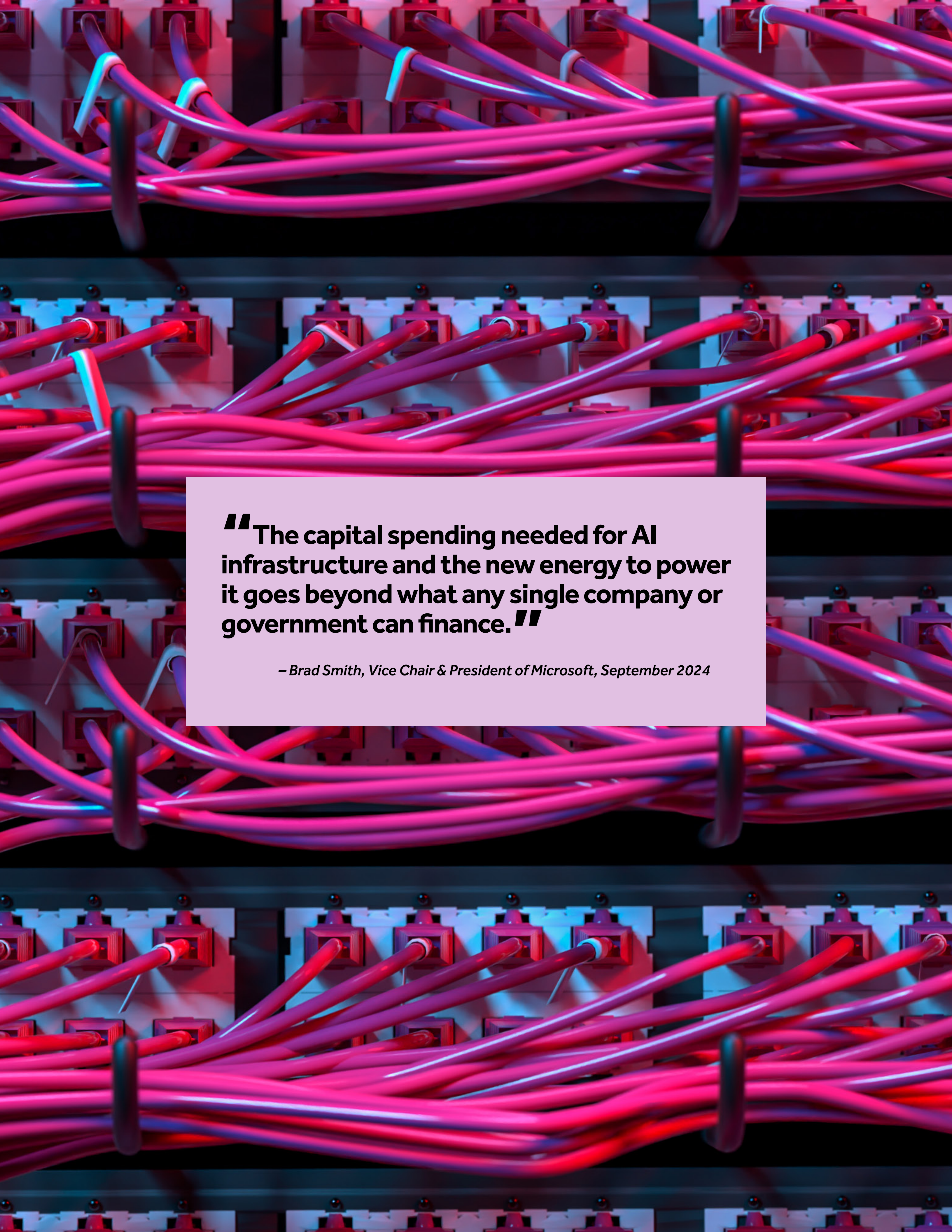




"The capital spending needed for AI infrastructure and the new energy to power it goes beyond what any single company or government can finance."

– Brad Smith, Vice Chair & President of Microsoft, September 2024

Foreword

Welcome to the thirteenth Impact Series report from our Research team. This time, we examine the resource challenges associated with the race for pre-eminence in Artificial Intelligence.

16 January 2025

The rapid adoption of AI over the past few years has led to a lot of big questions over intellectual property, privacy and security, and the future of work and human creativity. However, there has been less discussion on how much power will be needed to train and operate AI models and how societies should look to provide it. We have published this report to help companies and investors gain a deeper understanding of the likely scale of the growth in consumption linked to AI. We focus on the US, the clear AI market leader, where our forecasts for power-demand growth are well above the consensus. We examine what that implies for the world's ambitions to cut greenhouse gas emissions, as well as other matters such as national security.

We admit that there is plenty of uncertainty around our projections: ultimate levels of demand for power will depend on the pace of uptake of AI tools, as well as new efficiencies in hardware and in data-centre infrastructure. Nonetheless, we hope the report will provide a useful contribution to an emerging debate. We suspect that the optimal path from here involves careful, co-ordinated deliberation between policymakers, technology companies and the energy industry.

C.S. Venkatakrishnan
Group Chief Executive Officer
Barclays

"We do need way more energy in the world than I think we thought we needed before ... I think we still don't appreciate the energy needs of this technology."

– Sam Altman, CEO of OpenAI,
at the World Economic Forum Annual Meeting, January 2024

The race to implement Artificial Intelligence is well underway

Companies around the world have started to integrate AI tools across diverse applications, including chatbots, AI agents, content creation and scientific research. Big tech firms are responding with huge investment in data centres that can train and run models. Chipmaker Nvidia is vying with Microsoft and Apple for the crown of the largest company in the world by market capitalisation, its value nearly trebling over the course of 2024.

This rapid growth is placing new strains on resources. AI's thirst for power has always been strong – it is often cited that AI queries require about ten times the electricity of a traditional web search. And aggregate demand seems bound to rise further, as more and more companies look to exploit advantages that AI can offer and tech firms train ever-larger models in an effort to achieve human-like intelligence. Already, regulators are warning that grid systems could struggle to keep up, forcing higher prices on consumers. At Barclays, we have some of the most aggressive forecasts for data centre-led energy demand growth over the next five years (see Fig 1). Efforts to conserve power through efficiencies can likely only go so far in offsetting the proliferation of AI.

And what of plans to achieve net zero? "Hyperscalers" such as Meta, Alphabet, Amazon and Microsoft have been clear that data centres require uninterrupted energy, 24 hours a day, seven days a week. This has caused them to continue to rely on power from coal, nuclear and natural gas-fired plants, rather than intermittent renewables such as wind or solar, while maintaining 100% back-up power, often from diesel and gas generators, to guard against disruptions. That, in turn, has raised questions about whether Co2 emissions targets are achievable. It has also revived interest in nuclear power, despite concerns over the high cost of development, safety risks and the storage of spent fuel.

Policymakers need to walk a tightrope: balancing a desire to reap economic and geopolitical advantages, while respecting existing regulation and frameworks, from net zero to copyright. Countries will also be mindful of national security in their considerations in how to implement AI, which will likely inform decisions related to energy and technology infrastructure for years to come.

Ultimately, the adoption of AI is a global challenge, which points to an urgent need for dialogue between the public and private sectors. Policymakers, tech companies and the energy industry must forge new partnerships to deliver AI that are socially beneficial and – crucially – environmentally sustainable.

The relentless pursuit of power

Data centres are the "factories" for AI, where models are trained and operated. They also serve as warehouses and distribution centres for the storage and dissemination of data for many other applications, including websites, streaming services and cloud computing.

Today, there are more than 11,000 registered data centres around the world, according to the International Energy Agency (IEA); most of which are not yet involved in any kind of AI-related activity. Combined, their consumption of electricity (excluding cryptocurrencies) is about 1.0%-1.5% of the world's total, according to an IEA mid-2024. That proportion is higher in the US (~4%) and the EU (~3%) given their leading shares.

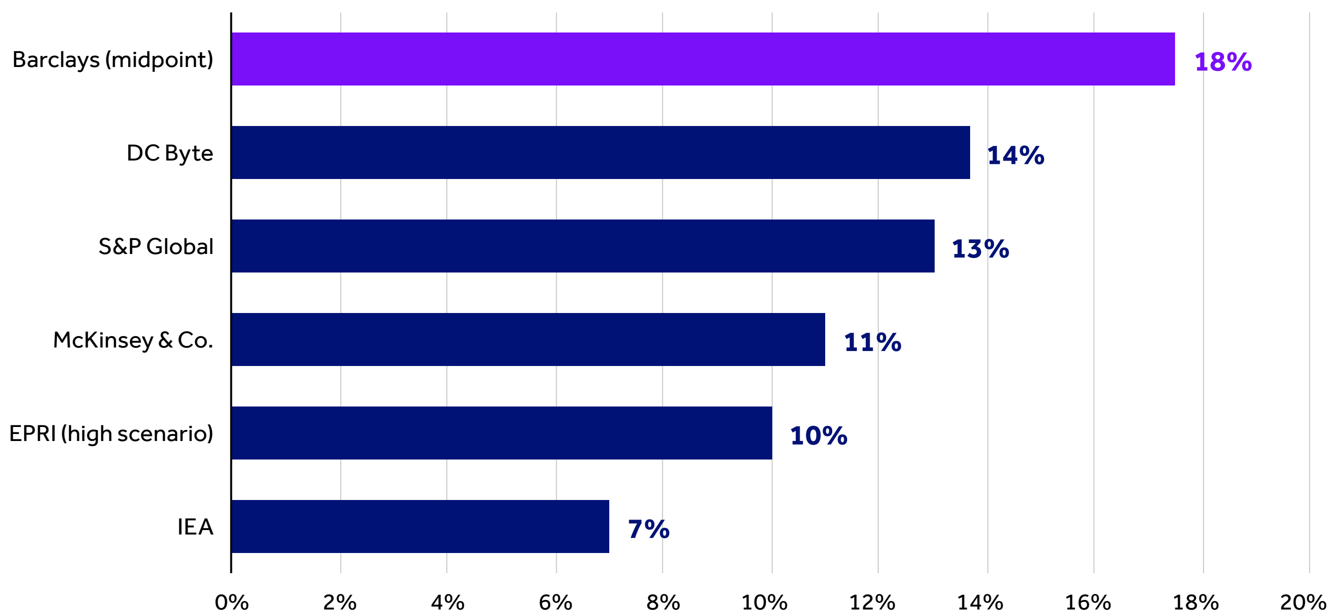
However, data centres' energy demands could change dramatically in coming years, thanks to the dissemination of AI. According to a June 2024 analysis from Barclays Research – which uses a bottom-up approach based on utilities' forward-looking supply contracts – annual demand to power data centres in the US could grow by a range of 14%-21% every year through 2030. This would imply US data-centre demand roughly tripling by 2030, from 150-175 terawatt hours (TWh) in 2023 to as much as 560 TWh – equivalent to 13% of current US electricity demand (note that this excludes crypto mining, which the US Energy Information Administration estimates at 0.6-2.3% of US electricity consumption in 2023). Our growth estimate for data-centre demand is significantly more bullish than others, including consultancy DC Byte, S&P Global, McKinsey, EPRI and the IEA.

There is a lot of uncertainty around these forecasts: relevant data is not always readily available, gains in efficiency are difficult to model and the pace of AI adoption is unclear. Plans to create more data-centre capacity could also be slowed by bottlenecks in the production of chips and key grid equipment, as well as regional grid capacity constraints. We also note growing not-in-my-backyard ("NIMBY") resistance to proposed data centres in certain regions, particularly since such facilities do not create many full-time jobs.

The broader point, though, is that AI and data centres could provide a much bigger spur to global electricity demand than was initially factored in to net-zero targets. The collective global demand of Alphabet, Meta and Microsoft has grown by 25% or more each year since 2017, and this growth may only accelerate with AI proliferation.

FIGURE 1

The rack pack: Forecasts for annual growth in power demand by US data centres, to 2030



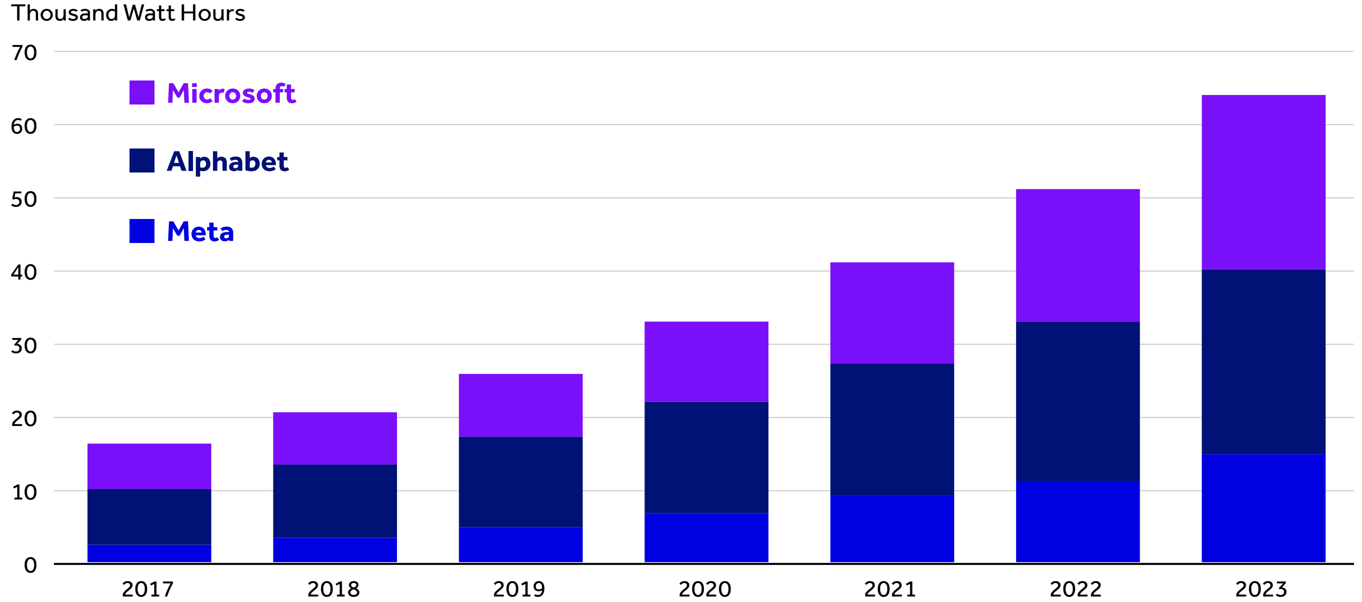
Source: International Energy Agency (IEA), Electric Power Research Institute (EPRI), McKinsey & Co, S&P Global, DC Byte and Barclays Research

"The chief obstruction to data-centre growth is not the availability of land, infrastructure, or talent. It's local power."

– Pat Lynch, Executive MD & Global Head of Data Centre Solutions for CBRE, May 2024

FIGURE 2

Gridlocked: Hyperscalers' global annual energy demand



Source: Companies, Barclays Research

Chips with everything: Powering models

AI's energy needs can be segmented into two overlapping phases: the training of models, and use of those models during the inference stage. Both phases are very resource-hungry, with data centre electricity usage already exceeding hundreds of megawatts. Such centres can be located almost anywhere there is land with access to power, but those focused on inference will likely remain near regions with large populations to limit network delay between users and the servers.

The quality of any large language model (LLM) depends largely on its size and the amount of data on which it is trained. Both parameters have grown rapidly amid efforts to achieve levels of intelligence approximating a human. The compounding effect of bigger models and more training data has been a roughly 7x increase every year in computing requirements for major LLMs.

The result is that models are being trained on ever-larger collections of chips. Meta chief Mark Zuckerberg told investors in October 2024 that the company is training its new Llama-4 model on around 100,000 GPUs, more than six times the previous model. Elon Musk's xAI claims to be in the process of doubling its "Colossus" supercomputer to 200,000 GPUs. Anthropic, which is backed by Amazon, said in December 2024 that it will train its next-generation Claude models on "hundreds of thousands" of AWS Trainium2 chips with five times the computing power of previous models.

Assuming AI scaling laws continue, models could start to exceed a billion exaflops by 2026 and hundreds of billions of exaflops by 2028. (One exaflop: A billion, billion calculations per second.) Training a single model could require several, if not tens of, gigawatts of power.

Forecasting the computing and energy needs for AI inference is more challenging. One trend seems certain: more consumers and businesses will adopt AI and the number of daily AI inquiries per user will grow. The key questions now: How quickly will this occur? Will larger generative AI models be broken into smaller application-specific models? How much AI inference will be conducted on smartphones and personal computers via "edge computing" – which involves the processing of data close to its source?

> **"Large language models (LLMs) require immense computational power for real-time performance. The computational demands of LLMs also translate into higher energy consumption as more and more memory, accelerators, and servers are required to fit, train, and infer from these models. Organisations aiming to deploy LLMs for real-time inference must grapple with these challenges."**
>
> *– Nvidia Blackwell Architecture Technical Brief, March 2024*

US takes the lead

The trend is most obvious in the US, where spending on construction of data centres has more than doubled since the release of OpenAI's ChatGPT in November 2022, according to US Census Bureau data, and has been growing around 60% year-over-year since October 2023. The latest wave of development has focused on more remote secondary markets, including parts of the Midwest, amid increasing power constraints in mature data-centre markets such as Northern Virginia, Atlanta, and Dallas.

But America will certainly not be expanding alone. Concerns over the sovereignty of AI technology (see box on p11) are likely to make all nations reluctant to outsource activities, to any great extent. In China, for example, the so-called "Eastern Data, Western Computing" project involves plans to construct eight major data-centre hubs, primarily in its western provinces. The Gulf region could become a particularly large player in the industry, as it combines abundant energy and vast amounts of capital. Saudi Arabia and the UAE have both launched major research centres and ministries devoted to AI.

Europe, too, will have to respond, as it grapples with a number of disadvantages, including the loss of cheap Russian gas, tight fiscal constraints and ambitious emissions targets. It also has some of the strictest data-protection standards in the world. Accordingly, some European countries are pursuing so-called "frugal" AI programmes that seek to balance investment in both digital and clean-energy needs, recognising that this technological revolution is proving much more capital-intensive than previous advances, such as the internet.

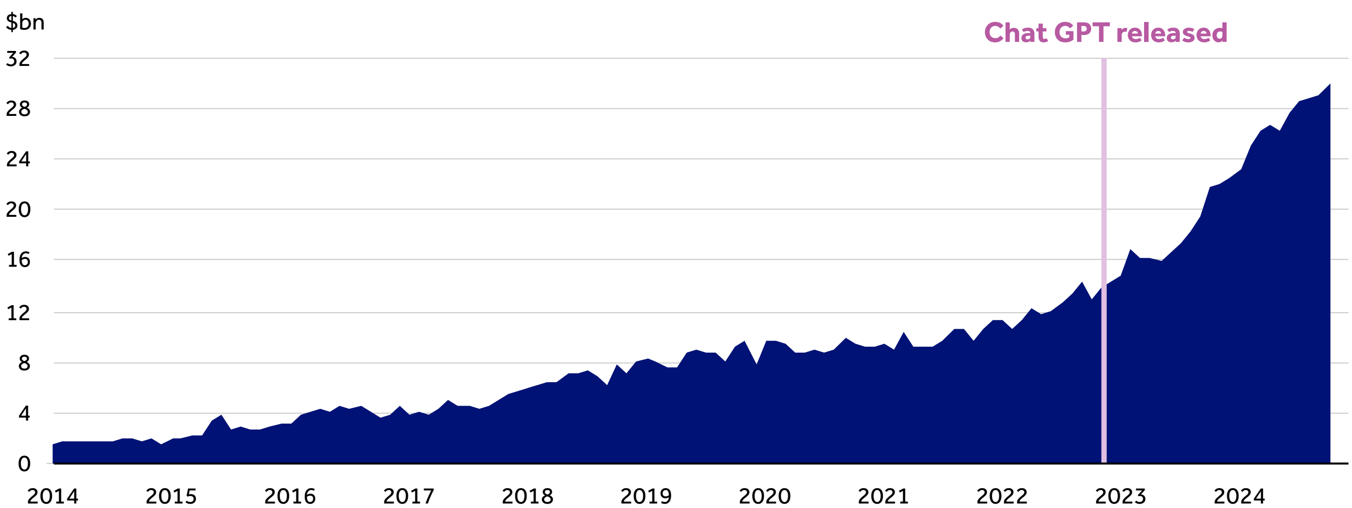
The EU also has a revised Energy Efficiency Directive (EU/2023/1791), which introduces a new scheme for rating the sustainability of data centres. Reporting requirements include electricity consumption and its share from renewable sources, usage of waste heat, and incoming and outgoing data traffic, among other data points. By May this year the Commission will look to establish the next phase of the rating scheme and/or minimum performance standards to achieve net zero emissions.

Momentum seems unlikely to fade in the US, where the Biden administration had described US leadership of AI globally as a "national security and economic imperative," highlighting the potential for advancements in scientific discovery, national security and energy innovation. Incoming President Trump has taken a similar tone, nominating former PayPal chief operating officer David Sacks to be his AI and crypto czar, as well as heading his council of advisers for science and technology.

AI and crypto are "two areas critical to the future of American competitiveness," Mr Trump said in a social media post on his nomination of Mr Sacks. "David will focus on making America the clear global leader in both."

FIGURE 3

Centres of attraction: US private data-centre construction spend (seasonally adjusted annual rate)



Note: Includes value of construction installed but excludes costs of land acquisition, racks and servers
Source: US Census Bureau, Barclays Research

Geostrategy: Location, location, location

Thus far, the location of data centres seems to have been mostly determined by proximity to vital infrastructure such as fibre-optic cables and power resources, as well as to large amounts of customers in sectors such as financial services, which often need real-time access to data. Cooler climates, tax and regulation have played a role too, leading to high "clustering" in certain countries such as Ireland or the US.

However, as the industry aims to build data centres to advance towards ever more powerful AI models, other strategic considerations may start to dominate. Data centres used for training new AI models may not need the same proximity to clients as those used for inference, or responding to prompts, where rapid access is more crucial.

More importantly, these new plants for AI do not just produce goods, but also turn the inputted energy and data into "intelligence," potentially mimicking the cognitive abilities of the human brain. The more powerful AI models become, the more decisions on location may be swayed by considerations over sovereignty and national security.

“Jensen and Sam’s law”

Granted, growth in AI-related activity does not automatically lead to much greater demand for power. Efficiencies are attainable, judging by Nvidia’s new “Blackwell” generation of Graphics Processing Units (GPUs). Such chips require more power than the previous generation, known as Hopper, but industry benchmark tests show big gains in computing performance for both the training and inference phases of AI (see box). Nvidia expects further energy efficiency as it continues to optimise its chips, their data transfer and memory systems, and the software that manages them.

“Updated regulations and technological improvements, including on efficiency, will be crucial to moderate the surge in energy consumption from data centres,” said the IEA, in its Electricity 2024 report.

Optimists also point to the potential efficiency gains made possible by AI, for all activities in an economy. A November 2023 report from Boston Consulting Group, commissioned by Google, claimed that insights from AI could help to mitigate 5% to 10% of global greenhouse gas emissions by 2030, simply by adapting currently proven applications and technology.

Yet efficiencies do not, by themselves, lead to lower consumption of power. We suspect that AI’s net effect on electricity demand will almost certainly be positive – based at least in part on an old law of economics known as the Jevons paradox.

In 1865, the English economist William Stanley Jevons observed levels of coal consumption in England in the 100 years or so after James Watt invented the steam engine – a technology that greatly improved the efficiency of the previous coal-powered standard. He noted that those gains in efficiency led to a much greater range of applications, across industries, even as the fuel required for any particular application fell. Total consumption of coal soared as a result.

That also held true in the big wave of computerisation in the 1990s, as powerful hardware developed by Intel was quickly consumed by more demanding software from Microsoft. The phenomenon became known as “Andy and Bill’s law,” after the companies’ respective CEOs. The 2020s equivalent? Perhaps “Jensen and Sam’s law”: every new generation of GPUs produced by Nvidia (CEO: Jensen Huang) leads to an ever-larger number of chips in data centres used by the likes of OpenAI (CEO: Sam Altman).

By the IEA’s current estimates, data centres’ total global electricity consumption could reach more than 1,000 TWh in 2026 – more than double the total of 2022 – when demand linked to crypto mining is included. That level of demand is roughly equivalent to the total annual electricity consumption of Japan. But it is worth noting that, due to a lack of transparency and certainty around demand linked to AI and data centres, the IEA has commissioned a report for the spring of 2025 to shed some more light.

“Nations succeed when they harness their resources to gain technological competitive advantage. For AI, those resources are the advanced chips, data and energy needed to generate the compute ... The US is leading on AI innovation but China, fixated on seizing the lead by 2030, is building faster – harnessing government-controlled data and increasing its production of chips and energy. Energy above all is critical to the US maintaining its lead.”

– OpenAI's Infrastructure Blueprint for the US, November 2024

Heat rush: Keeping AI cool

Servers in data centres are effectively electric boilers – most of the electricity that powers them is converted into heat. To keep chips and other components from getting too hot, two things need to happen: Heat needs to be removed from the servers, and this captured heat needs to be rejected from the data-centre building, often via water vapour, resulting in significant water use.

Industry data indicates that this cooling process accounts for over 50% of data centres' energy use. But this is a simple average skewed by a large number of small, inefficient data centres. In fact, the hyperscalers that are leading the AI charge have demonstrated much lower requirements for cooling, at less than 20% of their total energy consumption.

This reflects the benefits of scale, but also the use of better cooling systems. As server-rack energy density increases with more and more powerful chips, cooling the servers with fans becomes highly inefficient. Liquid-cooled systems – in which water is used to absorb and remove heat from the servers – is a much better option, as water conducts heat many times better than air. The water can then be continuously recycled through a close-looped system and the heat removed using a refrigerant-based vapour-compression cycle.

Such technology will be critical in maintaining energy efficiency in server-dense AI data centres, while limiting water use. An April 2023 study by researchers at the University of California, Riverside, found that AI's thirst can be considerable: GPT-3, OpenAI's LLM, consumed about half a litre of water for every 20-50 queries.

Ambitions at odds?

The hyperscalers themselves have committed to playing a key role in the decarbonisation push. Amazon, Meta, Alphabet and Microsoft are among the biggest buyers of power under long-term, clean-energy contracts, according to Bloomberg New Energy Finance. In May 2024, for example, Microsoft signed a record power purchase agreement (PPA) for renewable energy, signing on for more than 10.5 GW of solar and wind capacity in the US and Europe. That came on the heels of a PPA struck by AWS, Amazon's on-demand cloud computing service, to procure electricity from a wind farm in Ireland.

But there is a tension here. What these companies seek are sources of power that are "firm" – available at all times, even under adverse conditions – and also "dispatchable," programmed on demand at the request of grid operators, according to market needs. On both counts, renewables do not score highly. And already, existing infrastructure is creaking under the strain of meeting new AI-linked demand. We note reports that Elon Musk's 100,000-GPU data centre for his xAI start-up in Memphis, Tennessee has had to deploy mobile natural gas generators as it waits for more grid capacity. A New Orleans-based utility, Entergy, is developing three new natural gas plants to support the buildout of Meta's 2+ gigawatt campus in Richland Parish, in the North Louisiana Delta County.

One source of power that does score highly is nuclear, as it provides stable, carbon-free electricity that also reduces overall decarbonisation costs: by limiting the need for grid investment and battery storage to transmit and firm up solar and wind supply; and by creating extra benefits such as the production of hydrogen.

Small modular reactors (SMRs) – advanced reactors that have about one-third the generating capacity of a traditional nuclear facility – are in sharp focus, as they are relatively quick and cheap to build and enable on-site generation that can bypass the regulated utility process. Amazon said in October 2024 that it had bought a stake in nuclear developer X-energy, as part of a collaboration with the company aimed at deploying SMRs to provide low-carbon electricity to power its data centres.

FIGURE 4

How do sources of power stack up?

High / Med / Low

	Clean?	Firm?	Low land use?	Low transmission buildout?	Concentrated local economic benefits?	Direct heat applications?
Nuclear	High	High	High	High	High	High
Geothermal	High	High	High	Med	Med	Med
Hydropower	High	Med	Low	Med	High	Low
Renewables + LDES	High	Med	Low	Low	Low	Low
Renewables: offshore	High	Med	High	Low	Low	Low
Renewables: onshore	High	Low	Low	Low	Low	Low
Natural gas + CCS	Med	High	Med	High	Med	Med
Coal + CCS	Med	High	Med	High	High	Med
Natural gas	Low	High	Med	High	Med	Med
Coal	Low	High	Med	High	High	Med

Source: US Department of Energy, Barclays Research

Oklo, a Santa Clara, California-based company that designs SMRs, has signed a series of PPAs with data-centre operators including Equinix, Switch and Prometheus Hyperscale.

Geothermal energy, too, is gaining traction. Microsoft, flanked by Abu Dhabi-based AI company G42, is investing in a data centre powered by geothermal energy in Olkaria, Kenya, and has also signed a geothermal PPA in Aotearoa, New Zealand. Google has struck a deal with Berkshire Hathaway electric utility NV Energy to power its Nevada data centres, with energy from a geothermal power plant run by Fervo Energy.

More speculative still is fusion power – a proposed source of energy based on controlled fusion, which occurs when two nuclei combine to form a new nucleus. Washington-based Helion, backed by OpenAI's Altman, has announced a PPA with Microsoft, scheduled for deployment in 2028.

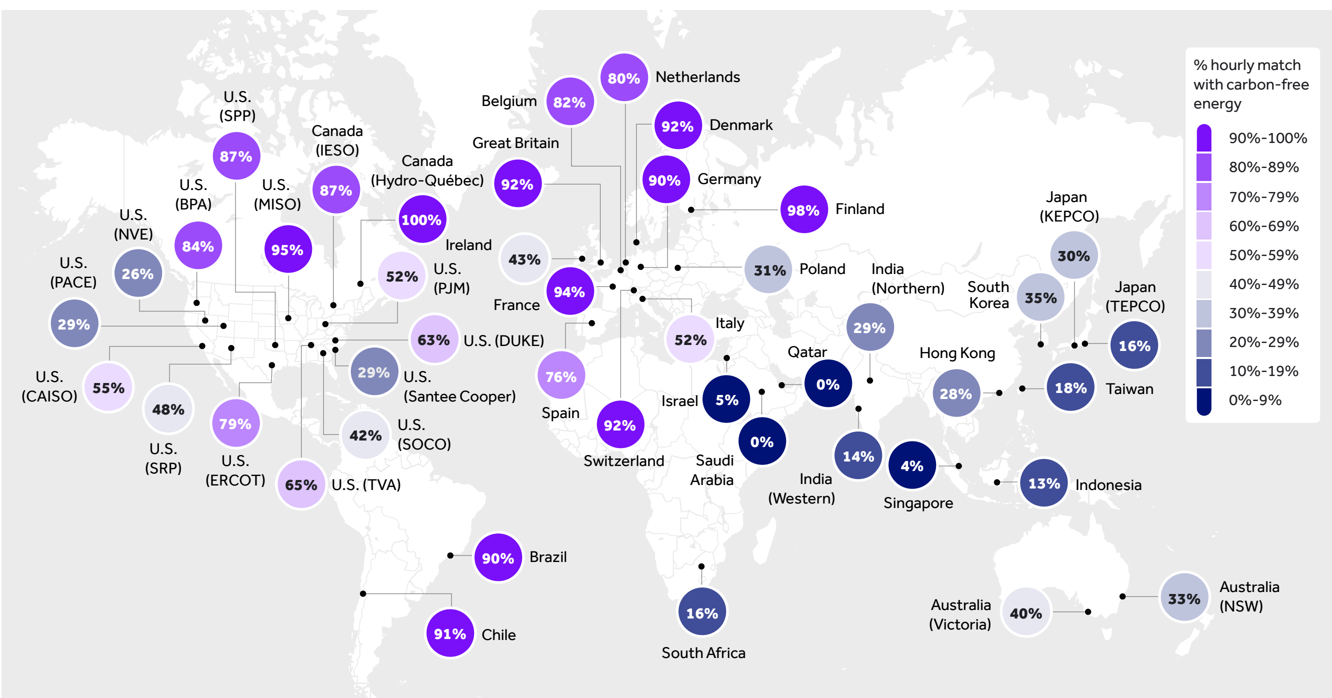
For now, the challenge of reconciling AI ambition with net zero goals is best encapsulated by Google, which has matched 100% of its global annual electricity demand with purchases of renewable energy since 2017. However, it still needs to rely on carbon-emitting energy sources that power local grids, because of differences in the availability of renewable sources such as solar and wind across the regions where the company operates. In reality, the company's data centres are powered by fossil fuels about one-third of the time globally, and half the time in the eastern portion of North America.

Still, Google has a clear goal to run on 24/7 carbon-free energy (CFE) on every grid where it operates by 2030 and has been a big advocate of new business models to help advance clean and firm power systems. If it delivers on its ambition, it will be procuring clean energy to meet the company's electricity needs, every hour of every day.

"No company of our size has achieved 24/7 CFE before, and there's no playbook for making it happen," the company has said. "But we see our efforts as part of a bigger picture: scaling new, global solutions for clean energy."

FIGURE 5

Global 24/7 data center carbon-free energy map



Note: Google 24/7 carbon-free energy percentage (i.e. % of matching electricity supply/demand at every hour of every day on the same grid system) where Google has data center operations, including third-party-operated facilities.
Source: Google, Environment Report 2024

Energy demand and emissions: Still on the up

The good news is that economies continue to become more energy efficient. The quantity of energy required per unit of global output fell by about 1.3% in 2023, following a 2% decline in 2022, according to the IEA. That trend is testament to technological advances and a structural shift towards services, rather than manufacturing.

In absolute terms, however, global demand for energy continues to increase. Total demand was up by about 2% in 2023, according to IEA estimates. This reflects growing requirements from energy-intensive developing economies, more than offsetting a fall in demand from advanced economies (of around 2%). In China, for example, it takes 40% more energy to fuel GDP than in the US, and almost double the energy to fuel the same growth as in the EU.

Moreover, two-thirds of that total global increase in energy demand in 2023 was met by fossil fuels, mainly oil and coal. As a result, total global Co2 emissions and energy-related Co2 emissions were up by 1.3% in 2023 to a record high of 37.7 gigatonnes (Gt), about 1 Gt higher than the pre-pandemic level.

The ongoing electrification of economies makes it crucial how that electric power is generated. In 2023, the electricity sector accounted for 36% of global energy-related Co2 emissions, and fossil fuels still account for 60% of global electricity supply. Hence, the speed of clean-energy transitions in the electricity sector in the years ahead will be a critical determinant of emissions trends and the rate of global warming.

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