Power hungry

Big tech's big investments to fuel AI's energy demands are not the only way the industry is shaping the transition to cleaner electricity. **By Mark Peplow**

Whether their core business is search engines, social media, shopping or computing, data fuels the US tech behemoths — Alphabet, Amazon, Apple, Meta, Microsoft and Nvidia — along with countless other companies. Now, though, it seems that the big-tech industry is increasingly focused on big energy.

These six US companies — the largest tech firms in the world, by market capitalization — are already substantial buyers of renewable electricity, but their needs are now being multiplied by the latest generation of artificial intelligence (AI) systems. In response, firms have been signing a flurry of deals with energy companies to establish new generating capacity.

In 2024, for example, Microsoft announced that it had agreed on a 20-year deal to buy energy from a dormant nuclear plant at Three Mile Island in Pennsylvania — the site of a nuclear accident in 1979 — which would reopen in 2028. Google (owned by Alphabet) and Amazon both revealed last year that they had made power purchase agreements (PPAs) with companies that plan to build a new generation of smaller nuclear plants known as small modular reactors (SMRs). Google and Meta are also investing in firms developing next-generation geothermal energy.

These high-profile developments have garnered huge media attention, accompanied by speculation that they could help to accelerate the global shift to cleaner power. But many researchers point out that the big-tech industry is influencing the energy transition in much more significant ways: through their cloud computing services, by applying machine learning to the management of electricity supply and demand, and, above all, by harvesting — and exploiting — data about that energy.

"In general, it's better to have them doing all this than actively opposing the transition," says Silvia Weko, a sustainability researcher at the University of Erlangen–Nuremberg, in Germany, who studies the role of big tech in the energy business. But she's not alone in a belief that there's a risk that energy systems are also becoming too dependent on a handful of companies. "Once they have that monopoly, they can do whatever they want with it."

The big-tech industry has a long history of building renewable-energy capacity to service its needs. Amazon, for example, owns roughly 25 gigawatts of its own installed capacity worldwide: mostly solar panels, with a smattering of wind. That alone is similar to the entire solar power capacity of the Netherlands. But the firm buys even more renewable energy from external suppliers through PPAs. These are long-term contracts to buy energy at a predetermined price, and Amazon has signed agreements that enable to it tap at least 33.6 gigawatts, according to the energy consultancy, BloombergNEF.

Sasha Luccioni, who studies the environmental impact of AI at US machine-learning company Hugging Face in New York City, says until about five years ago, this kind of approach had kept pace with big tech's growing energy needs. "They were on track until generative AI came along," Luccioni says. "I think that with the advent of these new, more energy-intensive models, the PPAs are not enough and now they're turning to nuclear and other ways of dealing with it."

In demand

Generative AI is a supersized form of machine learning that can be trained to recognize patterns within data in order to produce novel text, images and video. "It's still this big pattern-recognition engine, but now these models are being trained on all of the internet," says Raghavendra Selvan, a machine-learning researcher at the University of Copenhagen.

Training a model with billions of different parameters can take months of work at data centres that consume huge amounts of energy; and once the model is available for wider use, each query racks up further energy costs that can be ten times greater than a conventional web search.

Researchers say that those energy costs can be curbed. In January, for example, Chinese AI firm, DeepSeek, released a chatbot app based on its low-cost R1 model, which requires far less computing power to run than rivals developed by companies such as OpenAI in San Francisco, California.

Nevertheless, the rapid acceleration of AI

ELLEN SCHMIDT/AP/ALAMY

Fervo Energy's geothermal project in Utah followed a pilot in Nevada that generates energy for Google data centres in the state.

means that finding a constant and reliable source of power for data centres is a growing problem, especially because solar and wind power are inherently intermittent.

In hot water

Next-generation geothermal systems might be one solution. Many conventional geothermal systems tap into reservoirs of hot water deep underground, drawing it to the surface to create steam that can drive turbines and generate electricity. But there are relatively few places on the planet that have the right combination of heat, fluid and permeable rocks, says Lauren Boyd, a geologist who heads the Geothermal Technologies Office at the US Department of Energy (DoE) in Washington DC.

Next-generation geothermal systems seek to overcome this limitation by engineering suitable subsurface conditions — either through a process akin to fracking, which uses high-pressure water and chemicals to fracture rock layers, or by drilling carefully guided boreholes deep underground. Both techniques create a route for cool water to be pumped underground, where it absorbs heat before returning to the surface for use in a power station. This should open up many more potential sites to turn geothermal energy into electrical power, and the DoE estimates that operators in the United States could develop 90–130 gigawatts of geothermal power capacity by 2050.

Boyd says that although these systems are likely to be more expensive to build than solar or wind, they offer other advantages beyond providing a more constant flow of power. They take up a lot less space, so they could be built in areas where land availability is a constraint, and they use materials and technologies that can be sourced within the United States — a key political consideration, given that China dominates the supply chain for materials used to generate solar power.

The combination of public and private funding for next-generation geothermal start-up companies such as Fervo Energy and Sage Geosystems, both based in Houston, Texas — which have partnerships with Google and Meta, respectively — helped to triple geothermal investment in the United States from 2023 to 2024. "Right now, the number of companies and start-ups in this space in the United States is pretty dramatic," says Boyd. That puts the country in pole position in the race for next-generation geothermal power, although other nations — including France, Germany, Japan, Switzerland and the United Kingdom — have their own programmes.

Despite the enthusiasm, however, this new approach to geothermal power might take time before it has a noticeable impact on broader power supplies, and many experts agree that variable renewables linked to battery storage will likely be the backbone of decarbonization scenarios.

Going nuclear

Big tech's investments in SMRs, meanwhile, are helping to bolster a technology that many governments hope will assist their decarbonization plans. Proponents say that these reactors could be built in factories using production-line techniques to create 'modular' units that will ultimately drive down the cost of nuclear power. Major firms already developing SMRs, such as Toshiba and Rolls Royce, are being joined by a parade of start-up companies that are trying different techniques and materials, hoping their designs will have an edge.

"With nuclear, it's always the price tag that kills it, and there's nothing different about small modular reactors."

Yet behind the hype, there are no commercial SMRs currently in operation. "The press writes about them as if they already exist, as if we know that they're cheap and they're safe — but we don't know any of that," says Allison Macfarlane, director of the School of Public Policy and Global Affairs at the University of British Columbia in Vancouver, Canada, and former chair of the US Nuclear Regulatory Commission. She doubts whether SMRs will offer any economic benefit over conventional nuclear reactors, and they might even generate more nuclear waste, adding to costs. "With nuclear, it's always the price tag that kills it, and there's nothing different about small modular reactors," she says.

Macfarlane thinks that restarting dormant nuclear plants could offer a more promising strategy. That's what utility company Constellation Energy in Baltimore, Maryland, plans to do with the plant it owns at Three Mile Island, in Pennsylvania, which will help to power Microsoft's data centres. "That's the one model that I see as being successful," she says. However, she cautions that there are relatively few sites in the United States that would be suitable for that kind of make-over.

Power play

Weko and other researchers see big tech's investments in these burgeoning technologies as more than a quest for energy. Instead, they say it is part of a broader business strategy to play pivotal roles in every aspect of the energy transition, from individual homes to national grids.

Many homeowners already use Amazon's cloud-based AI assistant Alexa to manage their domestic energy use. But Weko has detailed (S. Weko *Rev. Political Econ.* https://doi.org/n8wk; 2024) how global energy-related companies also depend on Amazon Web Services (AWS), the biggest cloud computing company in the world with around 30% of market share and revenues topping US$75 billion in 2022. AWS servers help to manage data about the supply, demand and storage of energy, weather

CHIP SOMODEVILLA/GETTY

Part of the Three Mile Island nuclear plant will reopen to power Microsoft's data centres.

patterns, and a host of other variables. AWS also uses machine-learning systems to analyse those kinds of data, to forecast and potentially optimize renewable-energy production. "If you increase the amount of solar and wind on the grid, then it just gets more complex to control, because you need to match supply and demand," says Lynn Kaack, who studies the relationship between AI and climate change at the Hertie School, a university in Berlin, and is also the co-founder of non-governmental organization Climate Change AI.

Amazon is also investing in companies that are seeking other alternatives to fossil fuels, such as firms developing electrolysers to produce clean-burning hydrogen from water. One way they do this is by providing start-up business with free credits to use AWS cloud services. This stimulates work on clean-energy solutions, but it also ensures that these burgeoning technologies depend on AWS's digital infrastructure, cementing a technological lock-in effect. "After a certain amount of time, you run out of cloud grant. But you still have to use their infrastructure, because you've built your entire platform on top of it," Weko says.

Google and Microsoft use a similar strategy, says Cecilia Rikap, an economist at University College London who is studying big tech's role in the energy transition. Google's deal with geothermal start-up Fervo explicitly includes work on developing AI to improve the productivity and efficiency of the system once it's tapping into underground heat. A subsidiary of Alphabet, meanwhile, is developing a system called Tapestry that maps every electricity grid on Earth, which could help to rapidly identify faults and help to make grids more reliable and efficient. But Rikap worries about the consequences of a company the size of Alphabet having such information and influence. "They will start offering it as a service to governments around the world," she says. "They are making themselves indispensable, so it becomes impossible to think of an alternative without them."

Weko also says it's unclear how many of big tech's PPA agreements are spurring the expansion of renewable-energy generating capacity, as opposed to simply eating into existing supplies. Last year, for example, AWS bought a data centre that is entirely powered by the Susquehanna nuclear plant in Pennsylvania. But in November, its request to draw more power from the plant was turned down by the US Federal Energy Regulatory Commission. "They rejected it because they were worried that it would affect grid reliability and consumer prices," Macfarlane says.

Many researchers argue that the big-tech industry should focus more on improving the energy efficiency of AI, and say that DeepSeek's approach to creating R1 could help to create leaner models. To improve transparency around those efforts, Luccioni is helping to lead the AI Energy Score project to produce energy ratings for AI models, so that users, developers and policymakers can easily judge for themselves which are the most efficient. "I feel that asking companies to put the environment first is like asking a fish to climb a tree," she sighs.

Luccioni notes that although some forms of AI will be essential for the energy transition, these are not the most power-hungry applications. "Currently, the peak in energy demand is coming from large language models that are being used in superfluous ways," she says, pointing to ChatGPT as a particularly visible example. "These are not the ones that are helping us optimize our energy grids or do weather prediction. They're completely different things."

The release of DeepSeek-R1 is also a reminder that the AI race between China and the United States might have a profound influence on how big tech's impact on the energy transition ultimately plays out.

For example, Rikap points out that China's e-commerce giant and cloud service provider Alibaba is collaborating with the country's State Grid Corporation to develop AI that can manage electricity supplies. According to the environmental group Greenpeace, Alibaba already buys more renewable energy than any other Chinese tech company, purchasing some 1.61 terawatt hours in 2023 — similar to the entire electricity consumption of a small country such as Malawi.

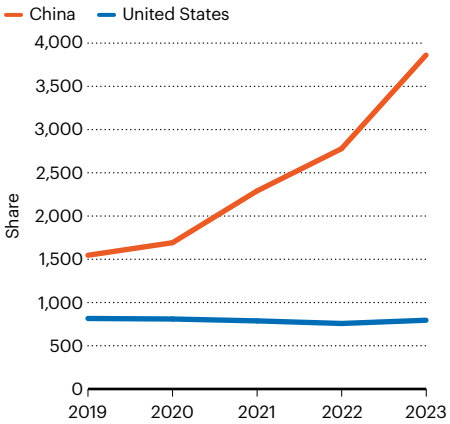
Meanwhile, China continues to build renewable capacity faster than any other nation, and the International Energy Agency expects that it will have at least half of the world's cumulative renewable electricity capacity by 2030. China's enormous investments in the energy transition are also reflected in data from the Nature Index, which show that China's research output on clean energy grew by 2.5 times between 2019 and 2023. That made its overall publication rate in 2023 in this area nearly five times higher than the United States, whose own output has remained relatively static since 2019. Clean-energy research made up more than 16% of China's entire Nature Index output in 2023, compared with under 4% in the United States.

It seems likely that China's big bets on clean energy research and AI will both pose major challenges to the US big-tech companies — and could further consolidate the country's lead in the energy transition.

Mark Peplow is a science journalist in Penrith, United Kingdom.

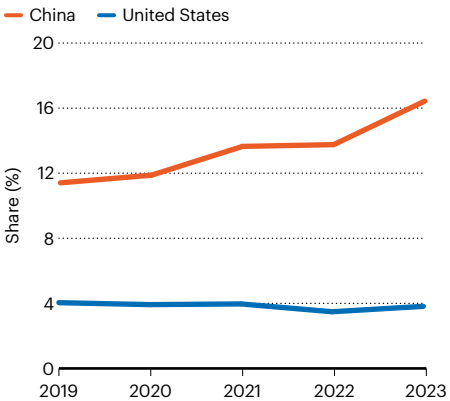
EXPONENTIAL CURVE

Between 2019 and 2023, China's Nature Index Share in clean-energy research rocketed at an ever-increasing rate, while the United States' output stayed flat. Part of this change reflects China's general rise in research output, but such a rapid shift is still remarkable.



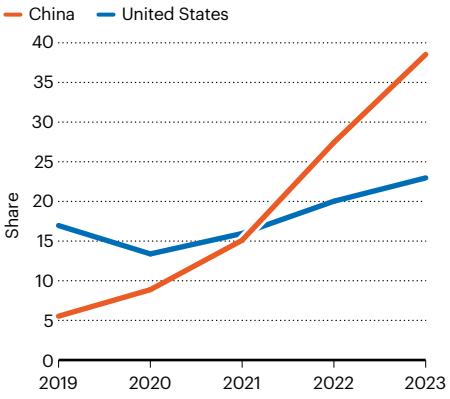
PUSHING FORWARDS

The key metric that shows that China's Nature Index output is increasingly focusing on green-energy technologies is Energy Share as a proportion of overall Share. For the United States, this percentage has remained stuck at around 4% as China's concentration on this topic continues to rise towards 20%.



COMMERCIAL GAIN

Research output from corporate institutions in the Nature Index on clean-energy topics is far lower than from other sectors, but even here there has been a noticeable increase in the Share from firms in China compared with the United States.



SOURCE: NATURE INDEX