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Data centres: how soaring demand threatens to overwhelm energy systems and climate goals

Policy briefing | May 2025

Executive summary

Until the last few years, the extraordinary growth of the digital economy had relatively few implications for energy demand and therefore carbon emissions. Improvements in the efficiency of the underlying technologies, particularly the data centres that provide the core of the modern internet had restricted overall energy demand growth.

The explosive arrival of generative Artificial Intelligence (AI), with the rapid diffusion of AI models following the launch of ChatGPT in October 2022, has transformed the industry and its impacts. The growth in demand for data and computing power is now so great that national energy systems are being reshaped by the construction and operation of new data centres, which globally today use about the same amount of electricity as France or Germany. That rising demand, in turn, creates significant new obstacles for the progress of decarbonisation. It is often being met, at the margin, by an expansion of fossil fuel electricity production and, where it is not, is placing new burdens on renewable energy generation, threatening the decarbonisation plans of other sectors.

Data centres today are responsible for at least 0.5% of global greenhouse gas emissions, based on lower-end estimates by the International Energy Agency.[1] In principle, the sector's power demands could be 100% renewably-sourced (or reasonably close), and the sector's small and stable share of overall emissions suggests few risks to climate goals. Regulators and governments have typically been content to allow Big Tech and data centre operators to set their own, voluntary targets on decarbonisation. In general, the policy response to data centres in the developed world has been extraordinary enthusiasm for rapid expansion on one side, with very little system-wide thinking about how the energy (and water) demands of data centres can be met on the other.

[1] International Energy Agency, *AI and Energy*, "AI and emissions", April 2025.

However, the sheer scale of data centre growth, following the proliferation of generative AI, has upset all of these calculations. Rapid growth has been met across the world with a return to fossil fuels as an energy source, since too often they are not only the cheapest but also the least intermittent available source of electricity. For example, 60% of additional US electricity demand is currently being met by an expansion of natural gas, whilst in both Germany and Poland, the expansion of data centres is extending the life of coal-powered electricity generation. The demand for very consistent electricity supplies, with minimal failure rates, combined with occasional spikes during peak processing times, make renewable energy a harder match for data centre needs. Either backup, non-renewable power is necessary, or a (expensive) battery storage facility must be provided. Additionally, future efficiency improvements are unlikely to lead to substantial reductions in emissions: echoing older industries like aviation, improvements in the energy efficiency of computing have typically created only more demand for computing. The result is a significant increase in forecast emissions from the sector, with the International Energy Agency forecasting the sector growing to account for 1.4% of global emissions in just five years – a footprint the size of Japan. The sector's contribution to greenhouse gas emissions is significantly larger if a whole-lifecycle view is taken of data centre operation, from equipment manufacture, to construction, to operation.

And the relationships of ownership and control inside the industry impose a steep hierarchy, in which the wider costs of data centre installations are borne by local communities and public grids for energy and water, but the revenues flow (especially for the larger installations) back towards a very small number of major corporations, typically located in the US. For the Global South, these hierarchies exactly parallel earlier, colonial relationships. They have consequences for decarbonisation because in many cases legacy energy systems, already under strain and facing tough demands for emissions reduction, are now being confronted by additional costs that jeapordise decarbonisation efforts.

A more interventionist approach from governments is required, backed up by robust evidence for policymaking, or it is likely that litigation demanding change would be initiated. This paper details the challenge and offers some initial policy recommendations as a guide to future work. We suggest three broad areas for policy intervention, at the UK and EU level in the first instance:

- Official national and supra-national assessments should be made of the likely paths of energy use and subsequent emissions from data centre expansion, and these scenarios considered against the national and supra-national frameworks for emissions control, for example the UK's Carbon Budget system;
- The legal, regulatory and policy changes needed to move data centre operations as close as possible to 100% renewables, taking a whole-lifecycle approach from construction into operation and including support for battery storage;
- The development of policy for minimising data collection, processing and storing, alongside a robust hierarchy of data centre applications. This will build on recommendations in the National Engineering Policy Centre's report on minimising the footprint of data centre operations. The problem of demand and purpose of data centre expansion is inseparable from the issue of their resource and emissions impact, and should be confronted directly by policy.

The rapid growth of the sector has run ahead of detailed policy research, with environmental organisations and even governments running to catch up with its expansion. More research and analysis is vital to provide a robust evidence base for detailed policy analysis and conclusions.

Opportunity Green applies a systems change approach to close the gaps in climate action. We recognise that we will not drive meaningful systemic change in the sectors we work on through a singular action, but rather that multiple levers must be pulled and different angles worked to achieve impactful change, focusing on achieving climate justice. Our approach therefore leverages our legal, economic and policy advocacy skills toolkit to address causes of and advocate for solutions for climate change across our target sectors. We are seeking funding in order to further develop the policy recommendations laid out in this briefing.

The scale of the challenge

The digitisation of everyday life over the last three decades had already entailed a ballooning of the volumes of data we generate, process and store. Global internet traffic has grown from 156Gb transferred every second in 2002, to 150,000Gb a second in 2022, driven by the arrival and spread of new technologies like smartphones and applications like mobile video.[2]

As increasingly large parts of economic and social life have moved online, data centres have assumed greater importance. These are specialised locations containing hundreds if not thousands of dedicated servers, collecting, processing and transmitting data from elsewhere that make the applications of the modern internet function. But collecting, processing, storing and transmitting data all comes at a cost. Data has a physical presence, whether in the magnetic material of an old hard drive or in the flow of electrons across a silicon chip. To sustain that physical presence and put the data to work requires physical resources: material, like copper wiring and silicon, or energetic, in the form of electricity. Expanding the size of our digital world requires an expansion of its demands for resources.

The primary demands of data centres are semiconductors used to provide the computing power; electricity needed to power the computing taking place and other operations; and water to cool those machines down to an efficient temperature. It is electricity demand and supply that this paper will be looking at, since this has the most direct impacts on climate change, although the other two are also extremely significant: for example, the largest "hyperscale" data centres uses 3-5m gallons of water per day, about the same daily consumption as a town of 40,000 people.[3] There is no set definition for a hyperscale centre, but typically a construction would be at least 10,000 square feet and upwards, consuming typically 20-50 MW of power. Only the very largest companies, usually the big three cloud providers (Amazon Web Services, Microsoft, and Google), are likely to be able to afford the costs of building at this scale.

This shift in the balance of computing activity has shifted the geography of data centres themselves. Demands for more remote processing power through the cloud and, now, AI, are shifting the location of computing power away from smaller-scale enterprise-level or collocated data centres into the vast operations of the Big Tech suppliers. Data centre capacity is typically measured in megawatts (MW), referencing the total power consumption of the centre, which helps abstract from complications about the specific use of the data or the applications to which the data centre is being put.

The arrival of Artificial Intelligence

Until recently, improvements in the efficiency of processing and storing data meant that even as the volume in use grew exponentially, the energy demands of the data economy remained relatively flat. Global demand for data centre computation increased 550% over 2010 to 2018, but global data centre energy use rose only from 194 terawatt hours to 205 terawatt hours over the same period.[4] A combination of technological progress in hardware efficiency, economies of scale in building the much larger hyperscale data centres, and better management of digital resources enabled what Lawrence Berkeley

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[2] World Bank, *World Bank Development Report 2021: data for better lives*, "Crossing borders". World Development Report 2021: Data for Better Lives | Crossing borders.

[3] Solon, O., "Drought-stricken communities push back against data centers", NBC News, 19 February 2021.

[4] Eric Masanet et al., "Recalibrating global data center energy use estimates", *Science* 367:984–986. Science Magazine.

Labs researchers (who provided this data) estimate to be an impressive 20% improvement in the typical energy efficiency of data centres over the same period.[5]

The arrival and very rapid diffusion of usable Large Language Models (LLMs) in late 2022, starting with ChatGPT's public debut, represents a dramatic break in that trend. LLMs, and similar versions of Machine Learning, require incredible volumes of data to be processed for the "training", with typically banks of specialised processors churning through combinations of the underlying data to seek out the patterns that humans find useful or meaningful – in generating natural-language speech, or drawing new pictures, or discovering new combinations of proteins for medical use. This capacity to produce new content makes "generative" Artificial Intelligence (AI) a distinctive technological breakthrough.

Once trained, an LLM or other generative AI machine can then be put to work on "inference": applying its trained models to different sorts of user data, like the natural-language prompts ChatGPT runs from, and generating output. This is less data-intensive than training, but still needs heavier processing, meaning more data centres with more chips consuming more energy. A ChatGPT query requires around ten times the electricity of a typical Google search enquiry, for example. A single Nvidia H100 GPU[6] has a maximum power output of 700W; at a typical utilisation in AI applications of about 61%, it uses more power than the average US citizen. Since launch in 2023, Nvidia has shipped 3.5m of these chips, which in use would require around 13 GWh of electricity, or slightly more than Lithuania's annual demand for electricity.[7]

These energy requirements are not only the pure computing power. Silicon chips in use run hot, and require cooling to maintain their efficiency (or, in extremis, function at all). Computing power alone is about 40% of typical data centre energy demand, with cooling another 40% and the remaining 20% taken by the associated infrastructure for the centre.[8] A typical data centre has an 80-90% baseload power demand, meaning it requires a high level of utilisation, constantly.[9] This energy consumption profile will vary with their primary function (storage vs computation, for example), whilst AI has introduced new energy demand profiles (intensive but flat in training vs less intensive but spiky demands for inference). Power demands will also vary by season (more power is needed in summer, for cooling) and geographical location (colder areas typically require less power).[10] Demands for cooling create their own resource pressures, particularly for access to water supplies, but here we consider only the energy requirements.

This demand profile is unusual, compared to other sources. Electric vehicles, for example, which are rapidly growing in use, typically have demands for power only at certain points of the day – when they are charging. Domestic electricity use typically spikes at certain times during the day, whilst non-domestic use, for instance in offices and shops, is continual for only part of the whole day. Electricity systems built to meet demand profile of this kind factor in a high degree of redundancy for much of the time,

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[5] Eric Masanet et al., "Recalibrating global data center energy use estimates", *Science* 367:984-986. Science Magazine.
[6] Graphics Processing Unit. The types of bulk calculations required by Machine Learning are very close to those needed for the rapid processing of computer graphics information.
[7] Anton Shilov, "Nvidia's H100 will consume more power than some countries…", *Tom's Hardware*, 26 December 2023. Nvidia's H100 GPUs will consume more power than some countries — each GPU consumes 700W of power, 3.5 million are expected to be sold in the coming year | Tom's Hardware.
[8] International Energy Agency, *Electricity 2024: analysis and forecast to 2026,* 2024, p.32. Electricity 2024 - Analysis and forecast to 2026, p.31.
[9] Independent Commodity Intelligence Service, *Data Centres: hungry for power*, January 2025. Europe Data Centre Power Demand | ICIS.
[10] Independent Commodity Intelligence Services, *Data Centres: hungry for power*, January 2025.

and as a result continual, new, intense demands present a significant challenge to existing grids.

For example, a world-first "byte blackout" was almost triggered in West Virginia in March.[11] Lightning strikes on a local transformer caused 60 data centres to flip from grid power to their own backup sources, in turn creating a massive glut of electricity across the grid and forcing operators to run emergency generator powerdowns to prevent cascading outages across the state.[12]

Energy demands and consequences for climate change

It can quickly be seen that the diffusion of AI technologies would lead to an immediate acceleration in electricity demand for data centres, with the IMF suggesting that data centres today use a similar amount of electricity to France or Germany, with their projections implying that, by 2030, global data centre energy use will be comparable to that of India – a fast-growing country of 1.4 billion people.[13]

This energy demand has consequence for greenhouse gas (GHG) emissions. The International Energy Agency conservatively estimate that the direct emissions contribution of data centres, excluding back up power and secondary sources like the emissions embodied in their construction, are currently about 0.5% of global greenhouse gases. They forecast data centre global power consumption in their "Base Case" scenario doubling from 2024 to 2030, reaching 945 TWh, or 3% of total electricity consumption and around 1% of global emissions. Their "High Level" scenario, with significantly greater data demand over the next five years, takes emissions up to about 1.4% of global GHGs.[14] Other global forecasts are somewhat larger again: for example, Goldman Sachs estimate global power consumption for data centres could rise 160% by 2030, from 2% of global electricity use in 2023 to more like 3-4%.[15] These differences are essentially due to different forecasts for AI demand growth, highlighting the importance of demand in determining future emissions pathways.

This global figure disguises significant national and local variation, with Ireland (for example) forecast by the International Energy Authority (IEA) to have one-third of its domestic electricity production dedicated to data centres by 2026, in the absence of policy changes, up from 17% in 2022.[16] Denmark is forecast to see about one-fifth of its generation capacity dedicated to data centres 2030.[17] For the US, where detailed figures are available from the Department for Energy (DoE), near-flat levels of electricity consumption by the sector began to rise sharply from 2017, as AI installations took off. From about 60 TWh in 2017, or 1.9% of total US electricity use, data centre consumption had risen to 176Twh by 2024, or 4.4% of total US use. At this rate of growth, data centres would eat up 12% of US' forecast domestic energy supply by 2028.[18] At the current rate

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[11] Grid Status, "Byte Blackout: how large data center loads are surfacing new issues", 18 April 2025. Byte Blackouts: How large data center loads are surfacing new issues.

[12] Tim McLaughlin, "Big Tech's data center boom poses new risk to US grid operators", *Reuters,* 20 March 2025.

[13] International Monetary Fund, *World Economic Outlook*, "Commodity Special Feature: market developments and the impact of AI on energy demand", IMF: Washington, D.C., April 2025.

[14] International Energy Authority, *Energy and AI*, "Energy demand from AI", April 2025. Energy demand from AI – Energy and AI – Analysis - IEA.

[15] Goldman Sachs, "AI is poised to drive 160% increase in data center power demand", Research Note, 14 May 2024. AI is poised to drive 160% increase in data center power demand | Goldman Sachs.

[16] International Energy Agency, *Electricity 2024: analysis and forecast to 2026,* 2024, p.32. Electricity 2024 - Analysis and forecast to 2026.

[17] Moalam Weitermeyer, "Denmark: a fast-growing market for data centers", blog, 19 February 2025, citing the Danish Energy Authority. These figures match IEA projections. Moalem Weitemeyer.

[18] Melodie Michael, "Data centres could consume 12% of US electricity within 4 years", CSO Futures, blog, 7 January 2025. Data centres could use 12% of US electricity within 4 years.

of expansion, the US state of Virigina, centre of the US and global industry with an estimated 70% of all internet traffic flowing across its borders,[19] would see electricity demand triple by 2030, far outstripping planned supply.[20]

This concentration of data centre construction and operation in a few key locations worldwide means that bottlenecks and constraints are emerging in electricity supply for data centres:

- Norwegian arms producer Nammo claimed in 2023 that its planned factory expansion was blocked as a result of TikTok opening a new data centre nearby, sucking up available electricity.[21]
- A proposed hyperscale data centre in Buckinghamshire, UK, has been estimated to require the same electricity in operation as over 35,000 households, but the developers had not accounted for this additional demand in their plans.[22]
- Ireland has been promoting itself as a centre for data processing since the late 1990s – Google, for instance, opened its European HQ there in 2004 – and it is estimated today that there are 81 separate data centres located in Ireland. Today, data centres use more electricity than all of Ireland's urban homes combined.[23]
- Google has just announced the construction of its first hyperscale data centre in Norway, at Skien, southwest of Oslo, for a cost of EUR 600m. This is expected to handle a significant portion of Google's global data business, with 240MW of electricity allocated for its first phase, but the company asked for 860MW, or just over 5% of Norway's entire national electricity output.[24]

The renewables challenge for data centres

Currently, coal power is the largest single source of data centre electricity, at 30% of global electricity used by the sector. Renewables (from all sources) are 27%, and natural gas is 26% with nuclear on 15%. This energy mix reflects the historic commitments of grids around the world, and means that data centres in 2024 accounted for around 180Mtons of CO_2 globally, or about 0.5% of all emissions.[25]

In principle, data centres ought to be easy to decarbonise, at least at the point of operation.[26] No new technology (unlike for ships or planes) is required to switch a data centre to renewable use. But in practice much of the new demand for capacity has been met by non-renewable sources, for three reasons:

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[19] North Virginia Regional Commission, "Data Centres". Data Centers | Northern Virginia Regional Commission - Website.
[20] Joint Legislative Audit and Review Commission, *Data Centers in Virginia*, JLARC Report 598, 2024. JLARC Data Centers Report.pdf | Powered by Box.
[21] Jonathan Yerushalmy, "Norwegian company says TikTok data centre is limiting energy for manufacturing Ukraine ammunition", *Guardian*, 28 March 2023. https://www.theguardian.com/technology/2023/mar/28/energy-hungry-tiktok-data-centre-ukraine-ammunition-production-nammo-norway.
[22] Foxglove, "Why Foxglove and Global Action Plan are challenging the Woodlands data centre", press release, 12 December 2024. Why Foxglove and Global Action Plan are opposing the Woodlands data centre - Foxglove.
[23] Jillian Ambrose, " Ireland's datacentres overtake electricity use of all urban homes combined", *Guardian*, 24 July 2024.
[24] Peter Udland, "Google data centre eyes 5% of Norway's electricity demand", *Montel News*, 26 Septmeber 2023. https://montelnews.com/news/1524382/google-data-centre-eyes-5-of-norways-power-demand
[25] International Energy Authority, *Energy and AI*, "Energy supply for AI", April 2025. Energy supply for AI – Energy and AI – Analysis - IEA.
[26] Construction and installation are harder to decarbonise, given the embodied carbon in both their construction and the manufacture of the components they use, from cooling systems to GPUs. See John Booth, "Discussing sustainability and decarbonisation in data centres", CFP Energy, 25 January 2025. Discussing Sustainability & Decarbonisation in Data Centres | CFP Energy.

- Sudden new demands on existing grids pose complications for connections and capacity, creating bottlenecks;
- Data centres require a consistent, continual power source with minimal variation in supply. Renewables can typically only supply this with additional battery backup, raising costs;[27]
- Gas turbines can be constructed rapidly at relatively low cost, and supply the continual power that data centres demand. The marginal cost of additional gas power for a data centre operator is likely to be lower than a renewable source, given these constraints.[28]

The last point needs expanding. Although *once installed*, renewable generation is today typically the cheapest available source of electricity, its requirements for specific geographies can push up the total cost per MWh supplied. Where there are significant pressures on existing grids and on suitable locations for renewable energy, the whole-life costs for renewable installation can rise above the next-cheapest fossil fuel, usually natural gas.

Because data centre expansion has been so rapid, it is increasingly *unlikely* to be sourced renewably: the cheapest source of power in the US, and the quickest to come online, is gas. On the most recent data, gas generation had a lower cost per installed kWh of capacity than solar or wind – $820kWh versus $1,588 and $1,451kWh respectively, taking the whole lifetime cost of generation into account.[29] Combined with the problem of intermittency, this can give gas generation a cost advantage for larger data centres. Intermittency can be dealt with by either on-site battery storage,[30] which adds substantially to installed costs, or connections to the grid, where congestion and capacity are themselves increasingly issues in the developed world.[31]

As a result, Bloomberg cites an estimate that gas power represents about 60% of new generation capacity being installed in the US right now,[32] with another 20 gas-fired power plants due online in 2024 and 2025 to meet demand.[33] Goldman Sachs estimates that future demand for electricity from data centres, out to 2030, will be met 60% by gas, and 40% by renewable sources.[34] The IEA is more optimistic, forecasting a data centre installation energy mix of 50% renewables versus 50% non-renewables in its central scenario.[35] The difference is due to different projections of total energy demand: as demand rises from data centre installation in different IEA future scenarios, the share of renewables in the generation mix declines. For their “Lift-Off” scenario, with a very rapid

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[27] Luca Pederetti, “'Renewables risk losing the AI data centre power prize to nuclear or even gas'”, *Recharge*, 14 November 2024. 'Renewables risk losing the AI data centre power prize to nuclear or even gas' | Recharge.

[28] This is a specific instance of the general case discussed in Brett Christophers, *The Price is Wrong*, London, 2023.

[29] Energy Information Administration, “Average construction cost”, Construction cost data for electric generators installed in 2022, 24 September 2024. Electricity - Construction cost data for electric generators -.

[30] Eric Hill, “Data center battery storage and AI: Cutting through the hysteria and solving problems”, Data Center Dynamics, 12 June 2024. Data center battery storage and AI: Cutting through the hysteria and solving problems - DCD.

[31] Adam Wilson and Tony Lenoir, ”Datacenters amplify grid congestion challenges as renewable curtailment rises”, *S&P Global Market Intelligence*, 30 September 2024. https://www.spglobal.com/market-intelligence/en/news-insights/research/datacenters-amplify-grid-congestion-challenges-as-renewable-curtailment-rises.

[32] Josh Saul, Naureen S. Malik, Mark Chediak, “AI Boom Is Driving a Surprise Resurgence of US Gas-Fired Power”, *Bloomberg*, 16 September 2024. https://www.bloomberg.com/news/articles/2024-09-16/us-natural-gas-power-plants-just-keep-coming-to-meet-ai-ev-electricity-demand.

[33] Myles McCormick, Jamie Smythe, Amanda Chu, “AI revolution will be boon for natural gas, say fossil fuel bosses”, *Financial Times*, 1 April 2024. https://www.ft.com/content/1f93b9b2-b264-44e2-87cc-83c04d8f1e2b.

[34] Goldman Sachs, “Generational growth: AI, data centres, and the coming US power demand surge”, 18 April 2024, p.6. Generational Growth AI, data centers and the coming US power demand surge.

[35] International Energy Authority, *Energy and AI*, ”Energy supply for AI”, April 2025. Energy supply for AI – Energy and AI – Analysis - IEA.

expansion, renewable energy as a share of total data centre energy use declines after 2045.[36]

For Europe, the IEA estimates that data centres will account for just under a third of new electricity demand by 2026.[37] These, again, are likely to produce a surge in demand for non-renewable electricity. New data centres in Ireland are already connecting directly to the gas grid,[38] whilst Microsoft is expanding its facility at Hambach, Germany with a EUR 3.2bn investment, helpfully placed next to the 400m deep Hambach coal mine. The company has refused to comment on the centre's power supply

Recent research by Beyond Fossil Fuels found that Europe (EU plus UK) could see 287 terawatt hours of new electricity demand from data centres by 2030, assuming a relatively high installation rate in line with current trends. [39] At 61% fossil fuel use (in line with Goldman Sachs' and S&P's projections for US installation), this would imply an additional 121m tonnes of CO_2e. Switching to 100% renewables would imply that 20% of projected new European renewable installations over the same period were dedicated to data centres alone, however, creating huge pressures for other sectors' power supplies and decarbonisation plans.[40]

And finally, with hyperscale operators especially looking for "behind-the-grid", on-site power generation to secure more reliable supplies of electricity, the efficiency of generation itself has been hit, with one study indicating around a 50% loss in relative efficiency of on-site gas generators in the US compared to larger, grid-linked power stations. This drive for reliability, even if at the loss of efficiency, magnifies the general problem of data centre energy consumption and so emissions output.[41]

If we look at not only the energy requirements, but the whole lifecycle of the data centre, including the embodied carbon in their construction and the manufacturing of components, the situation worsens. For the whole world, Morgan Stanley predict that data centre CO_2-equivalent emissions will *triple* by 2030, rising to equivalent of 40% of the US' total emissions, once account is taken not only of electricity use but also data centre construction. This rapid increase is, they estimate, about three times worse than it would have been without the arrival of AI.[42] Only approximately 60% of the total emissions are due to the operational power requirement, the rest being embodied carbon in the manufacturing and construction of the centres. The National Engineering Policy Centre's recent report, *Engineering Responsible AI*, also emphasised the need to take a whole-lifecycle approach to considering AI and data centre emissions.[43] If data centres do rely more heavily on renewables in the future, then these "Scope 3" emissions (using

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[36] International Energy Authority, *Energy and AI*, "Energy supply for AI", April 2025. Energy supply for AI – Energy and AI – Analysis - IEA.
[37] International Energy Agency, *Electricity 2024: analysis and forecast to 2026,* 2024, p.36. Electricity 2024 - Analysis and forecast to 2026.
[38] Dan Swinhoe, "11 data centers in Dublin set to rely on Ireland's gas network for power", *Data Center Dynamics*, 24 April 2023. 11 data centers in Dublin set to rely on Ireland's gas network for power - DCD.
[39] Beyond Fossil Fuels, *System Overload: how new data centres could throw Europe's energy transition off course*, 10 February 2025.
[40] Beyond Fossil Fuels, *System Overload: how new data centres could throw Europe's energy transition off course*, 10 February 2025.
[41] Zach Krause, "Data centers voracious energy demand drives gas power renaissance", East Daley Analytics, 13 February 2025. The article suggests 10-11 MMbBtu/MWh generated for on-site gas power at a data centre, compared to a more usual 6-8 MMBtu/MWh for gas grid generation.
[42] Dan Robinson, "Datacenters to emit 3x more carbon dioxide because of generative AI", *The Register*, 6 September 2024. https://www.theregister.com/2024/09/06/datacenters_set_to_emit_3x/.
[43] National Engineering Policy Centre, *Engineering Responsible AI: foundations for environmentally sustainable AI*, February 2025. February 2025 Engineering Responsible AI: Foundations for Environmentally Sustainable AI.

the Greenhouse Gas Protocol definition) will come to dominate, accounting for over two-thirds of a data centre's total emissions on one projection.[44]

Efficiency improvements can create their own problems

Until very recently, as noted above, data centres were becoming progressively more efficient. This helped stabilise electricity demand despite a very substantial increase in demand for computational power. Those efficiency improvements were already slowing prior to the arrival and rapid diffusion of generative AI. With the widespread use of generative AI, those efficiency improvements have essentially ground to a halt.

Generative AI has depended on being able to operate a growing scale to deliver its results – more data inputted for more processing to produce a wider range of applications. This has obvious implications for resource use, including electricity, and therefore consequences for decarbonisation. The launch of DeepSeek at the end of January 2025 was treated as a transformational moment, with immediate, dramatic impacts on US Big Tech share prices, based on DeepSeek's claimed dramatic efficiency and cost improvements.

Other things being equal, this ought to be good news for electricity demand and therefore decarbonisation. Unfortunately, a longstanding observation in economics suggests that efficiency improvements may perversely lead to *more* electricity demand so to more emissions. Jevon's Paradox was first coined in the late 19th century, when the economist Edward Jevons noted that improvements in the efficiency of steam engines did not (as might be expected) reduce the demand for coal. Rather, improved efficiency opened up new demands for steam power in a wider range of applications, and so lead to *increasing* demand for coal. In the years since, the same paradox has recurred: improved aeroplane fuel efficiency, for example, has not led to people spending less money on air travel. Instead, we find more people flying further because it is comparatively cheaper to do so.

The computer industry, virtually since its creation, has depended on a version of Jevon's Paradox for its sustained growth. Radical improvements in the power and efficiency of computer hardware have produced *increasing* demands for its use, since the decline in the cost of computing makes applications that once seemed unfeasible economically viable – from word processing to video streaming. This has long been identified as the fundamental business model for the computer industry: improved computing efficiency had to be matched by the expansion of applications for computing in order for the industry to continue growing.[45]

As suggested above, in recent years this has not mattered so much: data centres (and the digital industries in general) improved efficiency fast enough to keep pace with even the dramatic expansion in demand for computation and data processing. Demand for computation certainly grew, but efficiency improvements were large enough as to restrain energy demand growth. In recent years, those efficiency improvements have started to tail off. Machine Learning and AI operates by running intensive calculations at huge scale, guzzling more and more data and therefore energy to produce results. As the use of Machine Learning has grown, the energy requirements of processing all that data have grown with it, outstripping efficiency gains.

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[44] Paul Lin, " Demystifying data center scope 3 carbon with our findings", *Schneider Electric blog*, 11 July 2023. The first comprehensive attempt to quantify data center Scope 3.

[45] As Intel co-founder Gordon Moore put it as far back as 1990: "This business and its rapid growth continue to depend on the market expansion in order to be able to afford the investment to keep the technology moving." Gordon Moore, "VLSI Industry Trends", Stanford Seminar, 1990. Stanford Seminar - VLSI Industry Trends.

But note that the immediate response of the industry to DeepSeek's claimed efficiency improvements was to insist that these would only reinforce the operation of Jevon's Paradox – that the falling cost of AI would now generate further demands for its application.[46] Far from helping reduce the industry's energy demands, the underlying business model requires that improvements in efficiency generate more demand for computer power, and so potentially *increasing* demand for electricity and associated emissions.

Big Tech's industry expectation – and, it has to be said, necessary hope – is for the Paradox to continue to operate far into the future. This means that technological improvements alone are unlikely to deliver reduced energy use for the sector. Solving the problem of energy use and greenhouse gas outputs for data centres will require policy intervention.

Emerging industry energy solutions: nuclear power and colder climates

The industry itself is adapting to constraints on its expansion, both regulatory and physical. Increasingly, the major cloud providers are looking to nuclear power to provide energy for data centres, viewing it as relatively cheap, zero-carbon as usually measured, and providing reliable, interruption-free power. Recent announcements include:

- Amazon paid $650m to acquire Talen Energy's data centre, sited next to the company's 2.5GW Susquehanna nuclear plant, Pennsylvania, including a 10-year power purchase agreement.[47]
- Microsoft has signed a 20-year deal with Constellation Energy, owners of the mothballed Three Mile Island site in Pennsylvania, to provide electricity for a new data centre. As the BBC helpfully notes, Three Mile Island is notorious as the site of the US' worst ever nuclear disaster.[48]
- Google has signed the "world's first" agreement to purchase power from small modular nuclear reactors (SMRs) to supply its AI energy needs. Kairos Power plans to bring its first SMR online by 2030, with the whole fleet in operation by 2035. SMRs, based on nuclear submarine technology, are smaller than today's nuclear power plants, and are intended to be built with components made off-site, theoretically reducing costs.[49]

On the other side, Big Tech companies are seeking to reduce their energy requirements by locating data centres in colder locations, thus reducing the demand for cooling. Norway, Iceland and other Arctic circle countries are increasingly popular locations, but more exotic options are opening up. Microsoft ran an experimental undersea data centre off the coast of Orkney for two years,[50] whilst the European Commission's 16-month ASCEND study reported in July on the viability of space-based datacentres. The final

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[46] Anita Hamilton, "What Is 'Jevons Paradox' and Why Was Microsoft's CEO Posting About It Late at Night?", *Barron's*, 28 January 2025. Jevons Paradox: Why Microsoft CEO Satya Nadella Says It Applies to AI Too - Barron's.
[47] Dan Swinhoe, "AWS nuclear data centre campus in Pennsylvaniai", *Data Center Dynamics*, 4 March 2024. https://www.datacenterdynamics.com/en/news/aws-acquires-talens-nuclear-data-center-campus-in-pennsylvania/.
[48] Natalie Sherman, "Microsoft chooses infamous nuclear site for AI power", *BBC News*, 20 September 2024. https://www.bbc.co.uk/news/articles/cx25v2d7zexo.
[49] Michael Terrell, " New nuclear clean energy agreement with Kairos Power", Google blog, 14 October 2024. Google signs advanced nuclear clean energy agreement with Kairos Power.
[50] Rory Cellan-Jones, "Microsoft's underwater data centre resurfaces after two years", *BBC News*, 14 September 2020. https://www.bbc.co.uk/news/technology-54146718. The Microsoft report on the experiment is here: https://natick.research.microsoft.com/.

report found that launches and installations of solar-powered centres in low earth orbit by 2050 would help the continent meet its zero carbon goals, leapfrogging its major competitors in the US and China.[51]

Climate change itself is fast-emerging as a barrier to data centre operations. In the UK alone, the heatwave of summer 2022 took Google and Oracle's London data centres offline for several hours as extreme heat overwhelmed their cooling systems.[52] Floods over winter 2015 to 2016 took out Vodafone UK's main data centre in Leeds.[53] Industry body techUK has warned of the mounting "physical risks" to data centre operations from the consequences of climate change, with the frequency of floods and other extreme weather events rising fast in key data centre hotspots.[54] Aside from the costs to operators and end-users from outages, there are potential climate implications, too: for example, in data centres switching more often to fossil-fuel backup power sources, whether gas or even, in some cases, diesel generators.[55]

Relations of power and control

Although not typically discussed in the industry or policy literature, data centres embody distinct relationships of power and control that pose a direct challenge to socially just decarbonisation efforts. The fastest growing segment of the market, for "hyperscale" data centres capable of providing cloud-based AI capabilities, is dominated globally by a handful of US-based Big Tech companies, with some smaller national operators. The largest data centres are heavily capital- and resource-intensive, but typically create little in the way of local jobs or economic growth: for example, a new hyperscale datacentre to be constructed and operated by Black Stone in Teesside, north-east England, is expected to cost £10bn, and produce 4,000 jobs – implying an approximate cost per job of £2.5m.[56] And whilst this, like other investments, is private money, there are direct costs to the wider public in introducing very substantial new demands to increasingly congested public infrastructure like the energy grid. Black Stone's owners are exclusively US-based: any profits generated by the site will, as with other data centres around the world, flow offshore and a long way from local communities.

Such hierarchies of power can look even worse in the Global South, where many data centre operators are looking to expand, seeking to exploit lower energy and water costs. But the extractive, or even colonial, relationship here is even more pronounced, with major US companies investing heavily in capital-intensive sites that take much in the way of local resources, but deliver little in terms of local jobs, revenues and wealth.

These considerations have a direct impact on decarbonisation efforts, since, in effect, intense new demands for electricity are landing on top of what is already a system under strain. For the Global South, the costs of decarbonisation (for which investment is already

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[51] Conditional on inventing an eco-friendly rocket launcher by 2035 – details, details. April Roach, "Europe wants to send data centers into space — study says it's possible", *CBNC News*, 27 June 2024. https://www.cnbc.com/2024/06/27/europe-wants-to-deploy-data-centers-into-space-study-says.html

[52] Bloomberg News, "Google, Oracle data centres knocked offline by London heat", 22 July 2022.

[53] Max Smolkas, "Vodafone UK data center suffers outage due to floods", *Data Center Dynamics*, 5 January 2016. https://www.datacenterdynamics.com/en/news/vodafone-uk-data-center-suffers-outage-due-to-floods/.

[54] techUK, *Future Proofing Digital Infrastructure: climate resilience in the data centre sector,* November 2024. Future-Proofing Digital Infrastructure: Climate Resilience in the Data Centre Sector.

[55] Rich Miller, " Texas Data Centers Rely on Generators Amid Power Emergency", *Data Center Frontiers*, 18 February 2021. Texas Data Centers Rely on Generators Amid Power Emergency | Data Center Frontier.

[56] Jason Arun Murugesu, "Blackstone £10bn investment in Blyth AI data centre confirmed - BBC News", *BBC News*, 10 September 2024.

inadequate) will be raised still further, whilst very few of the benefits of data centre expansion will be felt locally.

If current favoured locations for data centres, usually in the Global North, remain congested, then the industry will begin to look elsewhere – both to other, second-tier Global North locations and then, increasingly, beyond that into the South. Understanding this dynamic is crucial since, as we have suggested above, variations in projected energy use and emissions from data centres are closely linked to variations in projected demand. Managing final demand for data centre outputs is therefore crucial to managing emissions arising from their energy inputs.

The problem summarised

To summarise, the problem of data centres for decarbonisation is:

- Data centre growth has been rapid, and is accelerating with the rapid diffusion of AI. Data centres demand continual, constant supplies of electricity.
- This creates novel demands for electricity that are not easily met by either existing power systems or in currently planned expansions.
- As a result, data centre growth has tended also to increase demand for fossil fuel outputs, as the cheapest marginal source of constant electricity supply.
- Improvements in efficiency inside the sector are likely only to increase demand for data centre use, reinforcing rather than resolving the problem of growing electricity demand.
- The size and scale of data centre operations, combined with concentrated ownership in a few, typically US-based, Big Tech operators, implies a hierarchical and arguably even colonial relationship of extraction that directly imperils national decarbonisation efforts. This may worsen if congestion in key Global North locations worsens.

Progress in efficiency improvements alone will therefore not be enough, and is likely to produce greater demands for power consumption by the digital economy, in line with past experience and the current business models of Big Tech. Those business models are themselves skewed towards an unequal exchange which sees a concentration of revenues flowing towards beneficial owners, whilst the costs of operation on others – including specific, local challenges for energy demands on congested and elderly grids, and the big, general problem of the GHG emissions.

The policy response

Public policy has not yet addressed the challenges of expanding data centre use. As examples:

- The UK's Seventh Carbon Budget published in February 2025, does not reference data centres, despite the electrical system's government-owned management body, NESO[57], noting elsewhere the likely consequences for power demand of its growth.

[57] National Grid Electricity System Operator, "Data centres: what are data centres and how will they affect the energy system?", March 2022. download.

- The EU has introduced new reporting requirements for the sustainability of individual data centres,[58] but has no plan for the management of their expansion overall. In fact, the EU's new Cloud and AI Act aims to at least triple the EU's data centre capacity within the next five to seven years, with accelerated approvals processes for data centres that meet energy and water efficiency requirements.[59] But as we have suggested above, *efficiency* can mean greater overall use – a very large data centre can be very efficient, but still have massive resource demands.
- The US has no Federal-level plan for managing data centre energy demand and no Federal-level plan to manage their carbon emissions.

In general, the policy response to data centres in the developed world has been extraordinary enthusiasm for rapid expansion on one side, with very little system-wide thinking about how the energy (and water) demands of data centres can be met on the other[60]: regulations and requirements on individual installations to meet renewable targets, or requirements (as recently announced in Ireland) for data centres to have on-site generation.[61]typically occurred at a local or regional level. The Appendix details interventions on data centre construction in OECD countries. As can be seen, interventions are typically sub-national and purely restrictive on announced plans, rather than national (or supra-national) and planned.

This is a flawed approach, since as we detail above it is exactly the macro-level, systemic impact of rapid expansion that is the problem with data centre growth. This is where the strains in energy systems emerge and where the problem of surging demand and emissions is acute.

Initial policy proposals

Policy on data centre expansion so far has been largely conducted outside of the framework of climate change policy and law. The primary aim here should be to develop robust, implementable policy for the UK and EU to limit data centre emissions that moves the problem from a patchwork of local and regional interventions that do not address the entire problem, into an effective framework for consent to development, transparency of impacts, and regulation of emissions.

As an initial assessment, areas for future work fall into three broad areas:

- National and supra-national assessments should be made of the likely paths of energy use and subsequent emissions from data centre expansion, and these scenarios considered against the national and supra-national frameworks for emissions control. Current estimates on emissions from data centres are subject to wide variation, and these could be usefully refined.
- The legal, regulatory and policy changes needed to move data centre operations as close as possible to 100% renewables, taking a whole-lifecycle approach from construction into operation and including support for battery storage. These could

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[58] European Commission, "Commission adopts EU-wide scheme for rating sustainability of data centres", news announcement, 15 March 2024. [Commission adopts EU-wide scheme for rating sustainability of data centres - European Commission].
[59] European Commission, "AI Continent Action Plan", draft, 2025, p.9.
[60] Caroline O'Doherty, "New data centres to get green light if they generate own power under new proposals", *Irish Independent*, 18 February 2025.
[61] Daniel Swinhoe, "Ireland's energy regulator proposes policy requiring data centers to match load with new power generation", Data Center Dynamics, 19 February 2025.

include consideration of the contribution of the users of data centres (Big Tech) to the tax system and allocation of funds to grid expansion/decarbonisation.

- Finally, to develop policy for minimising data collection, processing and storing, alongside a robust hierarchy of data centre applications. This will build on recommendations in the National Engineering Policy Centre's report on minimising the footprint of data centre operations.[62] The problem of demand and purpose of data centre expansion is inseparable from the issue of their resource and emissions impact, and should be confronted directly by policy.

The rapid growth of the sector has run ahead of detailed policy research, with environmental organisations and even governments running to catch up with its expansion. More research and analysis is needed to provide a robust evidence base for detailed policy analysis and conclusions.

[62] National Engineering Policy Centre, *Engineering Responsible AI: foundations for environmentally sustainable AI*, February 2025. February 2025 Engineering Responsible AI: Foundations for Environmentally Sustainable AI, p.18.

Appendix: recent data centre regulation for energy and the environment

Emerging data centre regulations for energy and the environment across the OECD	
European Union	EU Code of Conduct for Data Centres (Energy Efficiency) published 2008, but was only voluntary commitments and reporting. The 2023 Energy Efficiency Directive's Data Centre Sustainability Reporting Obligations introduced 6 June 2024, obligatory for data centres in the EU with power demand >500kW, where the operator is not already required to report to a member state. Requires reporting on data throughput, energy use, water use, waste heat utilisation and renewable energy use, amongst others.[63]
Ireland	Commission on the Regulation of Utilities "de facto" moratorium, November 2022, to remain in place until 2028; EirGrid, state-owned energy supplier, cancelled 30 proposed data centre plans, as of May 2022.[64]
Germany	Frankfurt issued city-level guidance for data centre construction, mandating energy efficiency, May 2021;[65] new city plan limited data centres to specific areas, and mandate connection to a city-wide waste heat system;[66] Germany's "Energy Efficiency Act" passed September 2023, regulating new data centre construction to limit waste heat, mandate renewable energy use, and limit Power Use Efficiency (PUE) to less than 1.2,[67] provoking industry objections and a relaxation of energy efficiency requirements.[68]
The Netherlands	Amsterdam and neighbouring region: one-year moratorium on data centre construction enacted 2019, expired 2020; 2020 plan mandated a "power budget" of 750MVA by 2030, construction in four designated areas only; PUE of 1.2 for new construction; and "nature-inclusive construction". Exemptions for small (<5MVA) constructions.[69]

[63] Candido Garcia Molyneux, et al., "New sustainaibility reporting requirements for data centres in the EU", Inside Climate and Environment, Covington, 19 August 2024. https://www.insideenergyandenvironment.com/2024/08/new-sustainability-reporting-requirements-for-data-centers-in-the-eu/.
[64] Peter Judge, "EirGrid pulls plug on 30 Irish data centre projects", *Data Center Dynamics*, 24 May 2022. https://www.datacenterdynamics.com/en/news/eirgrid-pulls-plug-on-30-irish-data-center-projects/.
[65] Peter Judge, "Frankfurt to regulate data centres", *Data Center Dynamics,* 13 May 2021. https://www.datacenterdynamics.com/en/news/frankfurt-to-regulate-data-centers/.
[66] Peter Judge, "Frankfurt updates its plans for environmental data center zoning", *Data Center Dynamics*, 27 July 2022. https://www.datacenterdynamics.com/en/news/frankfurt-updates-its-plans-for-environmental-data-center-zoning/
[67] Rostyslav Telyatnykov, et al., "Data center requirements under the new German Energy Efficiency Act", White and Case, 25 October 2023. https://www.whitecase.com/insight-alert/data-center-requirements-under-new-german-energy-efficiency-act.
[68] Peter Judge, "Germany: the first regulated data center market", *Data Center Dynamics*, 27 October 2023. https://www.datacenterdynamics.com/en/analysis/germany-the-first-regulated-data-center-market/.
[69] Peter Judge, "Amsterdam resumes data center construction, one year after moratorium", *Data Center Dynamics*, 1 July 2020. https://www.datacenterdynamics.com/en/news/amsterdam-resumes-data-center-building-after-years-moratorium/.

Singapore	Moratorium on new data centre construction introduced 2019, ended 2023; May 2024, published of "Green Data Centre Roadmap" to provide 300MW of capacity in near term"; Roadmap includes regulations on liquid cooling and higher data hall centres, with expectation all data centres are <1.3 PUE by 2030.[70]
USA	No Federal-level specific regulation, but specific states and counties have moved to implement restrictions: Atlanta, Georgia: City Council approved ban on data centre construction near rail transportation infrastructure;[71] Fairfax County, Virginia has moved to ban data centres from proximity to transport hubs and residential areas;[72] Groton, Connecticut: one-year moratorium on all construction from 2022 became ban on large (1,200sqm) data centres from June 2023;[73] Loudon County, Virginia has removed permitting rights from data centres, leaving construction approval at discretion of authorities with view to "building design, environmental sustainability, and noise."[74]

[70] Dan Swinhoe, "Singapore to unlock 300MW of data center capacity through industry energy efficiency initiatives", *Data Center Dynamics*, 30 May 2024. https://www.datacenterdynamics.com/en/news/singapore-to-unlock-300mw-of-data-center-capacity-through-industry-energy-efficiency-initiatives/.
[71] Thomas Wheatley, "Atlanta approves data center ban near Beltline and MARTA stations", *Axios Atlanta*, 5 September 2024. https://www.axios.com/local/atlanta/2024/09/05/atlanta-data-center-ban-beltline-central-business-district.
[72] James Jarvis, "Fairfax County board approves new data center regulations, promise further review", *Fairfax Now*, 11 September 2024. https://www.ffxnow.com/2024/09/11/fairfax-county-approves-new-restrictions-on-data-centers-supervisors-says-theres-more-to-come/.
[73] Peter Judge, "Groton CT blocks large scale data center projects, thwarting NE Edge", *Data Center Dynamics,* 29 June 2023. https://www.datacenterdynamics.com/en/news/groton-ct-blocks-large-scale-data-center-projects-thwarting-ne-edge/.
[74] Dan Brendel, "Loudoun lawmakers advance data center constraints, differ on economic ramifications", *Washington Business Journal*, 3 July 2024. https://www.bizjournals.com/washington/news/2024/07/03/loudoun-data-centers-zoning-by-right-amendments.html.