UK Energy Research Centre

Hyperscale Data Centres

For the Scottish Climate Action Committee and Economy, Tourism and Energy Committee

UKERC Consultation Response

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What can Scotland learn from other countries on the environmental impacts of hyperscale data centres?

Dr We Sun

Unlike some other countries, Scotland has not yet defined what a green data centre is. Ireland, which requires new data centres to match a rising share of demand with additional renewables, and Germany, which mandates heat reuse, offer useful reference points.

See also our responses below to the Economy, Tourism and Energy Committee's Q2: 'What impacts could increased data centre development have on Scotland's energy system?

How building and running hyperscale data centres in Scotland might impact on achieving climate and nature goals?

Dr Callum MacIver

From an emissions perspective, the impact depends on how hyperscale data centre sites are powered. While obtaining a connection to the transmission system is likely the preferred option for a hyperscale developer, long connection lead times could encourage some to consider off-grid powering options. The worst case scenario from an emissions perspective is by-passing a grid connection and being self-powered by fossil fuelled (e.g. gas or diesel) generators for full site demand.

This is distinct from being powered via a grid connection and making use of fossil fuel (e.g. gas or diesel) generators as part of a backup uninterruptible power supply (UPS). A UPS should be rarely used so the climate impact of such development would be orders of magnitude smaller than if the system was providing the sites full energy requirements. While low carbon UPS systems (e.g. supported by battery energy storage that is grid supplied or via co-located renewable energy) would be desirable, the climate case against use of fossil fuels in UPS system is likely to be more marginal than against off-grid fossil fuelled solutions.

For grid connected sites there is still a potential climate impact attached to new large scale demand in terms of how it impacts on the wider operation of the system, but it is one that could be managed within the wider transition to a clean power system.

The role of the power system is to service demand. There is widespread expectation that Data Centre demand will grow and a forecast of that expectation is already factored into e.g. NESO modelling of future clean power pathways. FES and Clean

Power 2030 modelled pathways are still able to meet clean power goals given their underlying assumptions on data centre demand rollout.

Work at the University of Strathclyde [1]investigated the impacted of accelerated growth in Data Centre demand beyond NESO forecasts and the impact of changing the location of that demand on GB system level metrics like gas use, emissions and curtailed energy. Building from a Clean Power compliant 2030 base case scenario based on the Further Flex and Renewables pathway outlined by NESO – a scenario with additional data centre demand and "business as usual" geographical distribution of that demand (majority around London and Southeast) the extra demand was shown to increase utilisation of both renewable and fossil fuel energy. Modest reductions in curtailed energy were observed with increased gas burn pushing up emissions by 15% over the base case.

A second scenario was explored with the same uplift in data centre demand over the base case, however this time, 2.3 GW of the 5.3GW assumed data centre installed capacity in 2030 is assumed to have been located in Scotland (up from 0.3GW). In this scenario renewable curtailment reduces by substantially more and the emissions impact is partially mitigated, down to 9% above the base case vs 15%. All data centre connections are assumed to be grid connected. Emissions impacts would be significantly increased if a portion of data centre demand was assumed to be directly powered by fossil fuels.

The key messages are:

• Clean power targets can be met according to NESO while incorporating a certain expectation of data centre demand rollout.

• If data centre demand rises faster than forecast then that is likely to put upward pressure on fossil fuel burn across GB within the power system and make it harder to meet clean power targets at a GB level.

• Having demand located in places like Scotland that have a surplus of renewables and export constraints could enable greater use of otherwise curtailed renewable resource and mitigate some of the pressure on emissions rises.

• This assumes grid connected data centres – data centre demand directly supplied by fossil fuelled plant would have a significantly higher emissions impact both at GB level and especially within Scotland.

What criteria should a hyperscale data centre meet in order to be considered "green"?Titles and numbering

Dr Wei Sun

The “Green” credentials of hyperscale data centres in Scotland needs an agreed definition. Scotland has not yet defined what a green data centre is. A definition could cover where the electricity comes from, using hourly rather than annual renewable matching, and energy efficiency, including waste heat reuse. Ireland, which requires new data centres to match a rising share of demand with additional renewables, and Germany, which mandates heat reuse, offer reference points.

What impacts could increased data centre development have on Scotland’s energy system, including:

Dr Simon Gill

There are a significant number of hyperscale data centres in the electricity network connection queue. Ofgem’s July 2026 analysis identified around 315 data centre projects with contracted capacities of up to 1,500 MW. It identified 40 projects in its ‘hyper’ category of 500 MW+[2]. The largest projects are likely to connect directly to the high-voltage transmission network. Smaller projects could connect through a distribution network and can also have significant effects on transmission.

The network infrastructure implications of data centres need to be considered as an integral part of any data centre development. The selection of sites should consider the implications of network capacity as a key part of the decision making. It is useful to look at the network at three levels:

The connection itself: this covers the assets dedicated to linking the data centre to the public network. Connection assets typically include a cable or overhead line and dedicated substation equipment.

Local network reinforcement: covers upgrades to shared cables, overhead lines, transformers, substations, voltage control equipment and protection systems. These upgrades enable the network to deliver the required power to the connection point while maintaining safety and security of supply.

Wider grid development: considers how new data centre demand, together with other developments on the electricity system, changes power flows across the wider national transmission network, how those changes affect transmission constraints, and what investment may be needed as a result.

For the connection itself, developers will typically pay the full cost of the necessary assets. They also need to consider what level of redundancy they need, meaning how much power they would still expect to receive from the network following a fault on the connection itself, such as the loss of an overhead line or a transformer. Regulations set out the standard design criteria, including standard levels of redundancy for different sizes of project. However, they also allow customers to request a different design, subject to safeguards for the wider network and other

network users. For example, a data centre could accept a connection with less redundancy and use on-site backup to maintain its operations following a fault[3].

The cost of (a) the connection and (b) the reinforcement of the local and wider transmission networks are paid for in different ways. For a direct transmission connection, the data centre developer generally pays the full cost of the connection through connection charges. The costs of local and wider transmission reinforcement are generally recovered through Transmission Network Use of System (TNUoS) charges. These costs are shared across generators and demand users, including electricity customers through their suppliers. It will be important to consider whether this constitutes a fair allocation of costs between the data centre and others[4].

Given the scale of data centres, both individually and collectively, where they locate will have implications for wider grid development across Great Britain. For example, data centres in the north of Scotland could do more to ease transmission constraints and reduce renewable curtailment than sites in southern Scotland or England. By contrast, depending on where they connect, data centres further south could increase network constraints or drive the need for additional transmission capacity. Understanding these interactions between data centre location and wider network needs will be an important part of the process of developing a strategic plan for the energy system.

The impact and fairness of transmission charges for renewable generators have been debated for more than a decade. Many of the same questions about how charges vary by location and who pays for network investment may also arise for data centres.

Phasing a data centre's connection and agreeing how it can vary its demand can affect overall network costs. A data centre may start operating with a smaller connection, with later phases needing additional capacity months or years later. Building for the site's full capacity from the outset may be more efficient than upgrading the network in stages. But if the Transmission Owner invests upfront and later phases are delayed or cancelled, some of that network capacity could go unused.

Separately, if the data centre can reliably reduce its demand on the grid when the network is under pressure, it may be possible to defer some reinforcement[5]. The network company needs to know how much demand can be reduced, for how long, at what notice, and how confident it can be of delivery.

A range of technical electrical characteristics need to be considered when connecting data centres. These include whether data centres introduce electrical harmonics or cause voltage fluctuations, as well as their effects on short-circuit currents and protection systems. Each of these technical considerations has implications for the operation, security and stability of the electricity system. Assessing them when connecting large data centres is important to ensure the power system continues to operate safely, securely and efficiently[6].

NESO and network companies should assess how data centres respond to faults and unusual operating conditions. For example, a fault on the transmission network

can cause a brief voltage dip. A data centre that cannot ride through the dip may disconnect and switch to backup power. A voltage dip can affect a whole region of the electricity system (although typically not the whole GB system), so there is a risk that several data centres in the same area could stop drawing power from the grid almost simultaneously.

For example, in Northern Virginia in July 2024, a transmission fault led to the sudden loss of around 1.5 GW of data centre demand from the grid[7]. A sudden drop in demand on this scale can raise grid frequency across the system and affect voltages more locally. When the data centres return to grid supply, the sudden increase in demand can have the reverse effect.

Evidence is needed on how confidence we can be that data centres will ride through faults, along with procedures to coordinate their return to grid supply. NESO and network companies will also need to assess how multiple data centres and other network users may respond to the same fault and determine whether connection requirements need to be revised or supplemented.

Dr Callum MacIver

There is a high degree of uncertainty around how much data centre capacity will connect to the electricity system (or connect with off-grid power solutions) and how much energy each data centres will subsequently use once connected or installed. What is clear is that the size of the data centre queue is potentially an order of magnitude larger than the capacity that is likely to connect over the next decade. Estimates suggest capacity in the region of 5-6 GW by 2030 and 8-10GW by 2035. This compares against a GB wide data centre queue that is reportedly upwards of 80 GW in size.

Perceived wisdom is that data centres would like to make strong use of their installed capacity once running with estimated utilisation rates typically in the region of 70% or more. However, in their latest Ten Year Outlook NESO significantly revised down their assumption on data centre “capacity factor” in the coming years from 70% in FES 2025 to 25-30%[8]. This is reportedly based on analysis of existing GB data centre demand profiles. This leaves a large disconnect between NESO forecast annual demand from Data Centres and prior reports from DSIT and Aurora[9].How much of the total data centre capacity that comes to GB will then locate in Scotland is even more uncertain and depends on various siting signals. Financial signals via e.g. AI growth zone support could encourage siting into Scotland but various other factors will influence siting decisions including latency, existing fibre and road infrastructure, availability of land, ability to obtain planning and consents as well as cooling options and access to water. The share of data centre load as a proportion of Scotland’s total energy demand is therefore very uncertain but has the potential to be substantial.

Electricity generation:

It is possible that significant new demand vectors coming to Scotland could improve the case for additional deployment of generation in Scotland, including via renewable sources like onshore and offshore wind.

Network infrastructure:

Locating new demand vectors in Scotland could place downward pressure on the long term need for transmission expansion by lowering surpluses and reducing the case for transmission build to export power out of Scotland. NESO estimated that £5bn in upgrade costs could be saved by locating 5GW of data centre demand in Scotland

Utilisation of curtailed renewable electricity:

Work from the University of Strathclyde[10] described in answer to Q4 for the Climate Action Committee showed that locating data centres in Scotland over the south of England has the potential to significantly reduce transmission based renewable curtailment.

Additional preliminary analysis of constraints within Scotland being carried out at the University of Strathclyde suggests that where you locate within Scotland is important to the scale of that impact. An analysis of the 2025 system suggests that data centres located North of the “B4 boundary” which splits Scotland’s two transmission areas owned by SSEN and SPT respectively, depending on scale, could be 2-3x more impactful on mitigating constraints than data centre demand that is located further south in Scotland (e.g. in the central belt or south of Scotland). This reflects the current situation whereby the main constraint relates to getting power through Scotland from North to South, as opposed simply getting power out of Scotland over the “B6 boundary” with England.

More analysis is required to forecast how these results evolve over time and into the 2030s when most of the data centre demand is likely to materialise. The locational value in terms of constraints reduction is likely to change as new transmission developments such as the Eastern Green Link projects and new generation capacity in various locations comes online. Nevertheless, this is an interesting result when compared with the observable data centre ‘queue’ within Scotland – which shows prospective capacity predominantly clustering in the central belt.

Dr James Day and Prof Meysam Qadrdan

Electricity Demand and Network Infrastructure:

Data centres will of course increase the overall Scottish electricity demand as they bring on new large loads. However, the impact of that load hinges significantly on what additional investments and operational constraints the data centres make. If the data centre commits to being flexible with its power consumption, such that during periods of peak stress it reduces its power draw from the grid, then pressure on network infrastructure can be reduced and spikes in wholesale energy price may be

moderated. As we transition to a higher penetration of renewables in the grid it is the demand during the most stressed hours that warrants more consideration rather than the overall annual demand. This distinction is particularly relevant to network capacity and security of supply; annual consumption still determines the additional energy that must be supplied. Data centres can make the necessary provisions to be flexible during crucial periods, by investing in energy storage assets (such as BESS or chilled-water storage) or by reducing the power drawn by servers through IT workload shifting or throttling.

Our modelling research examines IT workload shifting, batteries and cooling together, showing why available flexibility must be assessed by both magnitude and duration, including thermal and recovery constraints[11]. ENTSO-E identifies flexible connection agreements as a potential route to earlier network access, but also notes the short duration of conventional uninterruptible power supply batteries and the operational constraints on flexibility[12]. In Scotland, NESO identifies an opportunity for well-located demand to reduce renewable curtailment and associated costs; this benefit depends on connection location and should not be assumed for every development[13].

Electricity Generation:

If required, data centres could also partly supply their own power through the development of their own renewable electricity generation. In Scotland this would likely be done through wind power but solar power is also a possible option. This has been done by numerous large data centre projects around the world and should be considered on a case-by-case basis. Examples include Apple's solar projects at Maiden and its wind and solar developments for Viborg[14,15]. The IEA documents both direct investment in co-located renewables and power purchase agreements that help finance new renewable capacity[16]. Apple's Prineville PPAs and Amazon's agreement for Beinn an Tuirc 3 illustrate the latter approach[17,18]. However, matching annual consumption with annual renewable generation does not demonstrate that a data centre is supplied by low-carbon electricity every hour, so the remaining requirement for storage, flexibility and dependable supply must also be assessed[19].

Utilisation of Waste Heat:

Data centre waste heat utilisation can be a very effective way of increasing efficiency and reducing carbon emissions of the energy system overall. It rests heavily on the availability of nearby suitable heat sinks. The most established sinks for waste heat utilisation are district heating systems. This has been shown to be successful in the Nordic and north-west European regions at scale. The IEA identifies operating examples in Stockholm and explains the role of heat pumps in upgrading low-temperature waste heat for district heating[20]. There are other utilisations such as for agricultural purposes (heating for greenhouses) or supplying heat directly to nearby buildings. As with electricity generation, this should be considered on a case-by-case basis and could be a major improvement for how a data centre is integrated into the broader energy system.

The Scottish Government reports that heat networks supply just under 2% of Scotland's heat, so many developments would need new distribution infrastructure and committed customers as well as heat-recovery equipment[21]. ClimateXChange's assessment of Scottish low-temperature heat-network opportunities identifies data centres as potentially substantial heat sources, while acknowledging limitations in available site data[22]. Therefore, heat reuse should be assessed before site selection and cooling design are finalised, accounting for seasonal heat demand, heat-pump electricity consumption, pipework costs and long-term supply arrangements.

Utilisation of curtailed renewable electricity:

Additional demand can reduce renewable curtailment when it is connected on the generation side of a binding network constraint and operates while that constraint applies. Even relatively steady demand can help in those circumstances. Flexible demand can add value by concentrating consumption in periods when renewable output would otherwise be restricted. Arup's Demand for Constraints assessment for NESO explicitly considers data centres and models cases containing both flexible and baseload demand[23].

Facilities could increase useful electricity consumption during these periods by scheduling suitable computing tasks, charging batteries or storing cooling for later use. Their ability to do so depends on available work, computing capacity and storage headroom[24]. Low wholesale prices alone should not be treated as evidence that a facility is relieving a particular Scottish constraint. The change in curtailment should be assessed against a scenario without the development, using its actual connection location and operating profile. The assessment should also test future network reinforcement and renewable deployment, since the opportunity will change over the facility's lifetime.

Overall network balancing:

Data centres could contribute to frequency response, reserve and congestion management through suitable batteries and coordinated changes to computing and cooling demand. The services available depend on response speed, duration and operational constraints. Conversely, rapid changes in large loads or their simultaneous disconnection during a disturbance can create additional system challenges. ENTSO-E identifies both these risks and the potential for data centres to provide grid services[25].

Balancing assessments should include what happens after a response. Deferred computing must subsequently be completed, and discharged storage recharged, creating recovery demand that needs to be scheduled within network limits[26]. It would require service commitments to be measured at the grid connection and coordinated with the relevant network operator and NESO. Capacity reserved for facility resilience, connection management or another service should not be counted again unless simultaneous delivery is demonstrably feasible. Contracts and incentives should reward verified system benefit while preserving the operational reliability on which customers depend.

Dr Wei Sun and Dr Andrew Lyden

(Note: bracketed references after each heading indicate the Committee questions addressed: ETE = Economy, Tourism and Energy Committee (Q2 energy system impacts; Q3 assessment and planning); CAC = Climate Action Committee.)

1. **Where a data centre connects matters as much as how much electricity it uses. [ETE Q2, Q3]**

Scotland's main constraint is network capacity, not generation. Two facilities with the same annual demand can have opposite system impacts depending on which side of a network bottleneck they sit. Demand located behind constrained boundaries can reduce wind curtailment and network costs; NESO estimates up to £5bn of savings from locating 5GW of data centres in Scotland. Siting should be assessed against network constraints and planned reinforcement. We are examining siting with PyPSA-GB, an open-source model of the GB system.[27]

2. **Fault behaviour should be part of connection decisions. [ETE Q2, Q3; CAC: lessons from other countries]**

In July 2026, about 3.8GW of data centre load in PJM (US) switched to backup power simultaneously after a single transmission fault. Ireland, after similar large load-loss events, approved a Grid Code modification in September 2026 requiring transmission-connected demand to ride through faults; GB has no equivalent requirement yet. Our research shows that including ride-through behaviour can sharply reduce how much data centre load a network can safely host, and that equipment design (UPS, batteries, converter headroom) recovers much of it[28]. Ride-through capability should be requested early in connection studies and could form part of connection offers.

3. **Flexibility is real but conditional [ETE Q2: curtailed renewables, network balancing]**

AI training workloads can be shifted in time, and scheduling alone can cut emissions without extra hardware, with a tunable trade-off against service quality[29]. Fast, coordinated demand reduction also has measurable value for grid frequency stability, although the benefit levels off as more is added[30]. However, inference demand is much less flexible, and data centre flexibility will not balance intermittent supply on its own; storage, flexible low-carbon generation and whole-system planning are still needed. Flexibility should be contracted and measured, not assumed, and flexible or non-firm connection offers could speed up connection on constrained networks.

4. “Green” needs a definition. [CAC: “green” criteria, energy and waste heat, other countries]

Scotland has not yet defined what a green data centre is. A definition could cover where the electricity comes from, using hourly rather than annual renewable matching, and energy efficiency, including waste heat reuse. Ireland, which requires

new data centres to match a rising share of demand with additional renewables, and Germany, which mandates heat reuse, offer reference points.

5. Applications are better assessed together. [ETE Q3; CAC: mitigation systems]

Considering proposals collectively, with phased connections aligned to network reinforcement, would allow conditions to be set before facilities are built rather than after.

6. Bill impacts and future demand are uncertain. [ETE Q2: electricity demand; Q3]

Data centres pay for their connection and use of the network; whether they bear a fair share of the wider reinforcement they trigger needs examination. Demand forecasts are also uncertain: some AI inference may move to edge data centres and end-user devices, which we are examining in a DESNZ-funded study. Planning should test a range of outcomes and guard against stranded network investment.

Further detail: oral evidence to the Economy, Tourism and Energy Committee, 15 September 2026[31].

What actions should be taken to ensure that the economic and energy implications of data centre development in Scotland are appropriately assessed, planned for and managed at a pace that reflects the rapid growth of AI and demand for digital infrastructure?

Dr Simon Gill

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For example, in Northern Virginia in July 2024, a transmission fault led to the sudden loss of around 1.5 GW of data centre demand from the grid[37]. A sudden drop in demand on this scale can raise grid frequency across the system and affect voltages more locally. When the data centres return to grid supply, the sudden increase in demand can have the reverse effect.

Evidence is needed on how confidence we can be that data centres will ride through faults, along with procedures to coordinate their return to grid supply. NESO and network companies will also need to assess how multiple data centres and other network users may respond to the same fault and determine whether connection requirements need to be revised or supplemented.

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