Qualitative Review and Analysis of Present and Future Grid Connection Challenges in Great Britain

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***Abstract*—Grid connection delays pose a significant challenge for the National Energy System Operator (NESO) in Great Britain (GB). As of 2024, the average time between a connection request and the issuance of an offer has reached five years, with some applications facing projected connection dates over a decade away. While NESO is undertaking a reform process to address these issues, this too introduces uncertainty, as some sites may lose their existing positions in the connection queue.**

This study presents a qualitative, sector-based analysis of current and emerging grid connection challenges faced by stakeholders across various energy production and consumption sectors. These sectors include transportation (with a focus on rail electrification and the growing deployment of electric vehicles), renewable technologies and energy storage, as well as the expanding presence of data centres and logistics hubs.

Qualitative analysis is conducted to assess grid connection issues across different regions of GB, highlighting variations in future electricity demand and comparing these to national trends. The study also maps the geographic distribution of sector-specific energy demands, offering insight into regional disparities and the spatial concentration of anticipated load growth.

***Index Terms*—Grid Connection, Energy Storage, Renewables, Data Centres, Electric Vehicles, Transportation Electrification, Decarbonisation, Electrification**

I. Introduction

In recent years, there has been significant growth in the queue for connections to the Great Britain (GB) grid. As of June 2024, there was over 400 GW of new generation capacity in the connections queue, with 40% of this number holding offer dates beyond 2030 [1]. With the next major milestone in the net zero programme of a 68% emissions reduction only 5 years away [2], the increasingly complex and delayed process of connecting to the GB transmission network represents an urgent issue. One of the biggest challenges faced when considering the future of grid connections in GB is the diverse range of stakeholders that will be involved in the coming years. Responsibility for grid connections can fall to NESO, transmission owners (TOs) such as National Grid Electricity Transmission (NGET) and local distribution network operators (DNOs).

In transportation, the rail network is expected to significantly expand the existing extent of electrification with stated plans to electrify 13,000 Single Track Kilometres (STKs) as set out in the Traction Decarbonisation Network Strategy (TDNS) [3]. Electric vehicle (EV) uptake is expected to continue to increase, driven by government policies such as the end of the sale of new petrol and diesel-fueled vehicles from 2035 and continued support for EV infrastructure development [4]. This transfer of energy demand from fossil fuels to the electricity network is widely acknowledged to be a significant driver of increased load predictions through to 2050 [5].

Potential issues are evident in the sector of renewable generation, as fossil fuel generations continues to be replaced in the progress towards net zero. Restrictions to the effectiveness of renewable generation can already be readily seen in the levels of curtailment required for wind generation, primarily due to inadequate transmission infrastructure [6]. Finally, the prospect of increased deployment of large-scale data centres and logistics hubs is introducing further uncertainty into the planning of the future electricity system [7].

II. Methodology

A qualitative analysis of areas impacting grid connection challenges was conducted. This was achieved through interpretation of national resources and estimations such as NESO's Future Energy Scenarios (FES) [5], [8] predictions, as shown in Figure 1 or sector-based electrification and decarbonisation predictions such as TDNS [3].

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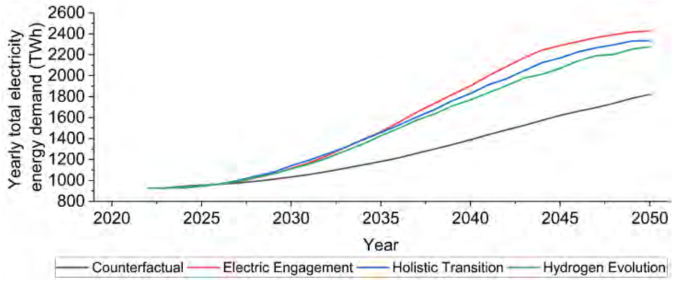


Fig. 1: NESO's FES show an increase in annual electrical energy demand from 925 TWh to 1821-2427 TWh depending on the level of future electrification.

The process for this qualitative analysis began with identifying geographic areas from open-source Ordnance Survey data [9] which gave regions classified as Statistical Reporting Areas for England, such as Yorkshire & the Humber or the North West and Civil Voting Areas for Scotland and Wales such as Lothian or Mid & West Wales. For this purpose, Scotland and Wales are broken down into more geographic areas than England for regions of similar size. This allows for better discrimination and analysis of the sectors in Wales and Scotland as compared to viewing them as whole nations. These areas are indicated in Figure 2 and the areas detailed within Table I.

The sectors selected for analysis included Railways, Road Transport, Shipping, Airports, Industrial Heat, Renewables, Logistics Hubs, Data Centres, and Energy Storage. The study focused on assessing future electricity demand within these sectors, deliberately excluding domestic consumption, such as heat pumps and electric vehicle charging, to avoid biasing the results based on regional population density. Heat pumps and home EV charging were also excluded for clarity.

Individual qualitative analysis was performed on each geographic area for each electrical demand sector by using open-source information that identifies current electrical consumption and expected increase. For some areas such as rail, road, shipping and airports, the approach for these was to identify geographic regions with high concentrations or planned investment in electrification programmes.

After all individual geographic regions have qualitative scores completed for each electrical sector being investigated, a final value was generated for each geographic region to indicate the level of grid connection demand anticipated compared to other geographic areas. The electrical demand sectors were given individual weightings (ω), as shown in Table I according to each sector's forecast electrical demand relative to the other sectors studied. Each individual sector score (p) is combined with the weighting ($p{\cdot}\omega$) and then averaged across the number of sectors (n).

The overall qualitative scoring ($\frac{\sum_{i=1}^{n}(p_i \cdot \omega_i)}{n}$) for GB can be seen in Figure 2 with the individual sector and final scores in Table I. Each electrical demand sector has an individual map in Figure 3. Geographic Information System (GIS) software was used to visually represent the scoring associated with each region and a graduated heatmap applied. This produces the coloured variation between regions.

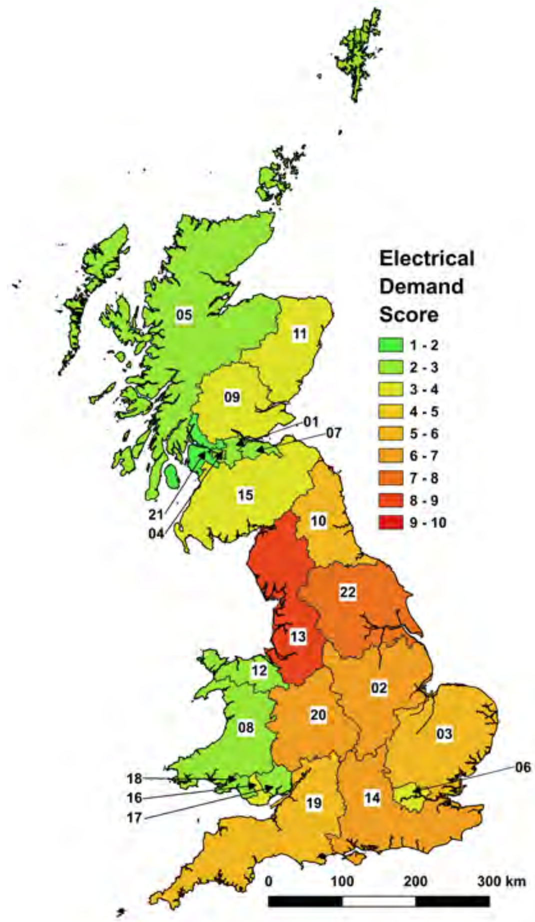


Fig. 2: Overall weighted map of GB electrical grid connection demand challenges. Numbers for areas link as per "Ser" column in Table I

III. Analysis

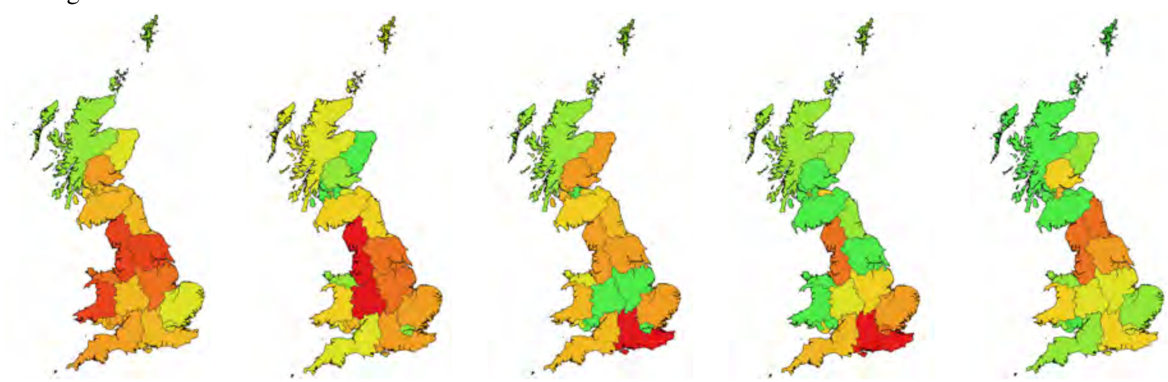
A. Rail

The United Kingdom's Government has set out a deadline to decarbonise the UK railways by 2040 under the TDNS [3]. This sets out the strategy to electrify up to 13,000 STKs of railway using conventional electrification, increasing the length of electrified track from the current 39% electrification to 96%. The rail network currently uses 3896 GWh of electricity each year for the current passenger and freight services on the electrified sections but the energy required by the current diesel services, which will need to be replaced with electricity, is calculated to be 5960 GWh bringing the total network consumption to just under a predicted 10 TWh.

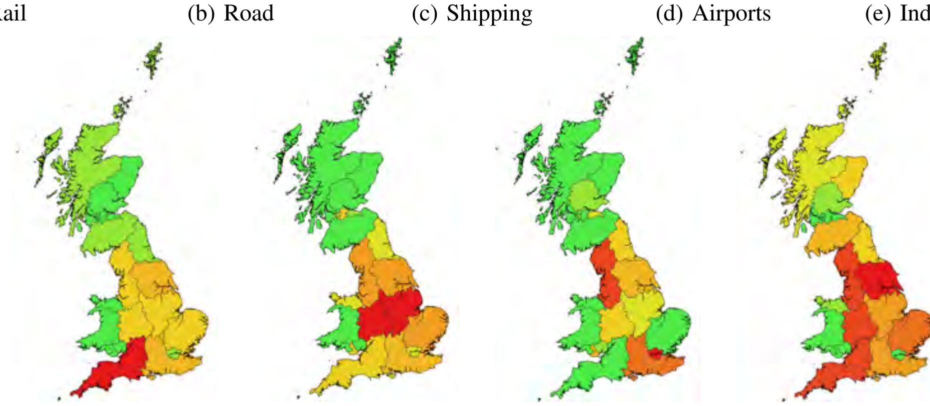
These calculations using Office for Rail and Road (ORR) data are corroborated by FES predictions [5], [20], [21]. Figure 3a shows how the distribution of unelectrified lines are predominantly in the north and west with Scotland and Wales having multiple key routes which are unelectrified. Electrical capacity is already limited in certain areas of the network [22], [23] and operators are currently required to use onboard

Ser	Area	Rail	Road	Shipping	Airports	Industrial Heat	Renewable	Logisitc Hubs	Data Centres	Storage	Final
		(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	
	Figure	3a	3b	3c	3d	3e	3f	3g	3h	3i	2
	Sources	[3]	[10]–[12]	[13], [14]	[15]	[16]	[17]	[18]	[19]	[17]	
	Weighting (ω)	2	8	2	3	8	6	4	4	10	
01	**Central Scotland**	6	2	1	2	6	1	5	2	2	2.9
02	**East Midlands**	8	8	2	5	4	5	10	4	7	6.1
03	**Eastern**	4	7	7	7	3	5	7	2	8	5.7
04	**Glasgow**	5	4	3	5	3	1	4	3	2	3.0
05	**Highlands and Islands**	3	4	3	3	1	3	2	1	4	2.8
06	**London**	4	3	2	8	4	3	4	10	2	4.0
07	**Lothian**	6	4	5	5	1	1	3	4	1	2.6
08	**Mid and West Wales**	9	5	6	1	5	1	1	1	1	2.9
09	**Mid Scotland and Fife**	7	3	7	1	5	1	1	3	3	3.1
10	**North East**	6	5	6	3	8	3	4	5	5	5.1
11	**North East Scotland**	4	2	7	3	3	2	1	2	5	3.1
12	**North Wales**	8	3	4	1	3	1	4	2	3	2.9
13	**North West**	9	10	7	8	8	5	7	9	9	8.2
14	**South East**	6	7	10	10	5	6	6	8	7	6.8
15	**South Scotland**	6	5	5	2	1	3	2	1	6	3.5
16	**South Wales Central**	7	6	2	5	2	1	5	6	1	3.3
17	**South Wales East**	7	6	1	1	2	1	2	3	1	2.5
18	**South Wales West**	6	4	4	1	3	1	2	2	2	2.6
19	**South West**	7	4	6	6	3	10	5	2	9	5.9
20	**West Midlands**	6	10	1	4	4	5	10	5	9	6.8
21	**West Scotland**	5	2	6	1	2	1	1	1	2	1.9
22	**Yorkshire and the Humber**	9	8	7	2	7	6	7	6	10	7.4

TABLE I: Sector and Region based scoring for grid connection demand. A score of 1 indicates the lowest challenge whilst 10 indicates the highest.



(a) Rail (b) Road (c) Shipping (d) Airports (e) Industrial Heat



(f) Renewable (g) Logistics (h) Data Centres (i) Energy Storage

Fig. 3: Sector based maps of GB grid connection demand challenges

diesel generators even whilst on an electrified section of track despite having the capability to run on electricity. This is a consequence of higher traffic densities since the electrification systems were installed, newer trains requiring more power for acceleration to achieve better service performance, and improved passenger environment systems.

B. Road

Continued electrification of road transport is expected to result in considerable additional electrical demand in the coming years, as indicated in Figure 3b, with NESO estimating the likely demand increase by 2050 as a result of EVs to be around 100 - 125 TWh higher than today [5]. Recent years have already seen a significant ramping up of public charge point installations, with the total number rising from around 28,500 at the end of 2021, up to around 73,000 by the end of 2024, including a more than 3 fold increase in chargers with a power rating more than 7 kW [24].

Continued expansion of this network of higher-powered chargers, as will be necessary to meet the future demands of a growing EV fleet, will present a significant electrical demand on the grid. It is likely that the expansion of higher-powered EV charging stations will target installation locations on the UK strategic road network, to maximise their accessibility. For this reason it is expected that the grid demand from future road vehicle electrification will largely correlate with the density of the trunk road network within a given geographic area.

Based on this analysis, it is expected that the greatest increase in demand will be seen around the conurbations of the West Midlands and North West, with additional large demands being seen in the East Midlands and Yorkshire.

C. Shipping

Whilst the majority of ships and vesselss that operate in and around the UK waters are fuelled by oil, port operations and docked vessels requiring shore power consume electricity. If all maritime vessels were to use shore power when berthed, they would consume 0.5% of the UK's electricity [25]. By 2050 this demand is expected to reach 250 GWh across all UK ports [26] with a demand of 50 MW for a large port with 50 ships all requiring shore power.

Decreasing carbon emissions will also require the electrification of port operations which include a number of vehicles and lifting equipment. Within GB these ports and the relative sizes are distributed around the coast relatively evenly as shown in Figure 3c, with slightly more on the South and East coasts than the North and West.

D. Airports

Similarly to shipping, whilst the GB aviation industry uses predominantley fossil fuels for flight, the airports on the ground require large amounts of electricity. Heathrow, one of the largest in GB, uses over 270 GWh of electricity each year [27]. This electrical energy is used for ground infrastructure such as terminals and passenger services as well as equipment necessary for aircraft operations such as Air Traffic Control (ATC) services, lighting and RADAR systems. To reduce emissions, irrespective of the aircraft fuel type, an increase in shore power is likely, reducing the need for the onboard Auxiliary Power Unit (APU) to be run whilst on the ground.

Future implementations of electric aircraft for short journeys or the use of Uncrewed Aerial Systems (UAS) for inner city operations could also increase the electrical demand of the GB aviation sector. GB airports are distributed with a high concentration of major airports in the South with additional major airports in the North West and Midlands, as seen in Figure 3d.

Medium scale airports are distributed amongst the remainder with a large quantity of small scale airports or airfields dispersed throughout the nation. A large number of island communities in the Scottish Highlands and Islands use small aircraft for short range island hopping flights which could be a target for electrification [28].

E. Industrial Heat

An October 2023 report from the Department for Energy Security and Net Zero outlined the scale of the challenge associated with decarbonising industrial process that utilise fossil fuels for heating, with these activities accounting for 16% of the total annual emissions in the UK [29]. Electrification opportunities for industrial activities range from utilising heat pumps for steam generation to introducing electric arc furnaces, such as the one recently approved for deployment at Port Talbot Steelworks [30].

Issues identified in the recent call for evidence concentrate on the relatively high cost of electricity, and most pertinently to this work, the grid connection delays present on the network [31]. Areas traditionally associated with industrial activity in GB such as the North East and North West are expected to experience the biggest grid connection demand challenges from the electrification of industrial heat. Overall however, it will not cause a significant impact when compared with other sectors in this analysis in many regions such as East Anglia, the South West, and the Midlands.

F. Renewables

GB Power Networks aims to combine the installed capacities of both Renewable Energy Sources (RES) and Energy Storage Systems (ESS) to reach net-zero emissions. In 2023, renewable generation reached a record 135.8 TWh, increasing by 0.3% compared to 2022 [32]. Wind generation rose by 2.2% to 82.3 TWh, while solar generation increased by 4.1% to 13.9 TWh, despite slightly less favourable weather conditions. However, bioenergy generation declined by 4.9% to 34.1 TWh due to outages at key sites.

Overall, renewables accounted for 46.4% of the UK's electricity generation, exceeding the share of fossil fuels for the third consecutive year [32], [33]. These renewable sites are distributed across GB as shown in Figure 3f. Despite these advancements in renewable generation, the expansion of RES has outpaced grid infrastructure development, leading to increased curtailment and inefficiencies in energy utilisation.

G. Logistic Hubs

The development of large-scale logistics hubs is facing mounting challenges due to outdated infrastructure and delays in securing adequate grid connections. While hydrogen remains a potential solution for long-distance haulage, many companies are already transitioning to fully electric trucks for regional distribution hubs as an immediate solution. Figure 3g highlights the regions where these logistics hubs are most prominent.

These vehicles require high-powered chargers, often rated at 350 kW or more, to support their demanding operations. This shift, coupled with the need for advanced refrigeration systems and 24/7 automated processes, is driving power requirements at logistics hubs from 1-5 MW to 20-50 MW. While co-locating ESS to deliver peak power as an alternative to large grid connections can be effective, it comes with a substantial capital cost.

H. Data Centres

Connection delays may have a significant impact on the deployment of large-scale data centres where power requirements have been steadily increasing from 5-10 MW to up to 90 MW such as the planned CyprusOne. In 2024, the Department for Energy Security and Net Zero outlined the importance of grid connection reform in response to increasing deployment of data centres in the Clean Power 2030 roadmap, predicting a total load of 3.61 GW by 2029 and a total energy demand of 35 TWh by 2050.

The UK government has emphasised its commitment to supporting the growth of data centres as a critical part of the digital economy, as shown in Figure 3h, with initiatives such as the Data Centre Sustainability Taskforce and targeted investments to improve grid infrastructure and energy efficiency.

I. Energy Storage

The increasing deployment of distributed RES has amplified the need for efficient grid-connected energy storage solutions to mitigate curtailment and maximise RES utilisation. As of 2024, GB has approximately 5.013 GW of operational battery energy storage systems (BESS), with an additional 5.115 GW under construction, bringing the total expected capacity to over 10.1 GW in the coming years [34]. The total battery storage pipeline also stands at 127.4 GW, with 40.2 GW already consented and 47.8 GW under development. Future projections estimate that GB BESS capacity could surge significantly by 2030, as shown in Figure 3i, attracting billions in investment [35].

Storage assets are critical in various electricity markets, including the wholesale market, balancing mechanism, and ancillary services, ensuring revenue stacking opportunities [36]. Over the past decade, England has dominated battery storage deployment, accounting for 83% of commissioned capacity since 2013, while Scotland, Northern Ireland, and Wales have contributed to 20% of recent installations. However, grid connection delays and infrastructure constraints continue to pose challenges to widespread deployment. While BESS primarily supports short-term grid flexibility, long-duration energy storage solutions, such as hydrogen and expanded pumped hydro, are increasingly emphasised to address seasonal variations in renewable generation [37].

IV. Discussion

From the above sector based analysis, the electrical demand in regions can be evaluated by looking at the impact of a combination of sectors. Northern Scotland is not expected to experience large increases in electrical energy demand, however, it will see rapid growth in wind generation and offers the potential for large energy storage projects as generation will heavily exceed demand.

Wales as a region has a predicted low growth for energy demand, however, investment decisions could drive demand in certain areas, such as industrial heat. Some specific areas may experience increases in demand due to the electrification of industrial processes. Similarly, the North-East industrial sector has considerable heat requirements and will see low-carbon technologies introduced in decarbonisation programmes, increasing the electrical demand.

The North East, North West and Yorkshire regions have a large amount of railway infrastructure that is unelectrified. Significant railway electrification projects such as the Transpennine Route Upgrade are underway with existing railway being upgraded and electrified for faster and more frequent services. Future electrification programmes or upgrades to increase capacity will increase the demand in this area along with investment and upgrades to EV charging on trunk routes running through these areas. There are a large number of main transport corridors that join the South and Midlands of England to Scotland. Increasing electrification of road transport will lead to considerable additional demand from EV charging infrastructure, especially in areas with dense road networks, such as the North West.

The Midlands regions will additionally see distribution hubs contributing a considerable increase in electrification as companies invest in greener infrastructure to support electric vehicle fleets. The South East is expected to see a large increase in demand from multiple sectors, including Road Transport, Shipping and Airports and will need appropriate upgrades to ensure capacity for the increased demand. Some areas like rail are already well electrified and would not necessarily see an increase in demand except in the case of new construction projects.

The South West is expected to see a sizeable increase in renewable energy generation infrastructure, which will likely coincide with a corresponding increase in storage capacity. Transportation electrification of rail, shipping and air could also see a notable impact within this region.

V. Conclusion

The qualitative, sector-based study demonstrates that electrification and grid investment must consider multiple sectors to accommodate regional growth in a holistic approach to decarbonisation. Growth in different individual industrial sectors will have a combined impact on regions to the extent that investment and upgrades in the electrical grid supply will need to consider combined impacts.

The industrial growth might not be co-located with domestic growth either, the Southern regions of England indicate less demand than Northern regions for industry. This study has excluded growth in energy domestic demand such as heat pumps and home EV charging, these will also increase demand in areas in line with population growth. However, the location of population centres could depend on future modal shifts in transport trends and climate change. Further work will be required to understand the population impact on future electrification and grid connection challenges.

Further work will also be required to explore the complex interactions between different sectors and the potential for shared grid infrastructure, such as through Vehicle to Grid (V2G) or Road to Rail Energy Exchange (R2REE). The deployment of energy storage systems could also help alleviate grid connection challenges and reduce the impact of peak demands on the wider national grid.

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