Western Gateway Area – Characterisation of the current energy system and preliminary scenarios towards Net Zero

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Executive Summary

In 2019 the UK strengthened its legally binding greenhouse gas (GHG) emission reduction targets to achieve net zero GHG emissions by 2050. In addition, the Sixth Carbon Budget covering the period between 2033 and 2037 was announced in 2021, which committed the UK to reach a GHG emission reduction of 78% with respect to 1990 levels by 2035. This report aims to study the Western Gateway Area – which covers parts of the South West of England and South Wales – to characterise its energy system, including current and planned infrastructure, in order to provide recommendations that can inform Net Zero pathways. The Western Gateway partnership is a UK's Pan-Regional Partnership and an Economic Powerhouse, which intends to work to power the UK's efforts to reach net zero, made up of 24 South Wales and South West England Local Authorities, and other combined authorities and partnerships.

This report aims to analyse the Western Gateway Area from an energy systems-wide perspective, identifying possible synergies between different network types, technologies, infrastructure, and demands, that will provide evidence to facilitate the development of a regional energy strategy. Given the urgency in strategic decisions in the region's resource, network and possible demand development, detailed system studies are critically urgent to inform strategic decision making. This study makes the first step towards synthesising regional energy information. It is a high-level characterisation, generated for multi-stakeholder dialogues, to develop detailed plans to reap the benefits of the region's rich clean energy resources, and possible pathways to cost-effective decarbonisation. It gathers public data and information on current and future infrastructure, and analyses 2 possible decarbonisation scenarios for the Western Gateway Area proposed in other studies, in order to present different energy system configuration alternatives and decarbonisation pathways. The first is a **high renewables/high electrification** scenario, and the second is a **high nuclear/high hydrogen** scenario.

Trends in emissions in buildings and transport sector show that most decarbonisation over the past decade has been achieved in the power sector. Given planning and construction times, it is highly unlikely to reach Net Zero by 2030. Efforts should be placed now in designing a detailed decarbonisation plan towards 2050, with concrete measures, timelines, investments, and regulations. Since Local Authorities are all interconnected through various networks, the Western Gateway Area could benefit from a detailed system study that characterises demands, networks, and energy supply alternatives – both spatially and temporally – and understands the synergies within the area for different scenarios. This could aid in developing robust transition pathways, with precise investment and policy measures (when, where, and what?) to reach Net Zero by 2050.

The key findings of this report are:

Power Generation

- Variable renewable generation (solar PV and wind) are currently the lowest cost power generation technologies and are expected to dominate the power generation mix. Hinkley Point C and/or small modular reactors in the area can provide baseload.
- In terms of generation mix, a **high nuclear/high hydrogen** scenario is advantageous in terms of the high capacities and grid stability that can be achieved by nuclear power plants, but has the disadvantages of being costlier than renewables and presenting long construction times. Conversely, a **high renewables/high electrification** scenario is quicker to construct, but presents balancing issues, requiring storage, demand-side response, and network management.

- High penetration of variable renewables imply the need for storage to account for variations in demand and supply, and in many cases the need for network reinforcement, as energy service demands such as heating and transport are expected to electrify.

Buildings

- Independent of the scenario, thermal insulation and energy efficiency measures in buildings are low regret measures, as these can reduce energy demands by 20-25%, and therefore reduce emissions and energy bills. The public sector will need to create funding mechanisms to ensure retrofit plans for existing buildings, and financial support for low-income dwellings.
- In a **high renewables/high electrification** scenario, air-source, ground-source, and hybrid heat pumps are expected to supply heat demands in buildings. This can be as individual units in rural, less dense, and not spatially-constrained buildings, or as heat supply for district heating networks, in more dense and urban areas. In a **high nuclear/high hydrogen** scenario, hydrogen boilers could be used for supplying building heating demands. In this scenario, low pressure polyethylene gas distribution networks can be used for hydrogen distribution and non-polyethylene distribution networks would need to be replaced. As for the case of energy efficiency measures, technology switching is expensive, and low-income dwellings are likely unable to afford it, requiring financial support.

Road transport

- For both scenarios, cars and light goods vehicles are expected to electrify, with no non-electric vehicles being sold after 2040. Decarbonisation pathways for heavy good vehicles are still uncertain. In a **high renewables/high electrification** scenario, super-fast charging infrastructure will be required along roads, with possible substation upgrades and network reinforcement. A **high nuclear/high hydrogen** scenario will require high purity hydrogen supply chains and refuelling infrastructure. Both alternatives require high investments and involve long permission and planning times.

Networks

- According to Western Power Distribution's investment plan submitted to Ofgem for RIIO-ED2, investments for South Wales and the South West add up to £2.853bn. Although this is not an exact match to the Western Gateway Area, these numbers can be used as a reference of the investments required **on electricity distribution only** over the next 5 years to be **on the road towards Net Zero by 2050** in the Western Gateway Area. Much higher investments are required to reach Net Zero by 2050 which evidences that goals to reach Net Zero by 2030 are economically prohibitive.
- Both transport and heat electrification will require reinforcement in distribution networks. Because investments in network reinforcements are costly and disruptive, network upgrades taking place over the 2020s should be oversized to be able to meet future electricity demands beyond 2035.
- Transport and heat electrification, increased variable renewable generation, increased nuclear generation, and demand profile shifts, will possibly require transmission reinforcements in the Western Gateway Area.

1. Introduction

In 2008 the UK Climate Change Act set out legally binding greenhouse gas (GHG) emission reduction targets, which mandated a reduction in 80% GHG emissions by 2050 with respect to 1990 levels. This legislation was modified in 2019, where the UK strengthened its targets to achieve net zero GHG emissions – a 100% reduction target – by 2050 [1]. In addition, the Sixth Carbon Budget covering the period between 2033 and 2037 was announced in 2021, which committed the UK to reach a GHG emission reduction of 78% with respect to 1990 levels by 2035 [2].

Several local authorities throughout the UK are working on Net Zero strategies and plans for attaining decarbonisation goals even before the official targets. In this context, this report aims to study the Western Gateway Area – which covers parts of the South West of England and South Wales – to characterise its energy system, including current and planned infrastructure, in order to provide recommendations that can inform Net Zero pathways. The Western Gateway partnership is a UK's pan-regional powerhouse, which *intends to work to power the UK's efforts to reach net zero whilst providing opportunities to those at risk of being left behind*. It is made up of Local Authorities, Combined Authority, City Regions, Local Enterprise Partnerships, and Governments (in Wales and Westminster) [3]. We aim to analyse the Western Gateway Area from a systems-wide perspective, and identify possible synergies between different network types, technologies, infrastructure, and demands.

This report aims to characterise the Western Gateway's energy system, including current and planned infrastructure, in order to provide recommendations that can inform Net Zero pathways. It gathers public data and information on current and future infrastructure, and analyses possible decarbonisation scenarios for the Western Gateway Area from an energy systems-wide perspective, identifying possible synergies between different network types, technologies, infrastructure, and demands. It is not meant to serve as a technical analysis of scenarios, but as a detailed characterisation of the energy system for discussion with key stakeholders, that will provide evidence to facilitate the development of a regional energy strategy.

Section 2 briefly describes the Western Gateway Area and its Local Authorities, together with each local authority's decarbonisation targets when available. Section 3 presents current and planned electricity generation technologies in the area, with their locations and capacities. Section 4 describes current network infrastructure for electricity, gas, and transport. Section 5 shows a snapshot of current annual demands for electricity and gas in domestic and non-domestic sectors in the area, and current demands for transport fuels. Section 6 and 7 present socioeconomic indicators and evolution of CO_2 emissions by sector, respectively, within the area. Based on the collected data and on other studies at national or regional levels, Section 8 analyses possible decarbonisation scenarios for the Western Gateway Area, concluding with some key findings presented in Section 9.

This is a report on preliminary findings for discussion with key stakeholders.

2. Western Gateway Local Authorities and decarbonisation targets

The Western Gateway Area comprises 24 Local Authorities, 12 of which correspond to South Wales, and 12 from South West England, as shown in Figure 1.

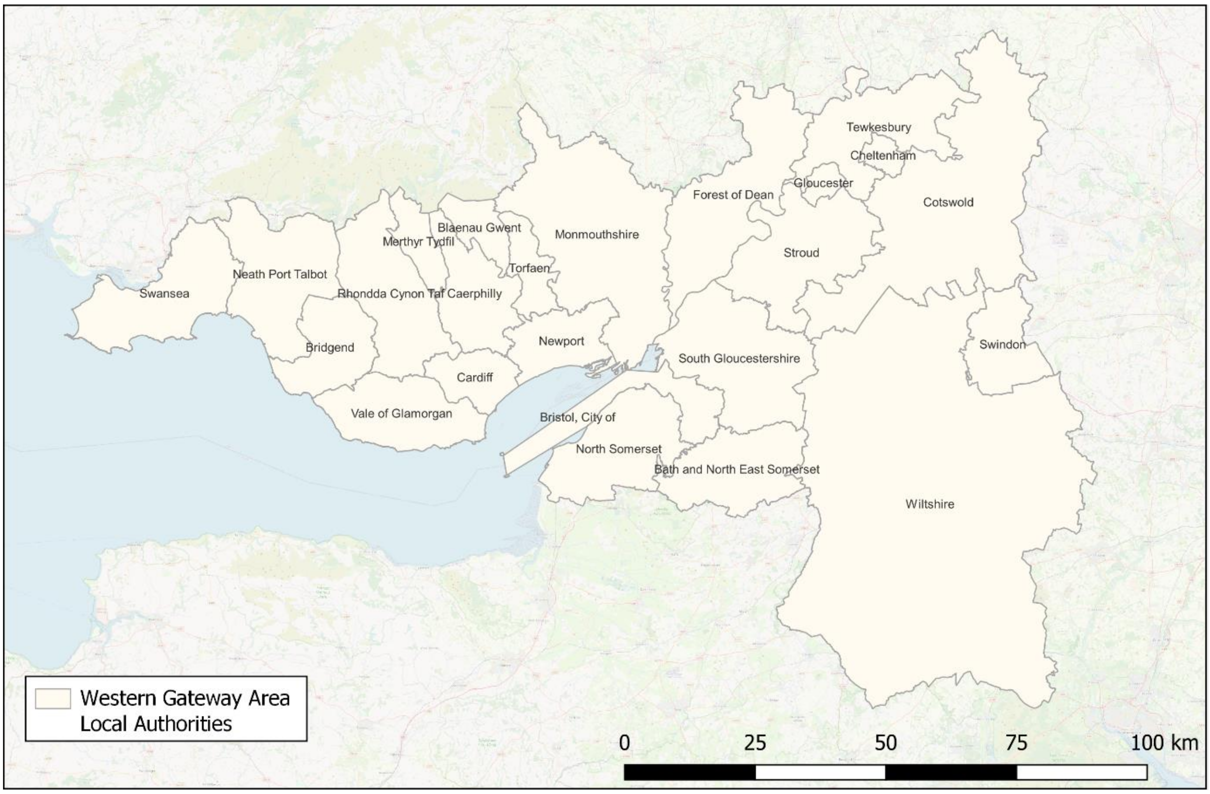


Figure 1: Western Gateway Area Local Authorities

Local and regional authorities are responding to the climate crisis with different goals, timelines, strategies, and plans. Table 1 summarises the Western Gateway Area Local Authorities' decarbonisation goals according to their published strategies.

Table 1: Western Gateway Area Local authority Net Zero goals.

Local Authority	Goals	Source
Bath and North East Somerset	Carbon neutrality by 2030	[4]
Blaenau Gwent	Public sector carbon neutral by 2030	[5]
Bridgend	Bridgend County Borough Council to be Net Zero by 2030	[6]
Caerphilly	Carbon neutral Council by 2030	[7]
Cardiff	Carbon neutral Council and City by 2030	[8]
Cheltenham	Carbon neutrality by 2030	[9]
City of Bristol	Carbon neutral in own operations (for gas, heating, electricity, vehicles) by 2025. Net Zero by 2030.	[10, 11]
Cotswold	Net-zero carbon as soon as possible, aiming for an 80% reduction against a 1990 baseline by 2030, and a 100% reduction by 2045, with no reliance on offsetting or the trading of carbon credits	[12]
Forest of Dean	Carbon neutrality by 2030	[13]
Gloucester	Net Zero council by 2030 and city by 2050	[14]
Merthyr Tydfil	Public sector carbon neutral by 2030	[15]

Monmouthshire	Net Zero council by 2030	[16]
Neath Port Talbot	Carbon neutrality by 2050	[17]
Newport	Net Zero council by 2030	[18]
North Somerset	Carbon neutrality by 2030	[19]
Rhondda Cynon Taf	Carbon neutral council by 2030	[20]
South Gloucestershire	Net Zero council by 2030 and ned-zero area-wide by 2045	[21, 22]
Stroud	Carbon neutrality by 2030	[23]
Swansea	Net zero council by 2030, and net zero Swansea by 2050	[24]
Swindon	Carbon neutral council by 2030 and carbon neutral area by 2050	[25]
Tewkesbury	Carbon neutrality by 2030	[26]
Torfaen	Carbon neutral council by 2030	[27]
Vale of Glamorgan	Carbon neutral council by 2030	[28]
Wiltshire	Carbon neutrality by 2030	[29, 30]

Furthermore, the Welsh Government stated its commitment to reach a carbon neutral public sector in Wales by 2030, and most of the Welsh Local Authorities in the Western Gateway Area are committed to this goal.

Table 1 shows that the vast majority of South West England's Local Authorities state their ambitions to reach carbon neutrality by 2030. This report will evidence how challenging it is to meet these ambitions, considering the length of planning and building times required to build the required infrastructure.

Searching for information about Local Authorities' decarbonisation plans, it was difficult to access detailed plans on the steps to reach carbon neutrality. We would like to highlight South Wales's Zero 2050 project [31] as a good practice. The project brings together 14 Local Authority areas in South Wales (Blaenau Gwent, Bridgend, Caerphilly, Cardiff, Carmarthenshire, Merthyr Tydfil, Monmouthshire, Neath Port Talbot, Newport, Pembrokeshire, Rhondda Cynon Taf, Swansea, Torfaen, and Vale of Glamorgan), most of which fall into the Western Gateway Area. The project looks at the different sectors involved and their future projected demands, and analyses scenarios to reach 65% GHG emissions reductions by 2030, 89% by 2040, and net zero by 2050.

3. Electricity generation capacity

This section presents current and planned electricity generation capacity by source in the Western Gateway area.

3.1. Renewables and battery storage

3.1.1. Installed capacity

Figure 2 shows operational installed capacities across the Western Gateway Area by generation source, for renewable electricity generation and battery storage [32]. Battery storage capacities are labelled for each site when available. For bioenergy, when combined heat and power (CHP) generation units are installed, installed capacities refer to electrical outputs.

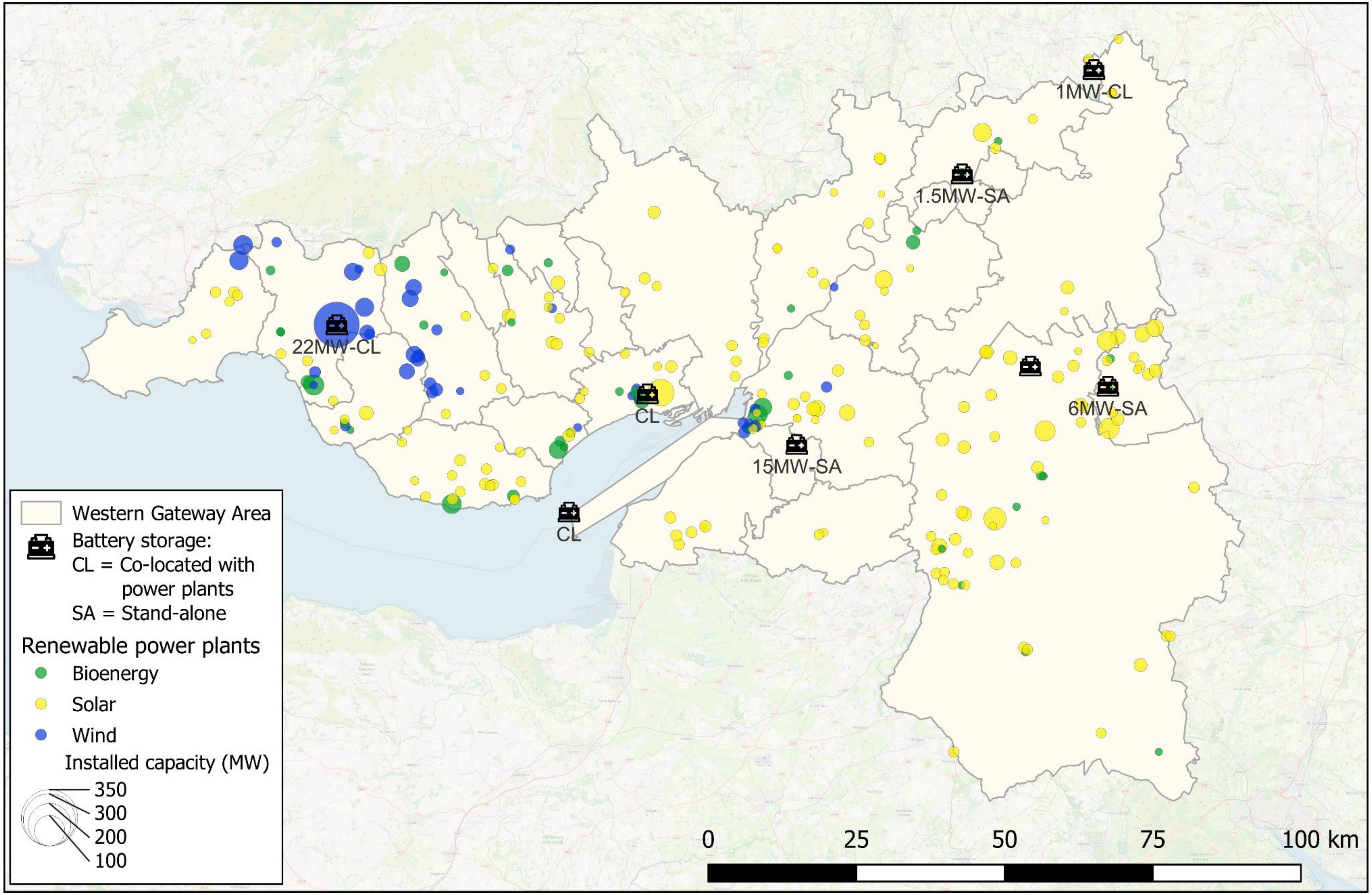


Figure 2: Renewable generation and battery storage operational installed capacity in the Western Gateway Area by generation source. Data from [32].

Total installed capacities by source are shown in Table 2. The total renewable generation installed capacity (wind, solar photovoltaics, and bioenergy) adds up to 2.3 GW. Out of the 95.5 MW reported of battery storage, 23 MW are co-located with renewable generation plants, while the rest are stand-alone systems.

Table 2: Total reported installed capacity by electricity generation source. Data from [32].

Source	Installed capacity [MW]	Total UK installed capacity [MW]	Installed capacity of Western Gateway Area over total UK
Wind onshore	616	13682.9	4.5%
Solar photovoltaics	1328.7	8633.72	15.4%
Bioenergy	349.09	6920.4	5%
Total	**2293.79**	**29237.02**	**7.9%**
Battery storage	95.5	823.8	11.6%

3.1.2. Under construction, awaiting construction, and submitted for approval

Figure 3 shows under construction and planned capacity of renewable electricity generation and battery storage plants in the Western Gateway Area. Awaiting construction sites (b) include both, sites that have been granted planning permissions, and sites that have been granted appeals. Figure 3(c) refers to sites whose planning applications have been submitted for approval.

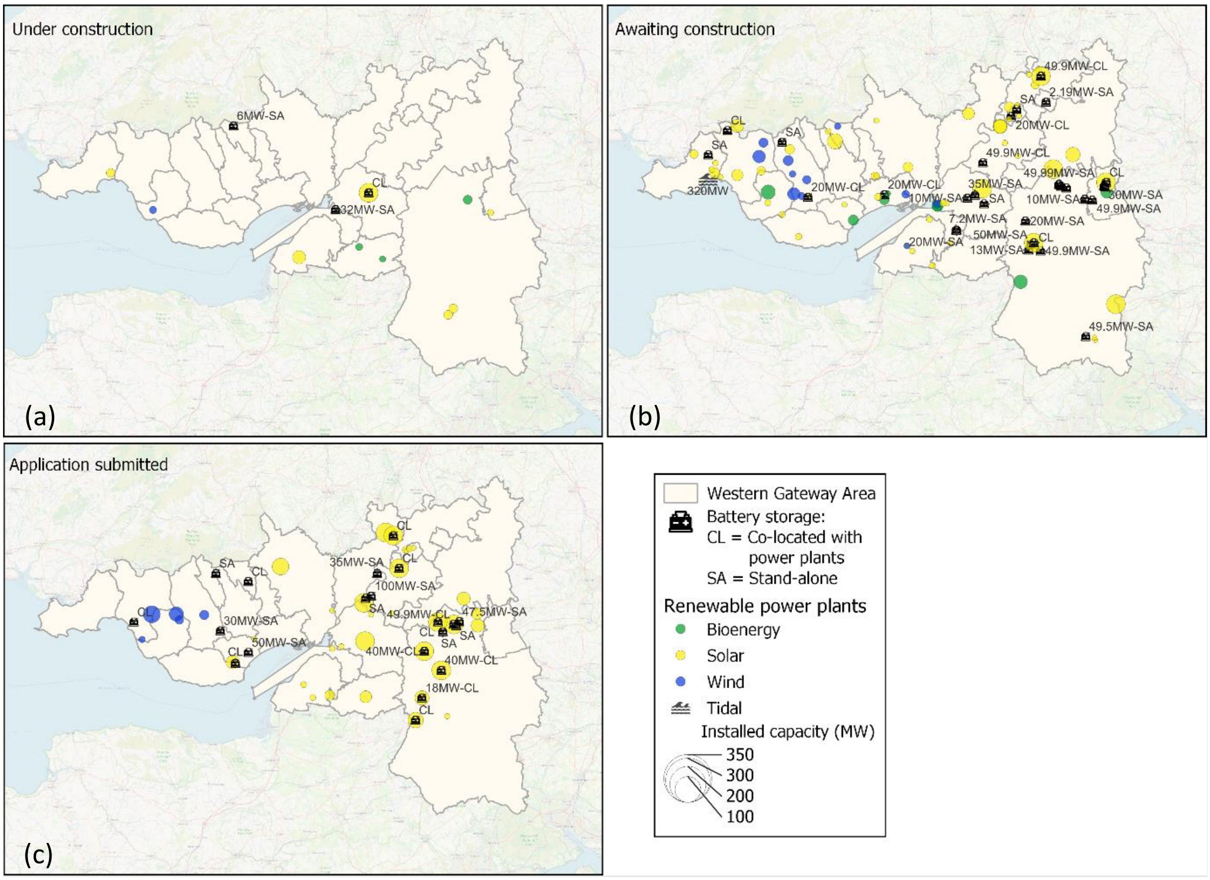


Figure 3: Renewable generation and battery storage in the Western Gateway Area by generation source, under construction and planned capacity. Data from [32].

Table 3 shows total capacity by source and development stage of renewable electricity generation and battery storage projects. Projects awaiting for construction will add 1013 MW of renewable generation, including a tidal project, plus 756 MW of battery energy storage. Finally, if all projects are built, including the ones submitted for approval, renewable capacity would nearly double current levels, reaching a total generation capacity of nearly 4.2 GW, with approximately 1.5 GW of battery storage.

Table 3: Total capacity by source and development stage of renewable electricity generation and battery storage projects. Data from [32].

Development stage	**Source**	**Capacity [MW]**	**Total UK capacity [MW]**	**Capacity of Western Gateway Area over total UK**
Under construction	Wind onshore	2.5	1255.8	0.2%
	Solar photovoltaics	87.9	514.54	17.1%
	Bioenergy	9.2	856.4	1.1%
	Total renewables	**99.6**	**2626.74**	**3.8%**
	Battery storage	38	899.4	4.2%
Awaiting construction	Wind onshore	70.7	6126.05	1.2%
	Solar photovoltaics	519.8	5323.6	9.8%
	Bioenergy	102.5	2222.71	4.6%
	Tidal	320	722.4	44.3%
	Total renewables	**1013**	**14394.8**	**7%**
	Battery storage	756.28	9274.4	8.2%
Application submitted	Wind onshore	109.6	5435.27	2%
	Solar photovoltaics	710.35	6883.9	10.3%
	Total renewables	**820**	**12319.2**	**6.7%**
	Battery storage	655.3	6579.62	10%

3.2. Fossil-fuelled power generation

Figure 4 shows installed fossil-fuelled power generation, including coal and natural gas power plants [33] and Western Power Distribution embedded capacity [34]. The coal power plant's installed capacity is 230 MW, gas installed capacity totals 2453 MW, and oil adds up to 135 MW.

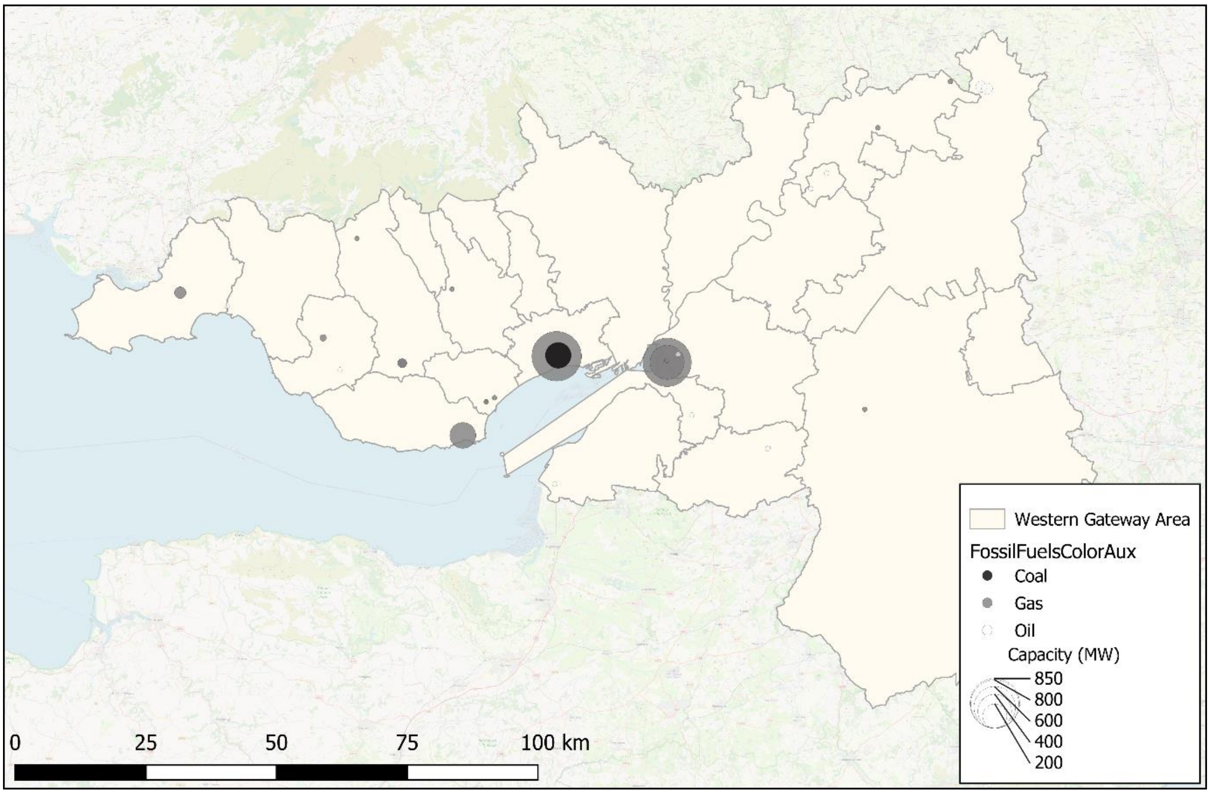


Figure 4: Fossil-fuelled power generation in the Western Gateway Area. Data from [33] and [34].

3.3. Nuclear generation

Several studies are examining different forms of nuclear generation to aid in Net Zero pathways. This includes conventional large reactors, small modular reactors (SMRs),and advanced modular reactors (AMRs), for electricity, heat, and hydrogen generation, considering deployment scenarios that range between 14 and 60 GWe by 2050 [35]. The UK is commencing a pilot programme for building a STEP fusion reactor targeted to be completed and commercially available in around 2040 [36]. The Western Gateway has led a strong 'Severn Edge' nomination combining land at Oldbury and Berkeley seeking a legacy opportunity for two de-commissioned nuclear sites. Although locations for all these reactors are yet to be defined, one major project which is currently under development is Hinkley Point C, with an expected electricity generation capacity of 3.26 GW [37]. Other possible sites include decommissioned nuclear power plants, with land at Oldbury also policy-compliant for new nuclear, albeit that at the time of publication Horizon has formally withdrawn the proposal for a new nuclear power station at Oldbury with the Planning Inspectorate. Figure 5 shows the location of both these sites, which are located within or very near to the Western Gateway Area.

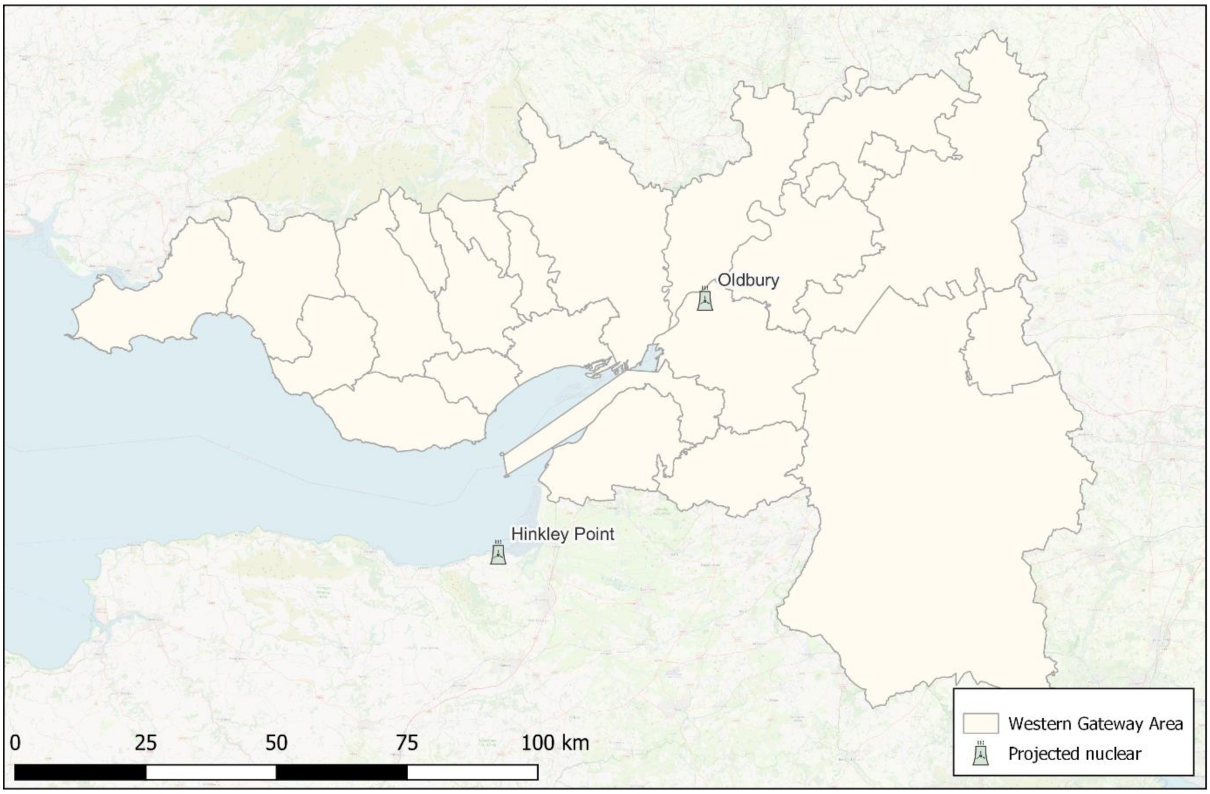


Figure 5: Possible nuclear reactor locations.

3.4. Load factors

Load factors are the ratio of how much electricity is generated as a proportion of the total generating capacity of a plant over a year. Table 4 shows load factors by source for the year 2020. UK load factors are presented when regional data was not available.

Table 4: Load factors by source, year 2020. Regional data for renewables obtained from [38]. Fossil-fuelled and nuclear data obtained from [39] (not available at regional levels).

Generation source		UK	South West England	Wales
Wind onshore			29.7%	31.6%
Solar photovoltaics			11.4%	11%
Bioenergy	**Landfill gas**		35.3%	28.4%
	Sewage gas		45.8%	44.3%
	Other bioenergy		44.6%	61.7%
Combined cycle gas turbine		35.4%		
Coal-fired stations		9.7%		
Nuclear		59.8%		

Fossil fuel plants' load factors have decreased over the last years as a result of increased installed renewable generation capacity. For example, combined cycle gas turbine stations have seen a constant decrease from 49.8% in 2016 to 35.4% in 2020. However, fossil-fuelled electricity generation is dispatchable, while wind and solar PV are not. This means that with increased renewable generation capacity, the system needs more operational flexibility to be able to balance supply and demand and provide ancillary services. Operational flexibility can be supplied by flexible generation (e.g. biomass, fossil-fuelled, biomethane, nuclear, hydro, or potentially hydrogen), storage (e.g. batteries, pumped-hydro storage, thermal storage, vehicle-to-grid), networks reinforcement or management, demand-side management, and other operation strategies. The costs of these alternatives are system-dependent [40]. This also means that for reaching net zero it is not enough to replace fossil-fuel power plants with equal renewable generation capacity, and operational flexibility must be accounted for.

4. Network and transport infrastructure

This section reviews the current network and transport infrastructure in the Western Gateway Area. It includes electricity and gas transmission and distribution lines for different voltage levels and pressure tiers, respectively, together with current transport infrastructure (roads, railways, and airports).

4.1. Electricity network infrastructure

The Western Gateway Area's has two distribution network operators (DNOs): Western Power Distribution (WPD), and Scottish and Southern Electricity Networks (SSEN). Figure 6 shows the electricity transmission infrastructure and distribution networks for both DNOs in the area.

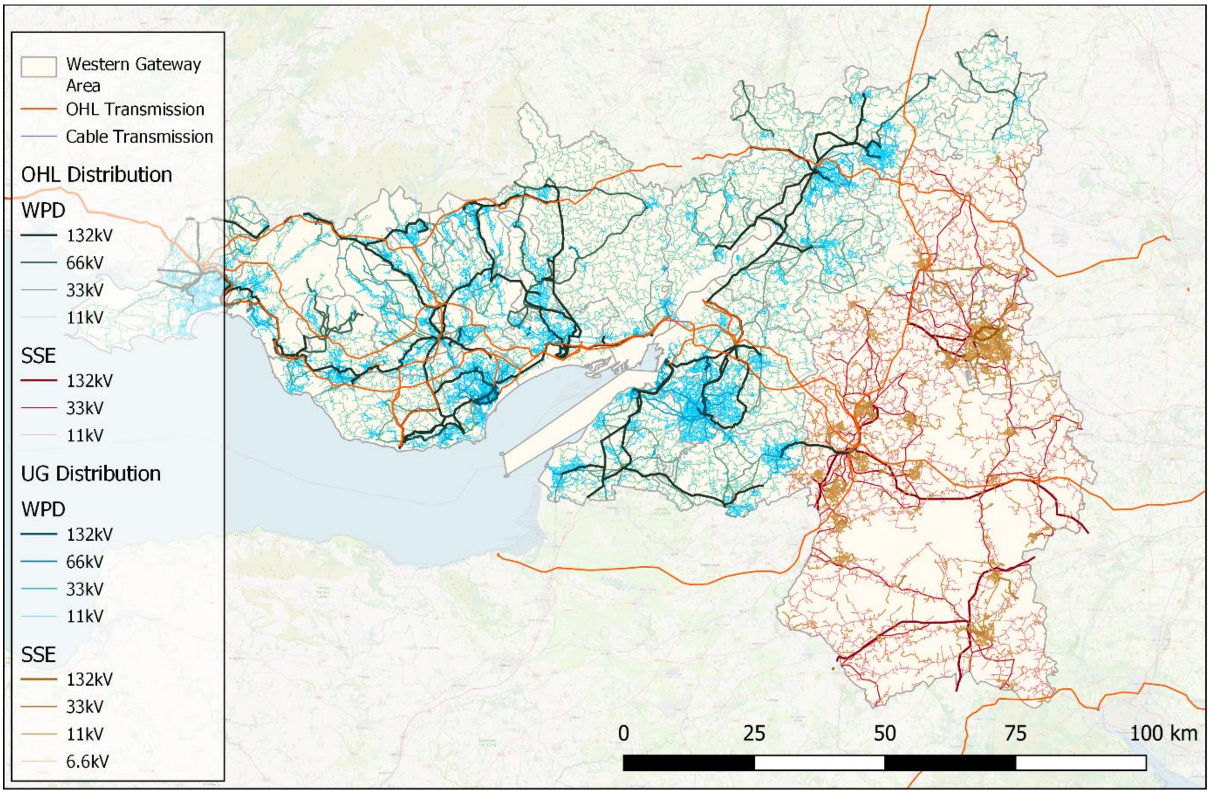


Figure 6: Electricity network infrastructure in Western Gateway Area. Data from [41-43] . OHL: Overhead lines. UG: underground.

Table 5 shows key performance metrics for areas among the Western Gateway Area within both DNOs. When available, data is compared to Ofgem's targets for each DNO's region.

The metric *Customer interruptions* (CI) is the number of customers interrupted per year, per 100 customers, over all incidents, when interruptions of supply have lasted 3 minutes or more. This excludes re-interruptions over the same incident.

The metric *Customers minutes lost* (CML) refers to the duration of supply interruptions per year. It is the average of minutes lost per customer per year, when interruptions have lasted for 3 or more minutes.

Table 5: Security and availability of supply metrics. Data available from [44, 45].

		WPD				SSE
	DNO	***WPD South West***	***WPD South Wales***	***WPD East Midlands***	***WPD West Midlands***	***SSE SEPD Southern Electric Power Distribution***
Security of supply	Customer interruptions (CI)	58.46	38.9	39.6	44.5	47
	CI Ofgem target	58.1	52.5	50.5	80.9	
	Difference	-0.6%	25.9%	21.6%	45%	
Availability of supply	Customers minutes lost (CML)	41.5	24.5	23.1	28.3	46
	CML Ofgem target	43.5	33.1	36.4	52	
	Difference	4.5%	26%	36.6%	45.7%	

Figure 7 shows Ofgem's benchmark for CMLs and CIs for all DNOs, compared to their targets and with each other, for the period 2020-21.

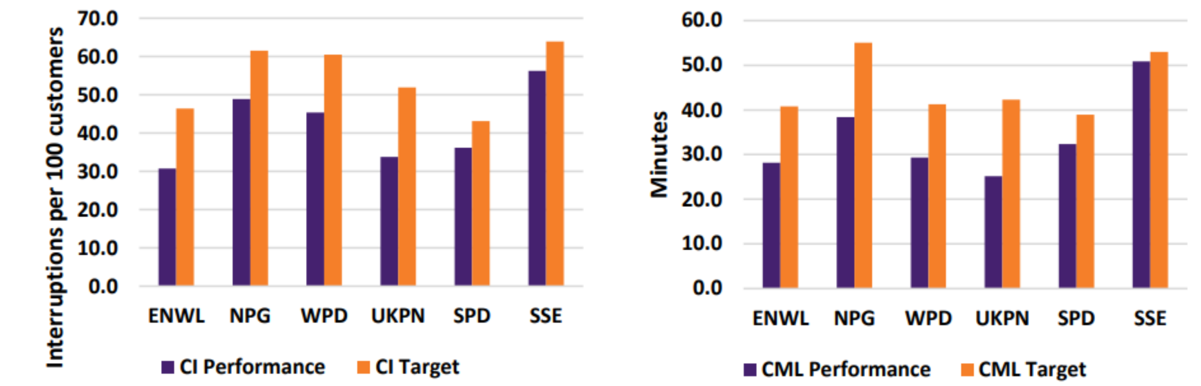


Figure 7: Annual Interruption Incentive Scheme performance by DNO group (planned and unplanned), 2020-2021. Customer Interruption (left) and Customer Minutes Lost (right). Figure from [46].

Table 5 and Figure 7 show that the performance of the DNOs involved in the Western Gateway Area (SPD and SSE) are starting from a relatively resilient base. Both have met and improved Ofgem's targets. WPD compares well against other DNOs, particularly in terms of CML. While SSE indicators in Figure 7 seem relatively high as compared to other DNOs, a closer analysis of data in Table 5 indicates that the SSE Southern Electric Power Distribution area (the one relevant to this study) performs relatively well, and better than Ofgem's targets. This means that both, generation and load customers, are experiencing middle-good range resilience/performance in the Western Gateway Area, and at this moment there seems to be no indication of an underlying resilience problem in the area.

4.2. Transmission and interconnectors

Figure 8 shows the transmission network and interconnectors around the Western Gateway Area.

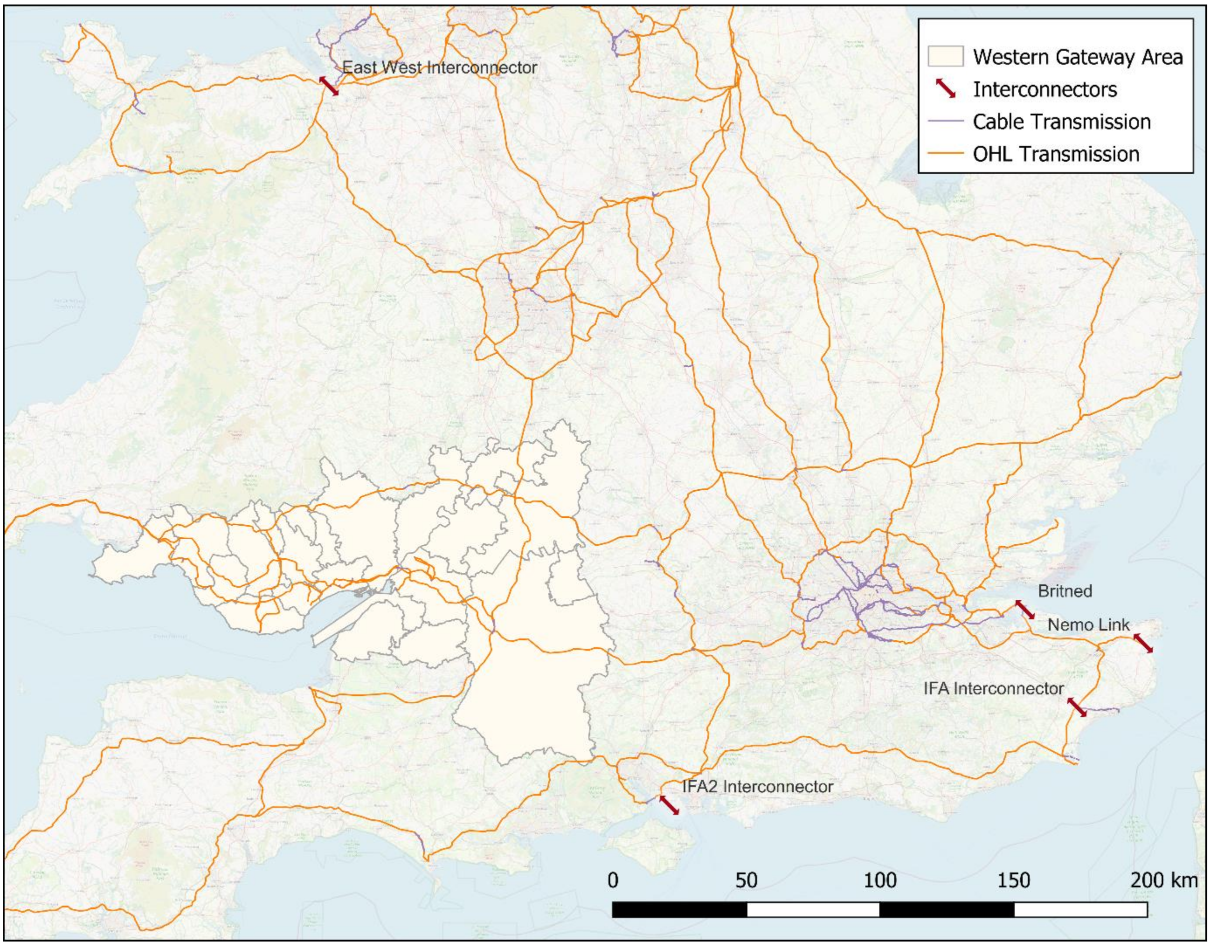


Figure 8: Interconnectors and transmission infrastructure around the Western Gateway Area. Data from [43, 47].

While there are no interconnectors within the Western Gateway Area, there are relevant interconnectors to Central Europe along the South East Coast. Table 6 shows the import and export capacities of these interconnectors. These have an important influence over power flows in the whole of the UK's south region, which imports and exports power with Europe [48]. Increased interconnection with the EU is expected to reduce emissions in Great Britain and the EU, by reducing both thermal generation and curtailment of renewable generation. A report commissioned by BEIS in 2020 concluded that with Known Policies, the percentual difference in cumulative CO2 emissions for Great Britain – in a high interconnection level with respect to a central case – ranges from -8% to -10% by 2050. For a Net Zero Policy, this difference ranges between 0.8% and -2.8% [49].

Table 6: Interconnectors' import and export capacities [47].

Project Name	Import – Current capacity [MW]	Export – Current capacity [MW]
Britned	1200	1200
East West Interconnector	505	585
IFA Interconnector	2000	2000
IFA2 Interconnector	1100	1150
Nemo Link	1020	1046

Figure 9, from National Grid's Electricity Ten Year Statement (ETYS) 2021 [48], shows expected power flow directions in South Wales and the South of England for the following years up to 2031. The arrows indicate an approximate scale of power flows in winter peaks.

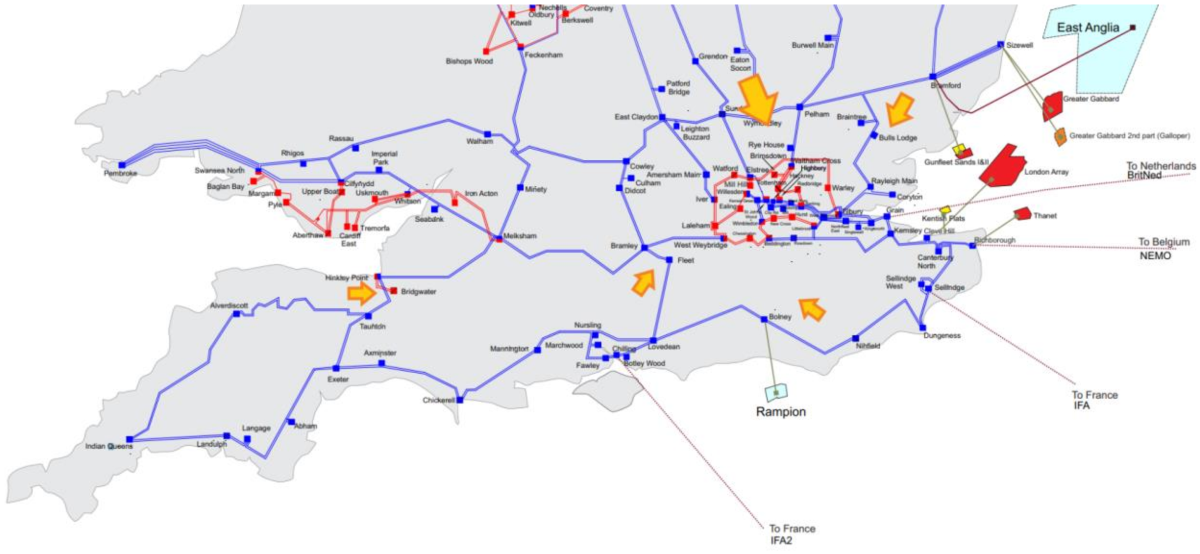


Figure 9: Likely power flow directions 2021-2031. Figure from [48].

National Grid presents its ETYS for 4 scenarios [50], namely *Leading the way*, *Consumer transformation*, *System transformatio*n, and *Steady progression*. The first 3 scenarios are expected to reach Net Zero by 2050, while Steady progression does not. The first 2 scenarios are also expected to meet the 6th carbon budget. *Leading the way* is the fastest credible decarbonisation scenario, undergoing both system and consumer transformations, expecting a significant lifestyle change in consumers, and a mixture of hydrogen and electrified heat. *Consumer transformation* is based on demand side response and changes in consumers behaviours, including energy efficiency measures and electrification of heat. *System transformation* considers consumers less willing to change their behaviour thus with lower energy efficiency, with flexibility being provided by the supply side and hydrogen being used for heating. Finally, *Steady progression* is the slowest decarbonisation pathway, without decarbonising heat (only power and transport), and with minimal consumer behavioural changes. Figure 10 shows expected generation capacity for the 4 Future Energy Scenarios for South England and South Wales.

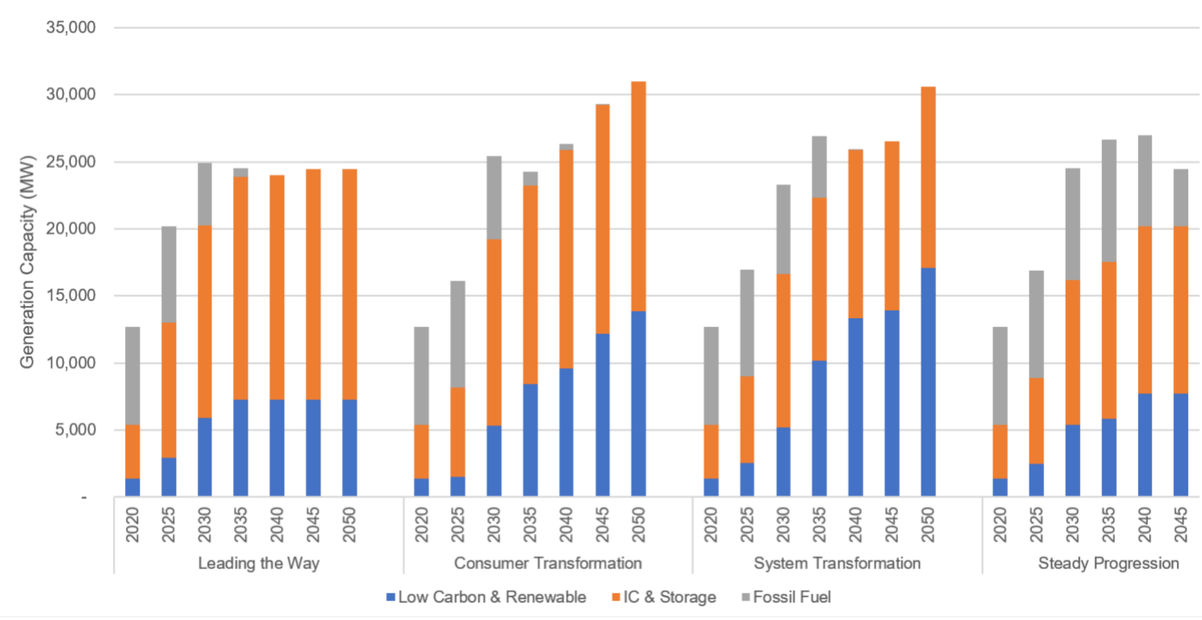


Figure 10: Generation capacity for South England and South Wales. IC: Interconnectors. Figure from [48].

Based on these scenarios and on capacity data presented in Table 2 and Table 3 (installed, under construction, awaiting construction, and application submitted), Figure 11 was elaborated. Figure 10 shows expected renewable capacity for the National Grid scenarios for the whole South England and South Wales. For the 4 National Grid scenarios, current renewable capacity was assumed as the average between 2020 and 2025. Then, the growth factor was calculated for the 4 scenarios, for 2025 and 2030. This growth factor was then used to multiply the current installed capacity in the Western Gateway Area, finding the 4 National Grid scenarios equivalent to the Western Gateway Area. The underlying assumption is that growth among South England and Wales is homogeneously distributed, so that installed renewable capacity in the Western Gateway Area will always represent the same share of the region. This is not necessarily accurate, thus Figure 11 should be considered as an approximation. Currently installed capacity, capacity under construction, awaiting for construction, and submitted for approval is illustrated in green. Comparing these capacities with the ETYS scenarios in Figure 11 for 2025, it could be concluded that if only under construction capacity is operative by 2025, then we would be in the *Consumer Transformation* scenario with regards to renewable capacity. If some of the capacity awaiting for construction is operative by 2025, then we could be on track to any of the other 3 scenarios. However, comparing with the 2030 ETYS scenarios in the figure, it could be concluded that even if all capacity awaiting for approval was built, we seem to be far from any of the ETYS scenarios. It should be considered that construction of renewable plants can take approximately 3 years [51].

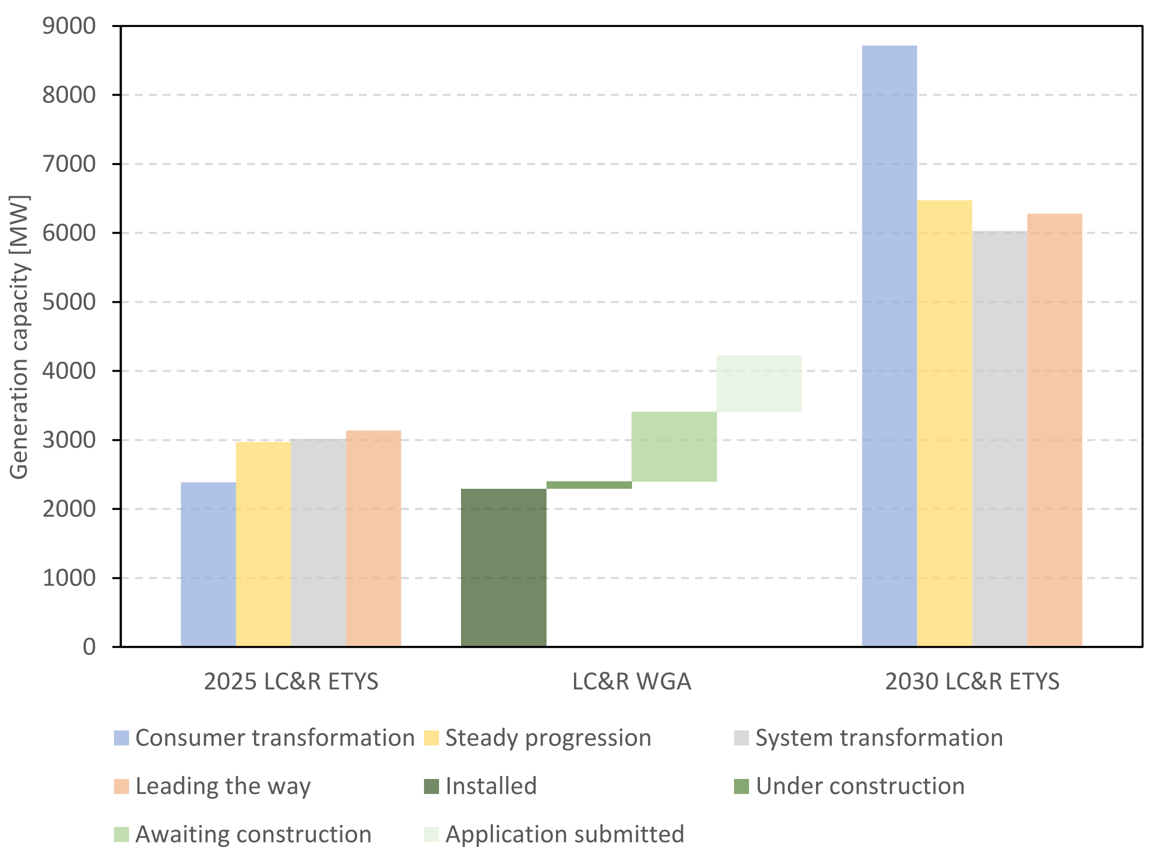
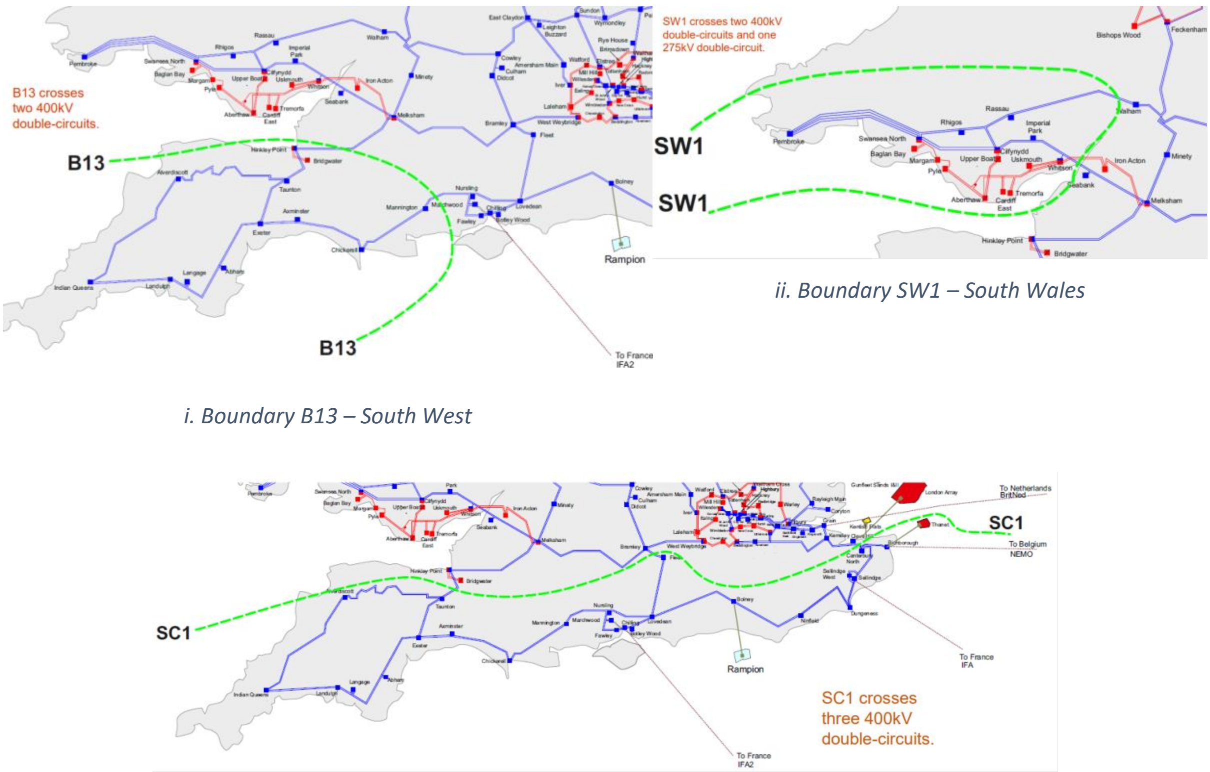


Figure 11: Scenarios for low-carbon and renewables installed generation capacity in Western Gateway Area. 2025 and 2030 LC&R ETYS scenarios are based on National Grid's scenarios [50] for South England and South Wales (Figure 10). The middle bars show the currently installed, under construction, awaiting for construction, and submitted application capacities in the area (Table 2 and Table 3). LC&R: Low carbon and renewable generation. ETYS: Electricity Ten Year Statement. GWA: Western Gateway Area.

The transmission network in the south (shown in Figure 9) has many connections around London, but towards the west the network is more radial with longer distances between substations. London is an area with high demands and power flows. Interconnectors and storage in the southern network are expected to increase, which together with increased demands could drive circuit overloads or voltage and stability issues. With additional interconnectors expected in the future, the southern region will require reinforcement to support all interconnectors importing/exporting simultaneously to avoid overloading.

Figure 12 shows the transmission boundaries which are more relevant for the Western Gateway Area. New interconnectors and generation connectors will produce larger power flows among these boundaries, in both directions. New nuclear generation at Hinkley may also require reinforcement of transmission around the area. Although Wales has seen some closures in generation units lately, which has freed up transmission capacity, the power export capacity in the area remains constrained. This means that if there is generation capacity growth in the area, transmission capacity could be limiting, requiring reinforcement [48].



i. Boundary B13 – South West

ii. Boundary SW1 – South Wales

iii. Boundary SC1 – South Coast

Figure 12: Transmission boundaries around Western Gateway Area. Figures from [48].

4.3. Gas network infrastructure

Figure 13 shows gas transmission and distribution installed pipelines. At distribution level, data was provided by Wales and West Utilities, and is shown for different pressure tiers. Wiltshire's gas distribution shapefiles were not available, as it is not covered by Wales and West, but by SGN.

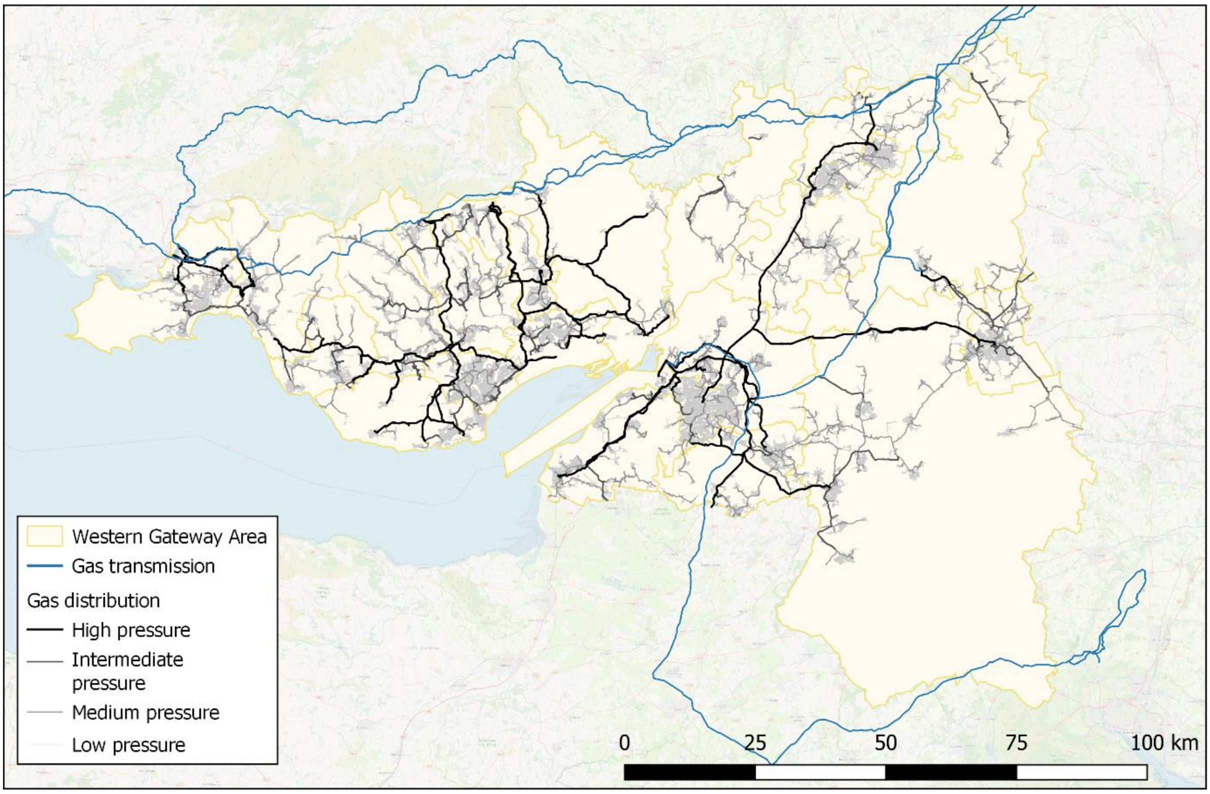


Figure 13: Gas transmission and distribution. Data provided by Wales and West Utilities and from [43].

Two alternatives are discussed in the literature for using existing gas infrastructure to distribute hydrogen to decarbonise the heating sector: blending hydrogen with natural gas, and distributing pure hydrogen. Hydrogen can be safely blended with natural gas to use the existing gas network as long as it is in small quantities. The quantity is limited by regulation and technical constraints, which depend on the characteristics of the network and on final appliances. Some research has concluded that a 20% hydrogen blend in volume is safe for most appliances and networks [52]. A UK study suggested that identifying and modifying vulnerable appliances would be required for blends over 10% volume of hydrogen. However, if actual limits were 20%, this would only equate to 7% of hydrogen in energy terms, due to hydrogen's density and heating value differences with methane [53]. This also implies that blending hydrogen with natural gas can be used as a pathway towards decarbonisation while a hydrogen infrastructure and supply chain is built, but will not achieve full decarbonisation.

A second alternative discussed in the literature is switching the gas network to transport pure hydrogen. The Iron Mains Replacement Programme, which started in 2002 and is planned to finish by 2035, seeks to replace all iron distribution pipes in the UK by polyethylene pipes, due to safety concerns [54]. While steel pipes may be unsafe to transport pure hydrogen due to possible material embrittlement, polyethylene pipes have been deemed safe to transport hydrogen at distribution pressures up to 7 bar, which includes Low pressure (LP), Medium pressure (MP), and Intermediate pressure (IP) distribution. Larger plastic pipes have also been proposed for hydrogen distribution pressures up to 17 bar [53]. This means that the mains replaced by the Iron Mains Replacement Programme are *hydrogen ready* and considered safe to distribute hydrogen, and they have long lifetimes (50-100 years) [53].

For the area covered by Wales and West Utilities, Table 7 shows the total length for each pressure tier, and the percentage of the total length which is made from polyethylene (PE), being potentially *hydrogen ready* to distribute hydrogen.

Table 7: Total length per pressure tier for Western Gateway Area served by Wales and West Utilities, and length percentage made from polyethylene (PE).

Pressure tier	Pressure range	Total length [km]	%PE length
LP	21 [mbar] - 70 [mbar]	15458	81.9
MP	270 [mbar] - 2 [bar]	2263	78.8
IP	3.5 [bar] - 7 [bar]	498	NA
HP	7 [bar] - ~70 [bar]	794	NA

In order to visualise what this means in terms of infrastructure upgrades that would be required for distributing pure hydrogen, Figure 14 shows the distribution of polyethylene/other materials distribution pipes in the City of Bristol. For a full conversion, all pipes would need to be switched to polyethylene. Additionally, new gas transmission infrastructure beyond would need to be installed.

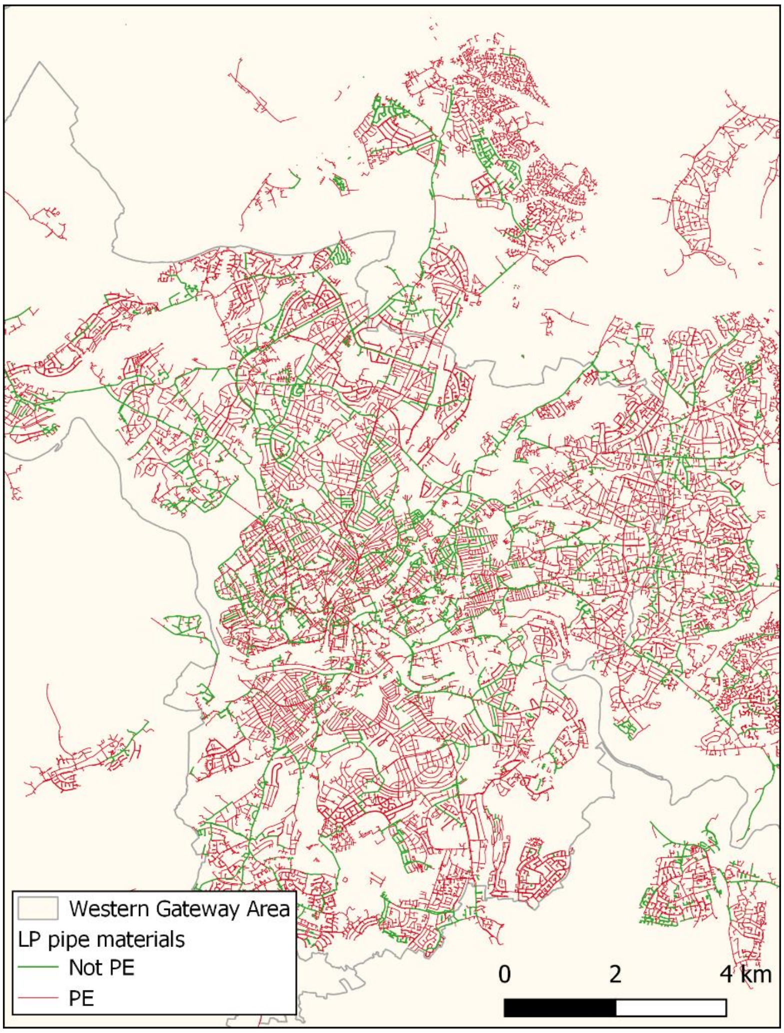


Figure 14: Share of polyethylene/non-polyethylene distribution pipe materials in the City of Bristol. Data provided by Wales and West Utilities.

4.4. Transport infrastructure: roads, railways, airports

Transport infrastructure in place in the Western Gateway Area is shown in Figure 15. As seen in the figure, two airports are located within the area – Bristol and Cardiff airports – which could represent future hydrogen demands for decarbonised aviation.

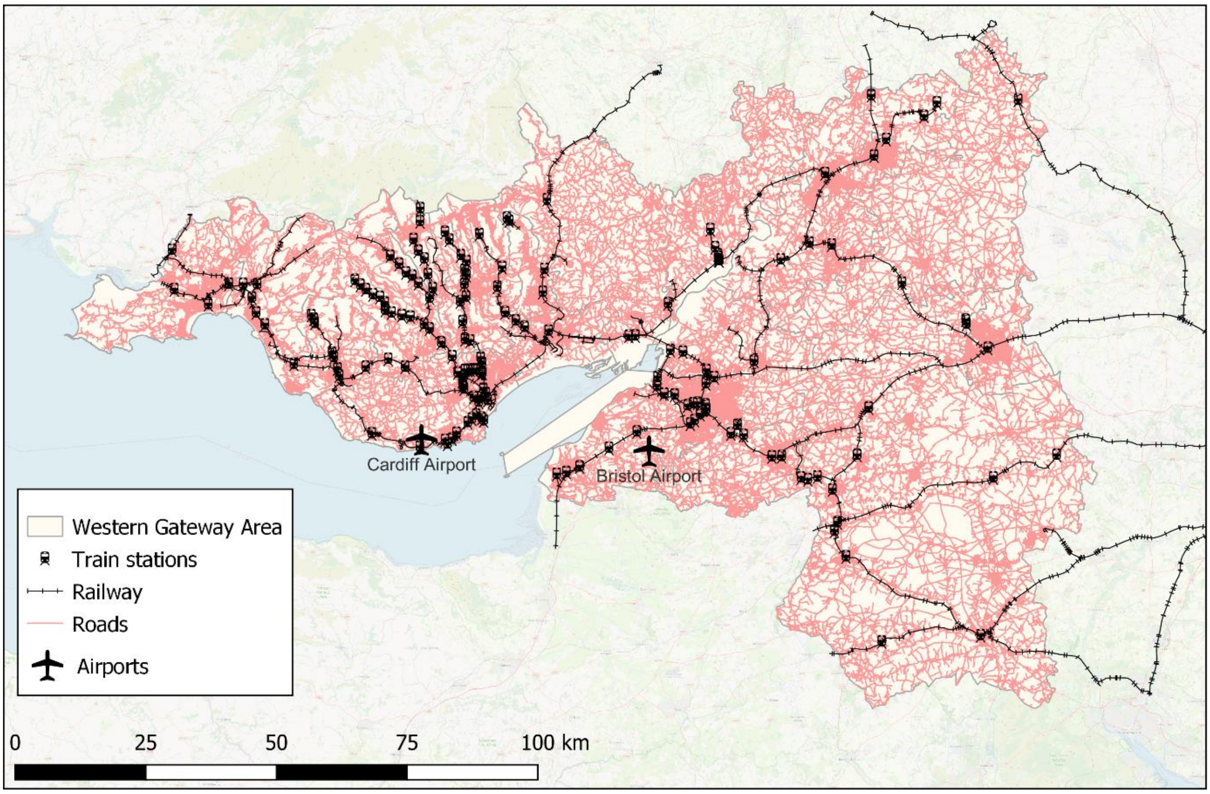


Figure 15: Transport infrastructure in Western Gateway Area. Data from [55, 56].

5. Demands

This section presents current energy demands in the Western Gateway Area. When available, demand data is provided for middle layer super output area (MSOA) [57] resolutions. Otherwise, it is shown for local authorities.

5.1. Domestic sector

Figure 16 shows domestic electricity and gas consumption per MSOA, for the year 2020.

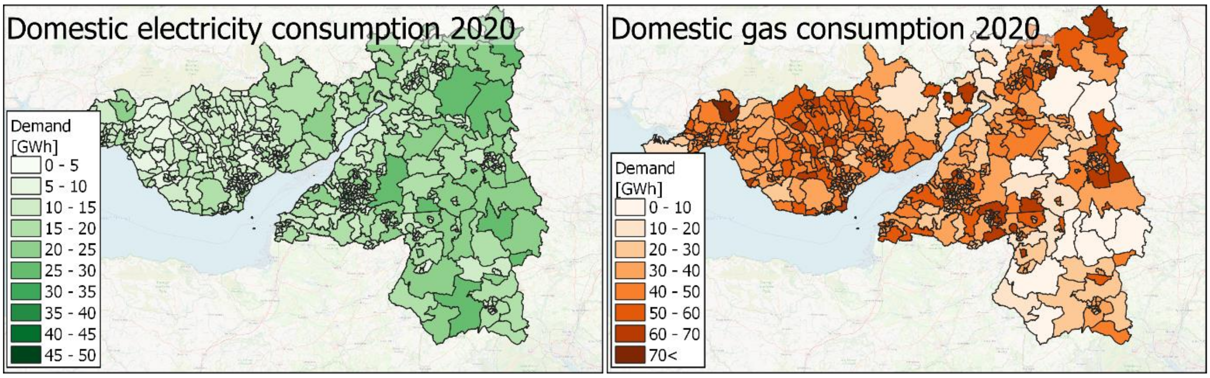


Figure 16: Domestic electricity (left [58]) and gas consumption (right [59]) per MSOA, year 2020.

Figure 17 shows the percentage of households in each MSOA by main heating source. As for the rest of the UK, the main heating source in the Western Gateway Area is gas heating, followed by oil. As seen in this figure, the percentage of houses which use electric heating is very low (7.7% of total households in the Western Gateway Area, compared to 77.9% of households that use gas). Domestic heat decarbonisation is one of the major challenges for reaching Net Zero and will be discussed later in greater detail.

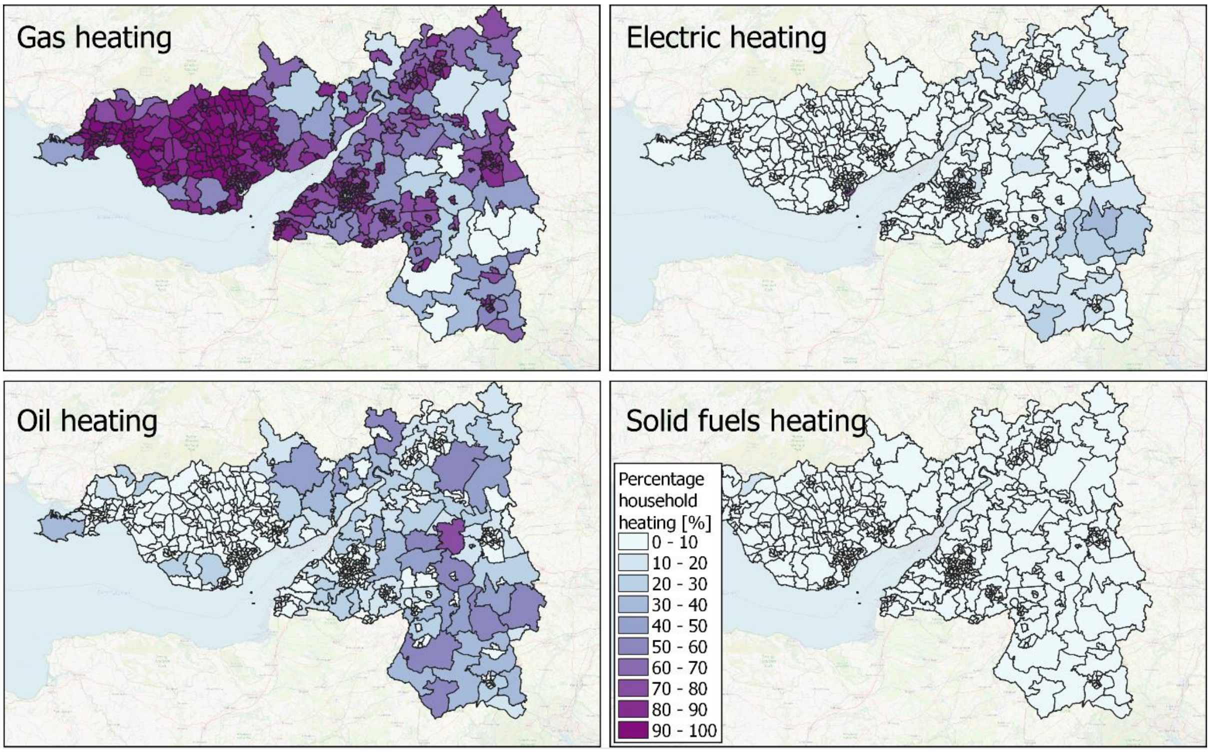


Figure 17: Percentage of households for each main heating source per MSOA. Data from 2011 Census [60].

5.2. Non-domestic sector

Figure 18 shows electricity and gas consumption in 2020 per MSOA for non-domestic sectors in the Western Gateway Area, including commercial and industrial sectors. Significant gas consumption in South Wales is driven by the cluster of industry located here.

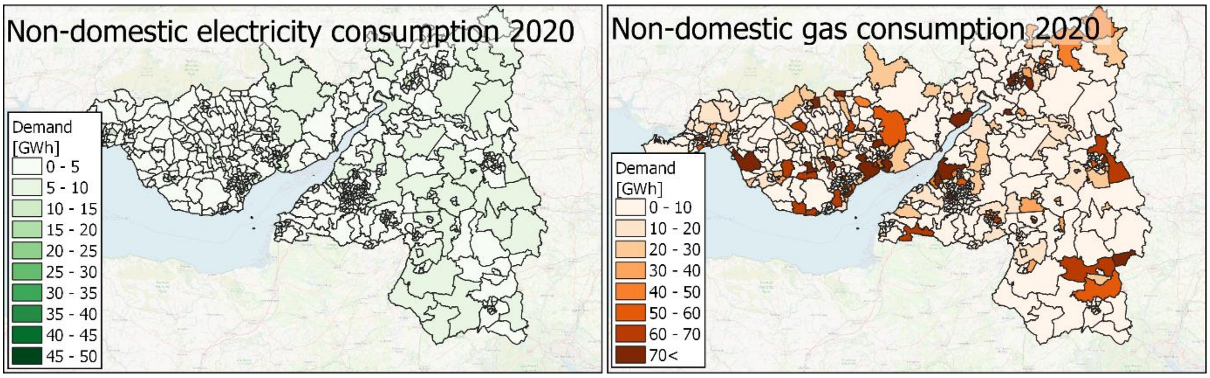


Figure 18: Non-domestic electricity (left [58]) and gas consumption (right [59]) per MSOA, year 2020.

5.3. Total electricity and gas consumption

Figure 19 shows the total electricity (left) and gas (right) consumption per MSOA in 2020, for domestic and non-domestic sectors in the Western Gateway Area. The bottom figures show electricity and gas demand densities, which correspond to total annual demand of each MSOA divided by its respective area.

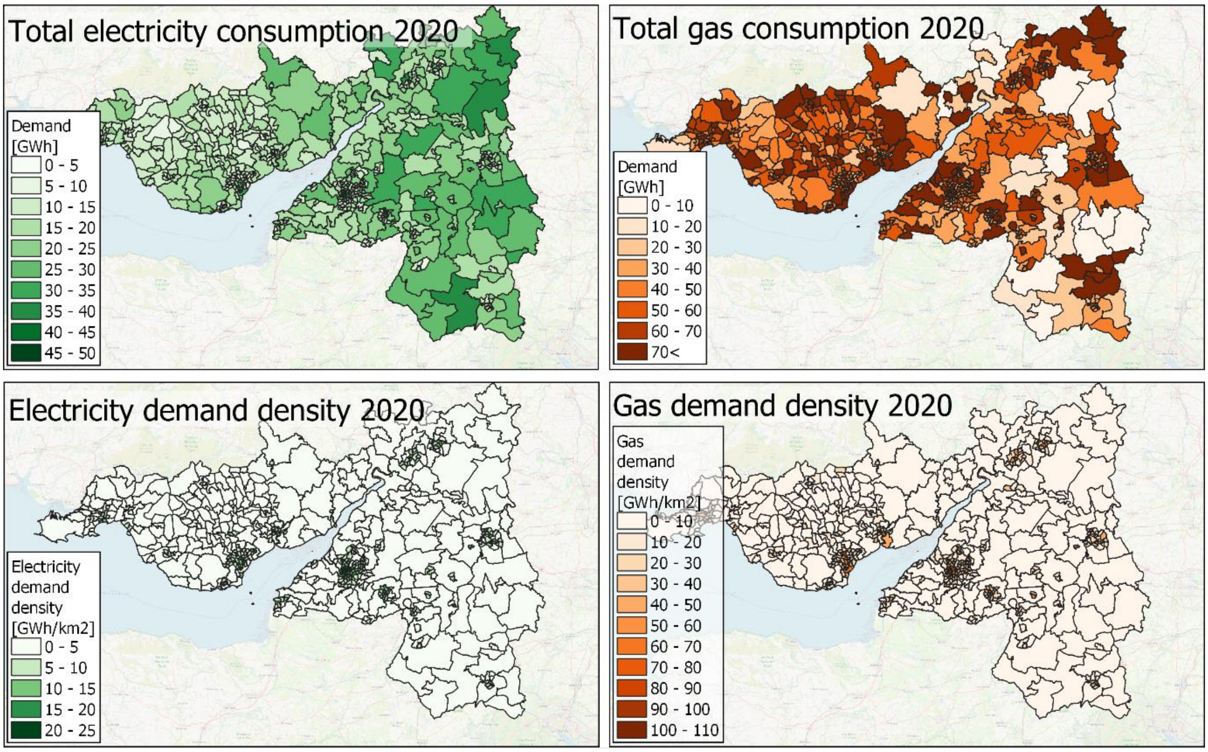


Figure 19: Total electricity consumption and electricity demand density (left [58]), and total gas consumption and gas demand density (right [59]) per MSOA, year 2020.

Domestic, non-domestic, and total electricity and gas consumption in 2020 for the entire Western Gateway Area are shown in Table 8.

Table 8: Annual domestic, non-domestic, and total electricity and gas consumption in the Western Gateway Area, year 2020. Data from [58, 59].

	Annual domestic consumption [GWh]	Annual non-domestic consumption [GWh]	Annual total consumption [GWh]
Gas	21923	10211	32135
Electricity	7365	1632	8997

As discussed later in Section 8.2, energy efficiency and housing retrofits are fundamental measures towards Net Zero [31, 61]. Insulation measures in homes are able to reduce energy consumption by around 20% [61], with consequent reductions in emissions and energy bills. For non-residential buildings, energy efficiency measures have the potential to reduce heat demands by around 25% [58]. These are low-regret measures that can speed-up decarbonisation, reduce energy costs, and reduce extra energy infrastructure capacity needs.

5.4. Road transport sector

Figure 20 shows the total petrol and diesel consumption for road transport per local authority in the Western Gateway Area, for the year 2019. Labels on the left figure represent the fraction of freight over fraction of personal transport, with respect to total energy consumption (diesel plus petrol).

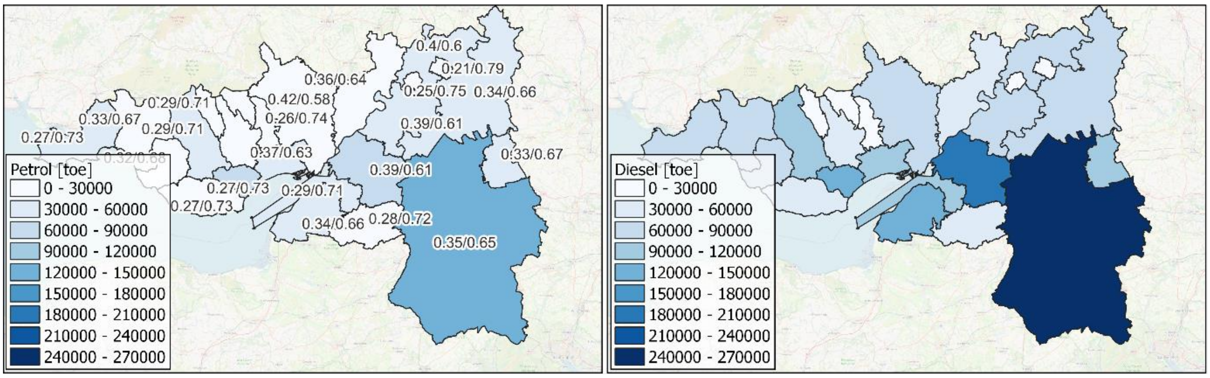


Figure 20: Road transport petrol and diesel consumption per local authority, year 2019. Data from [62].

Table 9 shows total road transport diesel and petrol consumption for the whole Western Gateway Area, for 2019.

Table 9: Total road transport petrol and diesel consumption, year 2019. Data from [62].

	Total consumption 2019 [toe]
Diesel	1931708
Petrol	905542

Table 10 shows the equivalent electricity consumption if current petrol and diesel demands were switched to electric vehicles (EV). To calculate the values in this table, thermal efficiencies for diesel and petrol internal combustion engines (ICE) were considered within the ranges of 25%-35% and 12%-30% [63], respectively. Current total consumption was multiplied by these ranges to obtain useful energy. To transform to equivalent electric vehicle consumption, the calculated useful energy was divided by 77%, the average efficiency of electric vehicles [63], and units were transformed to GWh. This yields the equivalent electricity consumption if these demands were electrified.

Table 10: Equivalent electricity consumption if internal combustion engines (ICE) were electrified. EV: electric vehicles.

	Total 2019 consumption [toe]	Lower range ICE efficiency	Upper range ICE efficiency	Equivalent EV electricity demand assuming 77% EV efficiency [GWh]		Percentage of current electricity consumption in the WGA	
				(lower ICE efficiency)	(upper ICE efficiency)	(lower ICE efficiency)	(upper ICE efficiency)
Petrol	1931708	12%	30%	3501	8753	39%	97%
Diesel	905542	25%	35%	3419	4787	38%	53%

As discussed later in Section 8.3, there is general consensus that the most cost-effective measure for decarbonising cars and light goods vehicles is switching to electricity. Decarbonisation alternatives for heavy goods vehicles remain uncertain, and include hydrogen or other low carbon fuels. It could thus be conservatively assumed that if only petrol vehicles would switch to electricity – conservatively because a fraction of light good vehicles and passenger cars currently also use diesel – this new demand for electricity would still represent an addition of between 39% to 97% over current electricity demand. This will be further discussed in Section 8.3.

Rail, aviation, and shipping are not analysed in this report.

5.5. Demand profiles

An essential factor to characterise energy demands is their seasonal and daily profiles. No specific profiles were found for the Western Area, but demand profiles for gas, electricity, and liquid transport fuels in Great Britain are presented in Figure 21. The figure shows that in winter daily demand peaks for gas can be nearly triplicated with respect to the summer. The figure also shows that the magnitude in energy units of gas peaks is around four times the magnitude of electricity peaks. Moreover, the graph shows daily demands, which means that in an hourly basis the variations are even greater. This is a crucial challenge for reaching net zero considering not only the magnitudes involved, but also that gas has the characteristic of being storable, and that its daily winter peak variation can be supplied by line pack storage (gas compressed in pipelines).

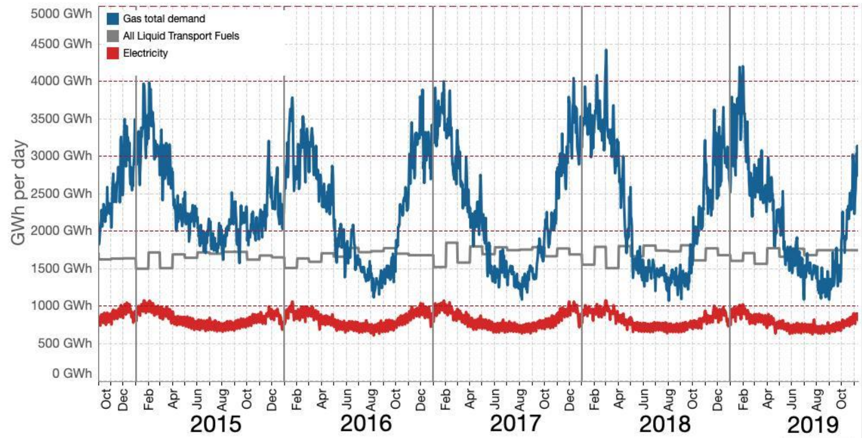


Figure 21: Seasonal demand profiles for gas, electricity, and liquid transport fuels for Great Britain. Figure from [64].

6. Socioeconomics

This section provides some basic socioeconomic indicators for the Western Gateway Area. Figure 22 shows population estimates (left) and population density (right) per MSOA for the year 2020. Estimates are provided as the last reported census results were from the 2011 Census. Population density is calculated dividing the total population per MSOA by its respective area.

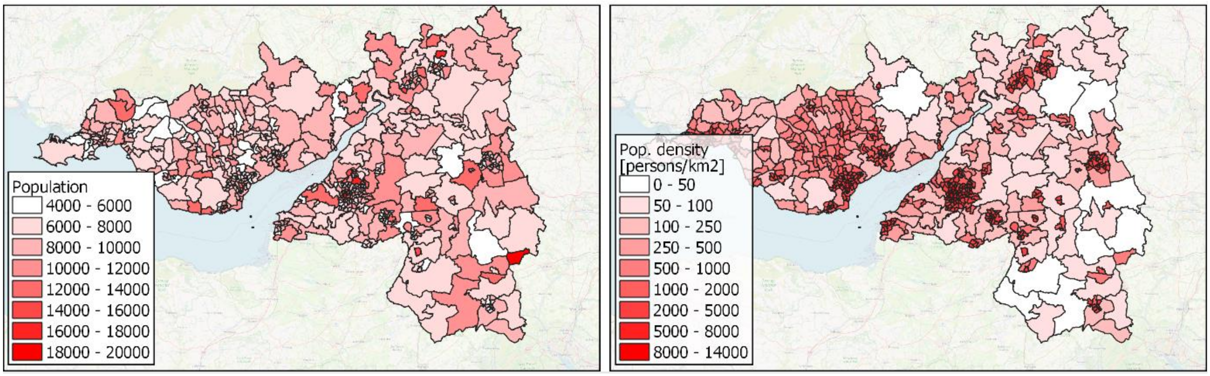


Figure 22: Population estimates per MSOA, year 2020. Data from [65].

Figure 23 shows the rural/urban classification for each MSOA, according to the 2011 Census.

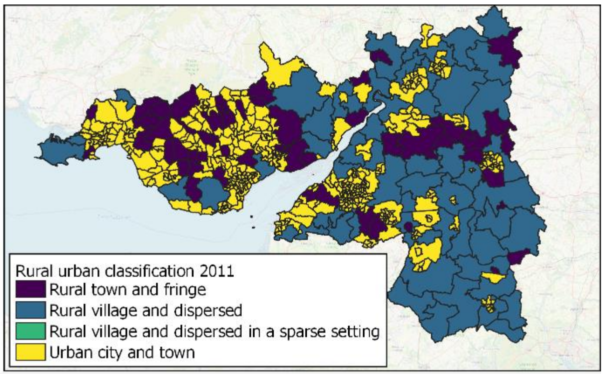


Figure 23: Rural urban classification per MSOA. Data from 2011 Census [66].

Figure 24 shows the average total household income per household for each MSOA, for the financial year ending in 2018.

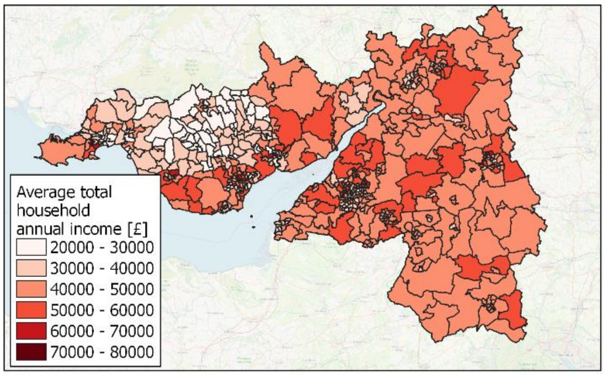


Figure 24: Average total household income per MSOA, finnancial year ending in 2018. Data from [67].

According to National Energy Action, 12% of all households in Wales in 2020 were in fuel poverty – defined as *spending more than 10% of their income on maintaining a satisfactory heating regime* [68]. The definition of fuel poverty in England is in the process of changing *to living in a home with an EPC* *of below C, whilst having a residual income below the poverty line* [68]. However, the percentage of households currently in fuel poverty was not reported. Data from Figure 24 shows that vast parts of the region are likely to be in fuel poverty with rising energy prices. This will present a challenge for these households to switch to lower-carbon heating technologies such as heat pumps, from gas or oil, for example. However, this could present an opportunity – if energy efficiency and thermal insulation measures are implemented – to both reduce carbon and decrease fuel poverty. This underpins the importance of ensuring a just transition to net zero, and not only a *cost-effective* one. It is important that households from all socioeconomic backgrounds can take part and benefit from a low-carbon transition, and policies that include financing mechanisms need to be put in place.

7. Emissions per sector

Figure 25 shows the evolution over time of total CO_2 emissions per sector, for the 24 Local Authorities in the Western Gateway Area. Non-domestic emissions correspond to the sum of commercial sector and public sector emissions. Land-use and LULUCF net emissions are excluded from this figure. For reference, for the years between 2005 and 2019, the sum of land-use and LULUCF emissions fall within the range of ±1.5% of yearly total emissions for the area.

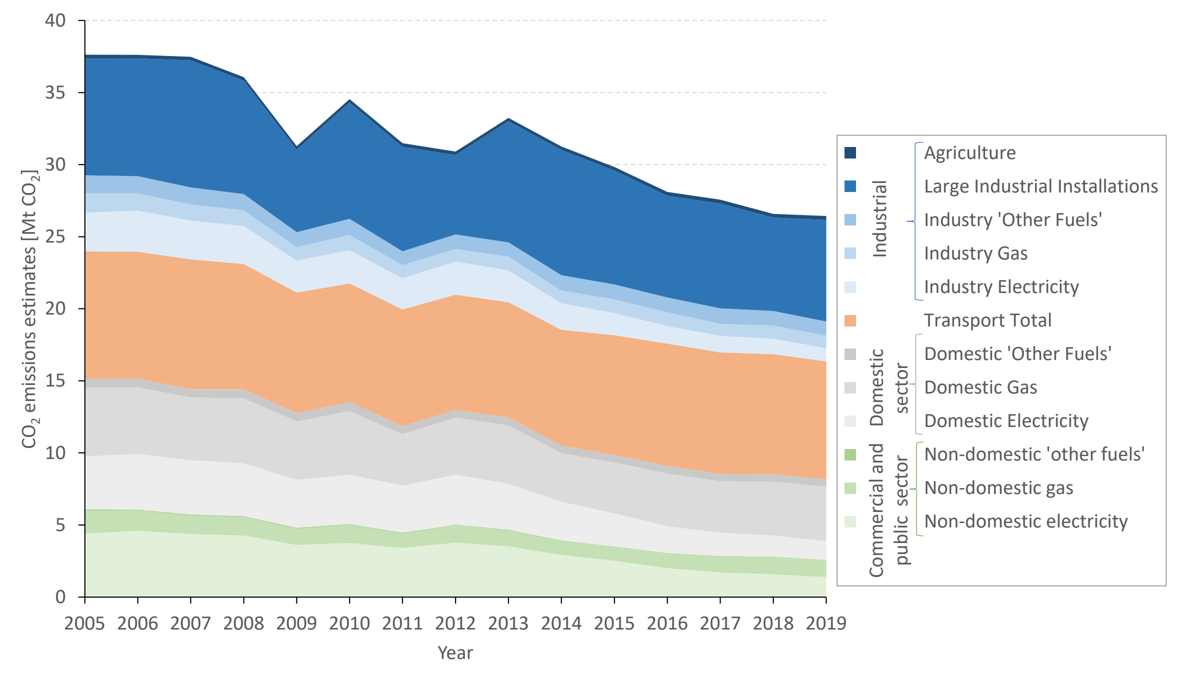


Figure 25: Western Gateway Area total CO_2 emissions. Data from [69]. Land-use and LULUCF net emissions are excluded.

The graph shows that emissions have decreased from 2005 over all sectors in the area. However, a closer analysis shows that the segments that have decarbonised are non-domestic electricity, domestic electricity, and industry electricity. Therefore, decarbonisation of the Western Gateway Area can be attributed to power sector decarbonisation, while heat and transport remain unaffected. Domestic, non-domestic, and industrial gas act as proxies for heating demands, and these remain relatively unaltered over the period. Transport emissions have also remained steady, decreasing in only around 7% in 2019 compared to 2005 levels.

8. Scenarios towards Net Zero

This section analyses two possible decarbonisation scenarios for the Western Gateway Area based on collected data presented on this report, and on information gathered from a series of available Net Zero reports for different geographies within the area. Net zero is likely to be met with a combination of changes regarding the energy system, such as electrification of heating and transport alongside a decarbonised grid based on renewables, storage, nuclear, and low-carbon fuels; hydrogen for heating and transport; demand- side and energy efficiency measures; and higher system integration, among others. We will focus our analysis in a **first scenario** based on high penetration of renewables and high levels of electrification of energy services such as heating and transport (**high renewables/high electrification**), and a **second scenario** based on high nuclear penetration and high hydrogen use (**high nuclear/high hydrogen**). Several measures, however, are common to both scenarios. The Committee on Climate Change (CCC) describes Core options as those which are common to most decarbonisation strategies, and should be considered as low-cost and low-regret alternatives [61].

8.1. Power sector

In the UK, power sector emissions have declined over the past decade as a result of coal power plants decommissioning, as shown in Figure 26. Most of the power sector's current emissions come from natural gas power stations [70], with some remaining coal that is set to decommission by the end of 2025 [61]. Renewable and nuclear generation supply over half of the UK's electricity demand. Also, at the moment the UK produces around 27 TWh of hydrogen from high-carbon sources which is used for non-energy industry.

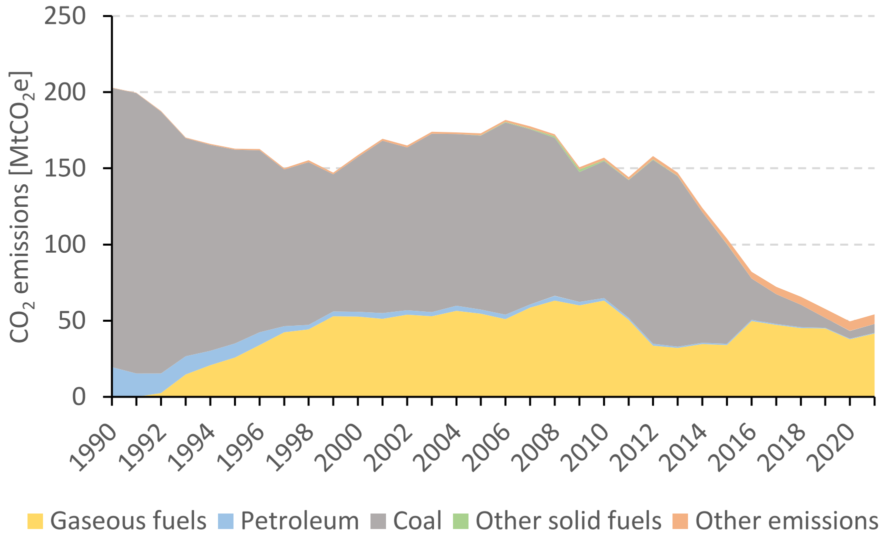


Figure 26: UK carbon emissions from power stations. Data from [71]. 2021 estimates are provisional.

Renewable power generation is currently cheaper in the UK than other sources of power generation, and is regarded as a core measure for all of the CCC scenarios [61]. The Western Gateway Area is particularly competitive in terms of solar photovoltaics within the UK [72], which is demonstrated by projects under construction or awaiting for construction adding up to 608 MW, and awaiting for construction (710 MW), as shown in Figure 3. However, increase in renewable generation such as wind and solar can cause impacts in the energy system given their variable and intermittent nature. Firstly, they may be unable to meet peak demands in periods with low outputs, requiring storage and/or backup generation capacity. Secondly, they cannot provide reserve to balance fluctuations on generation or demand. Thirdly, at certain periods generation may exceed demand, meaning that generation may need to be curtailed unless storage or transmission is available. And fourthly, renewable resources may not be co-located with demands, posing burdens over transmission and distribution networks, potentially requiring network reinforcements [61].

Low carbon firm capacity such as nuclear generation, bioenergy, and gas generation coupled with carbon capture and storage (CCS) are also considered as core measures for the whole of the UK [61]. The Western Gateway Area could benefit from the construction of Hinkley Point C (Figure 5), and by 112 MW of bioenergy generation currently under or awaiting for construction (Figure 3). Hinkley Point C, however, will be transmission-connected, so its benefit will not necessarily be regional. It is likely that gas power stations will continue to be used for peak demands and reserve, which is why there will be a need for negative emissions through bioenergy with CCS (BECCS), to abate natural gas remaining emissions [61].

The **high renewables/high electrification scenario** would require additional storage to be able to provide firm capacity and meet winter peaks. In a high electrification scenario heat pumps and electric vehicles would displace gas boilers and petrol/diesel vehicles respectively, increasing electricity demands and electricity peaks. This means that renewable power generation and storage would need to increase accordingly. Considering renewable and storage plants permission approval times and construction times, it is unlikely that 2030 Net Zero goals can be reached in this scenario, and a 2050 plan should be sought.

A **high nuclear/high hydrogen scenario** could see the construction of a fusion prototype reactor and/or might include emerging Small Modular Reactor or Advanced Modular Reactor technologies at Oldbury, alongside hydrogen production. New nuclear also remains a possibility. In terms of hydrogen, nuclear generation can either be used to power electrolysers for hydrogen production, or waste heat could be used for reforming methane to produce hydrogen, requiring CCS for it to be low-carbon. Although hydrogen and nuclear have higher investment costs than renewables, according to the CCC this is outweighed by flexibility requirements to support a highly renewable power system [61]. Hydrogen requires a development and demonstration programme for production, distribution, storage, and end-use previous to its deployment, which is unlikely to be built on time to reach Net Zero goals by 2030. Nuclear power plants also involve long planning and construction times, which means that a nuclear-hydrogen mix for this scenario could be more feasible by 2050.

8.2. Buildings

Heat decarbonisation in buildings is a major challenge for reaching Net Zero by 2050 [61]. As shown in Figure 25, domestic and non-domestic gas emissions in the Western Gateway Area have remained practically constant over the past nearly 20 years, and this is true for the rest of the UK as well. As shown in Figure 17, most households in the Western Gateway Area use natural gas boilers for supplying heating demands, while a considerable percentage also use oil for heating.

There is general consensus that energy efficiency and housing retrofits are fundamental measures towards Net Zero [31, 61]. New residential buildings are easier and less costly to decarbonise if thermally insulated during construction, and if low-carbon heating technologies are installed upfront. The Future Homes Standard announced in 2019 should ensure that new buildings comply with both measures by 2025. Other “easier to decarbonise” buildings are those not connected to the gas grid, buildings that are suitable to connect to heat networks, and buildings connected to the gas grid but without space nor heritage constraints [61]. The latter could benefit from hybrid heat pumps, which could still consume natural gas for supplying peak demands. It is also widely suggested that the residential sector undergoes a major retrofit programme, to both insulate housing stock and to change fossil fuel heating technologies for low carbon ones. Insulation measures should be implemented under all scenarios [31, 61] as they can diminish energy consumption by around 20% in homes [61], with consequent emissions and energy bills reductions. The South Wales Zero 2050 report [31] also recommends developing a robust supply chain for heat pumps to enable a faster uptake in domestic buildings.

The **high renewables/high electrification scenario** involves a high electrification of heat via heat pumps – air-source and ground-source. Additionally, this scenario could also include heat networks in urban more dense areas, supplied by heat pumps and low carbon options. The South Wales Zero 2050 project proposed an electrification scenario where 80% of dwellings in high heat density areas are connected to district heating. The remaining 20%, plus dwellings located in low heat density areas, are supplied by air-source or ground-source heat pumps [73]. A high electrification scenario would increase peak electricity demands, requiring in turn increased power generation capacity – as previously discussed – and would impact the electricity networks. An important indicator to assess this is the 1-in-20 peak demand, which is the peak energy demand that statistically could happen every 20 years. For the 3 South Wales cities studied in [73], a high electrification scenario reaches a 1-in-20 peak electricity of around 2.2 times 2018 levels in 2050.

The **high nuclear/high hydrogen scenario** involves heating in dwellings being supplied by hydrogen boilers, which in turn are connected to a repurposed gas network. The South Wales Zero 2050 project proposed a hydrogen scenario with these characteristics, where all dwellings connected to the gas network in 2050 are heated by hydrogen boilers, and new dwellings are heated by air-source or ground-source heat pumps [73]. A high hydrogen scenario would require investments in hydrogen generation capacity, CCS, storage, transmission, and distribution, along with deployment of hydrogen boilers at end-use. In terms of its impacts in 1-in-20 peak electricity, modelling for the same 3 South Wales cities presented in [73] suggests this could half by 2050 compared to 2018 levels under this scenario (excluding transport electrification). This scenario sees a new demand for hydrogen whose 1-in-20 peak is estimated at around 6 times the current electricity peak by 2050 [73].

Heat decarbonisation for non-residential buildings requires analogous measures as the residential sector. Energy efficiency measures have the potential to reduce heat demands by around 25% [61]. Heat supply technologies would be the same as for residential sectors for each scenario, depending on heat density, connectivity to gas networks, and construction years [61].

Regulation for energy efficiency in buildings is expected to be in place by 2025. While this will affect all newbuilds, a plan for retrofitting existing buildings will need to be deployed thereafter. Also, a conversion plan to low-carbon technologies for decarbonising heat in buildings, including financing mechanisms and network upgrades, will be required. The scale of the challenge make it very unlikely to meet Net Zero by 2030, and will still require systematic planning for successful decarbonisation by 2050.

8.3. Road transport

Cars, vans, and heavy good vehicles (HGVs) are the highest contributors to surface transport greenhouse gas emissions in the UK. There is a general consensus that the most cost-effective measure for decarbonising cars and light goods vehicles is switching to electricity, and that battery electric vehicles will represent 100% of new sales among these vehicles by 2040 [61]. Although hydrogen fuel cell electric vehicles are also an alternative for decarbonising these types of vehicles, battery electric vehicles are firstly cheaper, and secondly they benefit from being able to charge anywhere where there is an electricity grid. Conversely, hydrogen refuelling infrastructure is not extensively available. For example, in Wales there are only 2 hydrogen refuelling stations [74]. An important advantage of switching to either, battery electric vehicles or hydrogen fuel cell electric vehicles, are their higher efficiencies compared to internal combustion engines. A study in South Wales estimated that despite the demand increase in vehicle miles, annual energy consumption for cars in this area will approximately half by 2050 compared to 2018, and will reduce in approximately 23% for HGVs [74].

Decarbonisation alternatives for HGVs remain uncertain. Loads and distances travelled by HGVs make them more difficult to decarbonise. In a **high electrification scenario** with electric HGVs, battery volumes would need to be very large, and extremely-fast-charging stations would need to be deployed country-wide. However, battery energy densities are expected to improve by 2030, when their volume could be equivalent to that required to store hydrogen in a hydrogen fuel cell electric vehicle. A fast-charging network would imply the need for power network upgrades. This includes uncertainties around the need for upgrading substations, and on planning permissions times and possible delays [61, 74].

A **high hydrogen scenario** with HGVs using hydrogen fuel cell electric vehicles has the advantage of faster refuelling times (comparable to diesel). Barriers for deploying hydrogen fuel cell electric vehicles include high capital costs of installing refuelling stations infrastructure, the very high hydrogen purity required by vehicle fuel cells – 99.99%, which makes the production and supply chain more expensive than for hydrogen combustion in boilers, for example – and the fact that there are less vehicle options available in the market than for electric vehicles, as most HGVs are in early trial or prototype stages [61, 74].

Rail, aviation, and shipping are not analysed in this report.

8.4. Networks

Networks at all levels are expected to be highly impacted by decarbonisation towards Net Zero. This includes electricity, gas, heat, and possibly hydrogen networks, at both transmission and distribution levels. Apart from expected growths in demands, the integration of more variable renewable generation, electrification of heat and transport, and the production of hydrogen, will all impact current capacities as well as how the energy system is operated.

A report conducted by Vivid Economics and Imperial College London for the CCC [75] analysed the energy system implications of heat and transport electrification supplied by renewables for the UK, with a focus on energy networks. They concluded that given the flexibility of hybrid heat pumps and electric vehicles, they can be accommodated in the system at a relatively low cost up to 2035. Given their flexibility – supported by hot water storage and possible load shifting for the former, and by batteries for the latter – they are unlikely to increase electricity costs, and these could actually decrease if demands are met by renewables. The work also concluded that if hybrid heat pumps are used efficiently, they can deliver similar carbon savings with lower electricity costs than electric heat pumps. Electric vehicles can also be accommodated in the system to 2035 at low cost if smart charging is implemented in non-peak demand periods. In terms of generation capacity, renewable generation should increase significantly if heat pumps and electric vehicles are introduced at the rates required to meet net zero by 2050.

In terms of networks, in order to meet net zero goals by 2050, the required rapid uptake of heat pumps and electric vehicles will impact distribution networks, increasing maintenance and reinforcement costs by approximately 40% by 2035. However, distribution represents less than 10% of the electricity system costs. A primary consideration is that network reinforcements are costly and disruptive. Therefore, network upgrades taking place over the 2020s should be oversized to be able to meet future electricity demands beyond 2035. Since cable capacity only accounts for 8-10% of total upgrade costs, oversizing network infrastructure is relatively low-cost and should be regarded as a low-regret measure which could produce immense savings in future networks reinforcement [61, 75].

Transmission networks will also be affected by increased renewable and variable generation capacity, additional electricity demand, and increased interconnections to other countries. Transmission investments costs are largely sensitive to the location of new generation assets. The Western Gateway Area has high renewable potentials and expected nuclear power (with the deployment of Hinkley Point C), which could enable the area to be a net exporter to other parts of the country, particularly to the Greater London area. However, according to conversations with expert practitioners in the Western Gateway Area, transmission capacities could pose a barrier for this. In Wales, National Grid extends in the North, and in the South, but there is a weakness along the central area where wind resources are located. Transmission lines from South Wales to the east pass under the Severn estuary, implying that investments for reinforcing this line are high. On the other hand, exploiting solar resources in the South West of England will also require transmission reinforcement, or ultimately a new radial line running from west to east. Planning permissions for large distribution lines can take 5-6 years, while planning permissions for new transmission lines can take 10 years or more. This, added onto construction times, collides with Local Authorities' plans to reach Net Zero by 2030. Further challenges are related to seasonal demand variations and climate change effects. Uptakes in electric vehicles could pose extra burdens in the South West of England over summer holidays season, creating new peaks and possibly line congestions due to augmented demands and temperature loads.

8.5. Socioeconomics

As seen in Section 6, available data shows that vast parts of the region are likely to be in fuel poverty with rising energy prices. This will present a challenge for these households to switch to lower-carbon heating technologies such as heat pumps, from gas or oil, for example. Energy efficiency and thermal insulation measures present an opportunity to both reduce carbon emissions and decrease fuel poverty. However, insulation measures in dwellings are expensive and dependent of the type and year of construction. For example, according to the Energy Savings Trust, loft insulation in England, Wales, and Scotland can cost between £500-£700; cavity wall insulation can cost between £410 and £2500 depending on the type of house; and solid wall insulation can cost between £10000 and £14000 depending if it is internal or external. An average retrofit cost for double-glazed windows in a semi-detached house is around £7500. This highlights the importance of ensuring a just transition to net zero, and underpins the need for support for low-income houses to be able to adopt these measures. The same applies for technology switching.

9. Conclusion/key messages

This report has looked at the main features that constitute the Western Gateway Area energy system, from energy generation, infrastructure and demand and their possible synergies, leading to some of the area's possible transition pathways towards Net Zero. This section summarises the main findings of this study. Firstly, in terms of power generation, variable renewables (solar PV and wind) are currently the lowest cost power generation technologies and are expected to dominate the power generation mix. Hinkley Point C and/or small modular reactors in the area can provide baseload. They can also be used to produce low carbon hydrogen via electrolysis, or via steam methane reforming coupled to CCS. High penetration of variable renewables also imply the need for storage to account for variations in demand and supply, and in many cases the need for network reinforcement, as energy service demands such as heating and transport are expected to electrify. Figure 27 summarises current generation capacities by source, capacities under construction, awaiting for construction, and those that have submitted their planning applications.

Western Power Distribution's investment plan submitted to Ofgem for RIIO-ED2 [76] – the period that runs from 1st April 2023 to 31st March 2028 – details a total investment for the whole area of approximately £6.679bn. Of this, investments for South Wales licence area correspond to £1.116, and £1.737bn to the South West, adding up to £2.853bn. It should be noted that the South West licence area includes Local Authorities outside the Western Gateway Area, and that the Western Gateway Area includes a fraction of SSE's licence area. However, these numbers can be taken as a reference of the investments required by Western Power Distribution over the next 5 years to be **on the road towards Net Zero by 2050** in the Western Gateway Area. Much higher investments are required to reach Net Zero by 2050, and this represents only investments in electricity distribution networks. This evidences that goals to reach Net Zero by 2030 are not only technically unlikely, but also economically.

In terms of generation, both scenarios analysed in this report present advantages and disadvantages. A **high nuclear/high hydrogen** scenario is advantageous in terms of the high capacities and grid stability that can be achieved by nuclear power plants, but has the disadvantages of being costlier than renewables and presenting long construction times. The global median for construction times of nuclear reactors connecting to the grid in 2020 was 84 months, and has fluctuated between 58 and 120 months over the last 20 years [77]. Conversely, a **high renewables/high electrification** scenario is quicker to construct, but presents balancing issues, requiring storage, demand-side response, and network management.

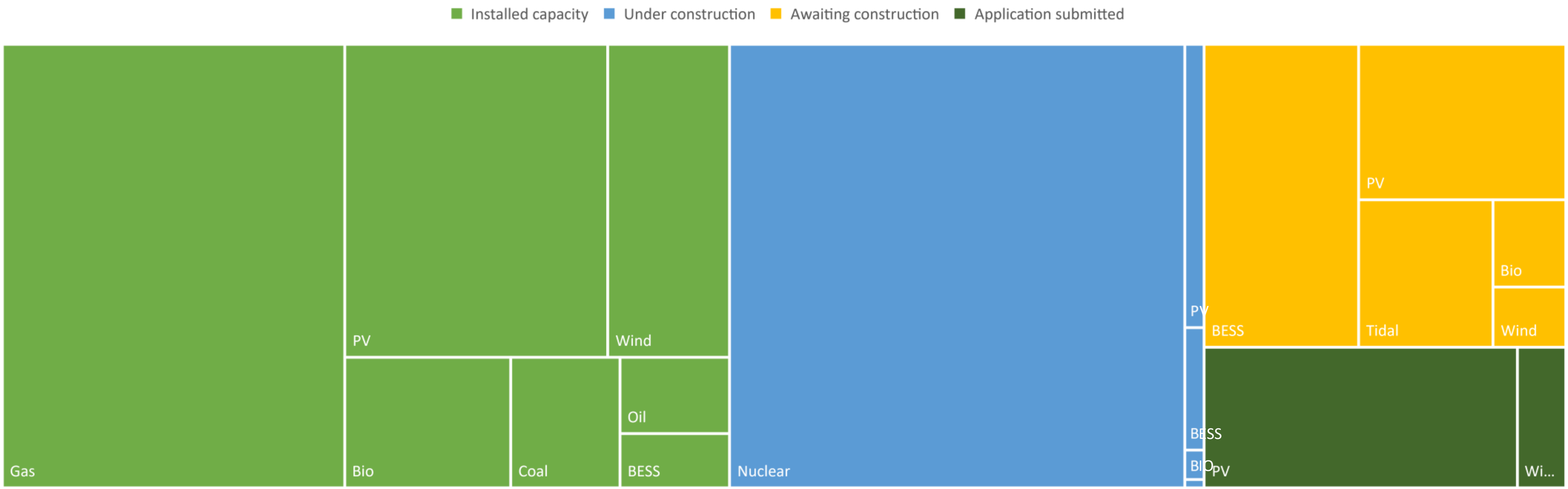


Figure 27: Western Gateway Area power generation and battery energy storage installed capacity, under construction, awaiting for construction, and planning applications submitted. Total chart area is 11.2 [GW].

Low-regret measures that are recommended independent of the scenario include thermal insulation and energy efficiency measures in buildings, as these can reduce energy demands by 20-25%, and therefore reduce emissions and energy bills. Local authorities should ensure retrofit plans for existing buildings, and financial support for low-income dwellings.

The provision of energy service demands can vary depending on the scenarios. In a high electrification scenario, air-source, ground-source, and hybrid heat pumps are expected to supply heat demands in buildings. This can be as individual units in rural, less dense, and not spatially-constrained buildings, or as heat supply for district heating networks, in more dense and urban areas. In a high hydrogen scenario, hydrogen boilers can be used for supplying building heat demands. In this scenario, low pressure polyethylene gas distribution networks can be used for hydrogen distribution. In this scenario non-polyethylene distribution networks would need to be replaced, as well as gas transmission networks. As for the case of energy efficiency measures, technology switching is expensive, and low-income dwellings are likely unable to afford it, requiring financial support.

For both scenarios, cars and light goods vehicles are all expected to electrify, with no non-electric vehicles being sold after 2040. Decarbonisation pathways for heavy good vehicles are still uncertain. In a **high renewables/high electrification** scenario, super-fast charging infrastructure will be required along roads, with possible substation upgrades and network reinforcement. A **high nuclear/high hydrogen** scenario will require high purity hydrogen supply chains and refuelling infrastructure. Both alternatives require high investments and involve long permission and planning times.

Both transport and heat electrification will require reinforcement in distribution networks. Because investments in network reinforcements are costly and disruptive, network upgrades taking place over the 2020s should be oversized to be able to meet future electricity demands beyond 2035. Transport and heat electrification, increased variable renewable generation, and demand profile shifts will possibly require transmission reinforcements in the Western Gateway Area. Because the area presents a high potential for renewable generation with relatively low demands, as well as projected nuclear generation, it could be a net electricity exporter either to the rest of the UK, or internationally. In any of these cases, congested radial transmission lines running west to east would require reinforcement, as well as interconnecting infrastructure, which comes at high investment costs.

Finally, trends in emissions in buildings and transport sector show that most decarbonisation over the past decade has been achieved in the power sector. Given planning and construction times, it is highly unlikely to reach Net Zero by 2030. Efforts should be placed now in designing a detailed decarbonisation plan towards 2050, with concrete measures, timelines, investments, and regulations. Since Local Authorities are all interconnected through various networks, the Western Gateway Area could benefit from a detailed system study that characterises demands, networks, and energy supply alternatives – both spatially and temporally – and understand the synergies within the area for different scenarios. This could aid in developing robust transition pathways, with precise investment and policy measures (when, where, and what?) to reach Net Zero by 2050.

10. References

[1] UK Government, *Climate change Act 2008*. 2008.

[2] Department for Business, Energy & Industrial Strategy,. *Guidance - Carbon Budgets*. 2021; Available from: https://www.gov.uk/guidance/carbon-budgets].

[3] Western Gateway. *About the Western Gateway*. 2022 [cited 2022; Available from: https://western-gateway.co.uk/about-western-gateway].

[4] Bath & North East Somerset Council. *Responding to the Climate Emergency*. 2022 [cited 2022; Available from: https://beta.bathnes.gov.uk/responding-climate-emergency-0].

[5] Blaenau Gwent County Borough Council, *Decarbonisation Plan 2020 to 2030*. 2020.

[6] Bridgend County Borough Council. *Council launches consultation as part of Net Zero 2030 target*. 2022 [cited 2022; Available from: https://www.bridgend.gov.uk/news/council-launches-consultation-as-part-of-net-zero-2030-target/].

[7] Caerphilly County Borough Council. *Decarbonisation Strategy: Reduce, Produce, Offset, Buy*. 2022 [cited 2022; Available from: https://www.caerphilly.gov.uk/My-Council/Strategies,-plans-and-policies/Corporate-strategies,-plans-and-policies/Decarbonisation-Strategy].

[8] Cardiff Council, *One Planet Cardiff - Our vision for a Carbon Neutral City by 2030*. 2020.

[9] Cheltenham Borough Council. *Climate Emergency*. 2022 [cited 2022; Available from: https://www.cheltenham.gov.uk/info/61/climate_and_sustainability/1622/climate_emergency].

[10] Bristol City Council. *Council action on climate change*. 2022 [cited 2022; Available from: https://www.bristol.gov.uk/policies-plans-strategies/council-action-on-climate-change#:~:text=We've%20developed%20the%20Bristol,net%20zero%20carbon%20by%202030].

[11] Bristol One City, *One City Climate Strategy - A strategy for a carbon neutral, climate resilient Bristol by 2030*. 2020.

[12] Cotswolds District Council. *Cotswold climate and ecological emergencies*. 2022 [cited 2022; Available from: https://www.cotswold.gov.uk/environment/climate-action/cotswold-climate-and-ecological-emergencies/].

[13] Forest of Dean District Council, *Climate Action for Forest of Dean - Climate Emergency Rapid Action Plan*. 2020.

[14] Gloucester City Council. *Gloucester City Council brings forward carbon neutral commitment ahead of COP26*. 2021 [cited 2022; Available from: https://www.gloucester.gov.uk/about-the-council/news/latest-news/gloucester-city-council-brings-forward-carbon-neutral-commitment-ahead-of-cop26/].

[15] Merthyr Tydfil Council. *Decarbonisation*. 2022 [cited 2022; Available from: https://www.merthyr.gov.uk/council/decarbonisation/decarbonisation/].

[16] Monmouthshire Council. *Climate Emergency*. 2021 [cited 2022; Available from: https://www.monmouthshire.gov.uk/climate-emergency/].

[17] Neath Port Talbot Council, *Decarbonisation and Renewable Energy Strategy*. 2020.

[18] Newport City Council. *Newport declares ecological and climate emergency*. 2021 [cited 2022; Available from: https://www.newport.gov.uk/en/Council-Democracy/News/articles/2021/November-2021/Newport-declares-ecological-and-climate-emergency.aspx].

[19] North Somerset Council, *North Somerset Climate Emergency Strategic Action Plan*. 2020.

[20] Rhondda Cynon Taf Council. *Tackling Climate Change RCT*. 2022 [cited 2022; Available from: https://www.rctcbc.gov.uk/EN/GetInvolved/Campaigns/ClimateChangeRCT/TacklingClimateChangeRCT.aspx].

[21] South Gloucestershire Council, *Climate Emergency Strategy*. 2020.

[22] South Gloucestershire Council. *Climate and nature emergency in South Gloucestershire*. 2022 [cited 2022; Available from: https://beta.southglos.gov.uk/climate-emergency-in-south-gloucestershire].

[23] Stroud District Council. *This is how we'll lead the way to help the Stroud district become carbon neutral by the year 2030*. 2021 [cited 2022; Available from: https://www.stroud.gov.uk/news-archive/this-is-how-well-lead-the-way-to-help-the-stroud-district-become-carbon-neutral-by-the-year-2030].

[24] Swansea Council. *Climate change and nature recovery*. 2022 [cited 2022; Available from: https://www.swansea.gov.uk/climatechange?lang=en].

[25] Climate Emergency UK. *Climate Action Plan Explorer*. 2022 [cited 2022; Available from: https://data.climateemergency.uk/councils/swindon-borough-council/].

[26] Tewkesbury Borough Council, *Carbon management programme - Background, baseline and first stage action planning*. 2020.

[27] Torfaen County Borough Council. *Climate change and nature emergency*. 2021 [cited 2022; Available from: https://www.torfaen.gov.uk/en/AboutTheCouncil/Climate-change/Climate-change-and-nature-emergency.aspx#:~:text=In%202019%2C%20Torfaen%20Council%20declared,to%20reduce%20our%20carbon%20emissions.].

[28] Vale of Glamorgan Council. *Project Zero*. 2022 [cited 2022; Available from: https://www.valeofglamorgan.gov.uk/en/living/Climate-Change/Project-Zero.aspx].

[29] Wiltshire Council. *Cimate emergency*. 2022 [cited 2022; Available from: https://www.wiltshire.gov.uk/article/1003/Climate-emergency].

[30] Wiltshire Council, *Wiltshire climate strategy*. 2022.

[31] Zero 2050 South Wales, *Zero 2050 South Wales - Main Report*. 2021.

[32] Department for Business, Energy & Industrial Strategy,. *Renewable Energy Planning Database: quarterly extract. Renewable Energy Planning Database (REPD): April 2022*. 2022; Available from: https://www.gov.uk/government/publications/renewable-energy-planning-database-monthly-extract].

[33] Neon Neue Energieökonomik, Technical University of Berlin, and ETH Zürich. *Open Power System Data*. 2020; Available from: https://data.open-power-system-data.org/conventional_power_plants/].

[34] Western Power Distribution. *Embedded capacity register*. 2022 [cited 2022; Available from: https://www.westernpower.co.uk/our-network/embedded-capacity-register].

[35] Energy Systems Catapult, LucidCatalyst, and National Nuclear Laboratory, *UK Energy System Modelling: Net Zero 2050. Nuclear Deployment Scenarios to Support Assessment of Future Fuel Cycles*. 2021.

[36] UK Atomic Energy Authority. *STEP Spherical Tokamak for Energy Production*. 2022; Available from: https://step.ukaea.uk/].

[37] EDF. *About Hinkley Point C*. 2022; Available from: https://www.edfenergy.com/energy/nuclear-new-build-projects/hinkley-point-c/about].

[38] Department for Business, Energy & Industrial Strategy,. *National statistics - Regional Renewable Statistics*. 2021 [cited 2022; Available from: https://www.gov.uk/government/statistics/regional-renewable-statistics].

[39] Department for Business, Energy & Industrial Strategy,. *National statistics - Digest of UK Energy Statistics (DUKES): electricity. Plant loads, demand and efficiency*. 2021 [cited 2022; Available from: https://www.gov.uk/government/statistics/electricity-chapter-5-digest-of-united-kingdom-energy-statistics-dukes].

[40] J. Cochran, M. Milligan, and J. Katz, *Sources of operational flexibility - Greening the grid*. 2015, National Renewable Energy Laboratory.

[41] Western Power Distribution. *Western Power Distribution*. 2022 [cited 2022; Available from: https://dataportal2.westernpower.co.uk/].

[42] Scottish & Southern Electricity Networks. *Scottish & Southern Electricity Networks Tools and Maps*. 2022 [cited 2022; Available from: https://www.ssen.co.uk/our-services/tools-and-maps/].

[43] National Grid. *Network route maps*. 2022 [cited 2022; Available from: https://www.nationalgrid.com/electricity-transmission/network-and-infrastructure/network-route-maps].

[44] Western Power Distribution. *Key performance targets*. 2020/2021; Available from: https://www.westernpower.co.uk/about-us/key-performance-targets].

[45] SSE, *Powering change. SSE plc Annual Report 2021*. 2021.

[46] Ofgem, *RIIO-ED1 Network Performance Summary 2020-21*. 2021.

[47] National Grid Electricity System Operator. *Interconnector Register*. 2022; Available from: https://data.nationalgrideso.com/connection-registers/interconnector-register].

[48] National Grid Electricity System Operator. *Electricity Ten Year Statement (ETYS) 2021 - Electricity transmission network requirements*. 2021 [cited 2022; Available from: https://www.nationalgrideso.com/research-publications/etys/electricity-transmission-network-requirements/south-wales-england-boundaries].

[49] Aurora Energy Research, *The impact of interconnectors on decarbonisation - Prepared for the Department for Business, Energy and Industrial Strategy (BEIS)*. 2020.

[50] National Grid Electricity System Operator. *Net Zero and the Future Energy Scenarios*. 2021 [cited 2022; Available from: https://www.nationalgrideso.com/future-energy/future-energy-scenarios/fes-2021/scenarios-net-zero].

[51] IEA. *Average power generation construction time (capacity weighted), 2010-2018*. 2019; Available from: https://www.iea.org/data-and-statistics/charts/average-power-generation-construction-time-capacity-weighted-2010-2018].

[52] HyDeploy. *Pioneering the safe use of blended hydrogen in gas networks to reduce carbon emissions*. 2022 [cited 2022; Available from: https://hydeploy.co.uk/].

[53] Staffell, I., D. Scamman, A. Velazquez Abad, P. Balcombe, P.E. Dodds, P. Ekins, N. Shah, and K.R. Ward, *The role of hydrogen and fuel cells in the global energy system.* Energy & Environmental Science, 2019. **12**(2): p. 463-491.

[54] Cambridge Economic Policy Associates Ltd, *HSE/Ofgem: 10 year review of the Iron Mains Replacement Programme*. 2011.

[55] Ordnance Survey. *OS Open Roads*. 2021; Available from: https://data.gov.uk/dataset/65bf62c8-eae0-4475-9c16-a2e81afcbdb0/os-open-roads].

[56] OpenSteetMap. *OpenStreetMap*. 2022 [cited 2022; Available from: https://www.openstreetmap.org/].

[57] Office for National Statistics. *Middle Layer Super Output Area (MSOA) Boundaries*. 2016 [cited 2022; Available from: https://data.gov.uk/dataset/2cf1f346-2f74-4c06-bd4b-30d7e4df5ae7/middle-layer-super-output-area-msoa-boundaries].

[58] Department for Business, Energy & Industrial Strategy,. *Lower and Middle Super Output Areas electricity consumption*. 2022 [cited 2022; Available from: https://www.gov.uk/government/collections/sub-national-electricity-consumption-data#lsoa/msoa-data].

[59] Department for Business, Energy & Industrial Strategy,. *Lower and Middle Super Output Areas gas consumption*. 2022 [cited 2022; Available from: https://www.gov.uk/government/statistics/lower-and-middle-super-output-areas-gas-consumption].

[60] Nomis. *Central heating - Table population*. 2011 [cited 2022; Available from: https://www.nomisweb.co.uk/census/2011/qs415ew].

[61] Committee on Climate Change, *Net Zero Technical report*. 2019.

[62] Department for Business, Energy & Industrial Strategy,. *Road transport energy consumption at regional and local authority level, 2005-2019*. 2021 [cited 2022; Available from: https://www.gov.uk/government/statistics/road-transport-energy-consumption-at-regional-and-local-authority-level-2005-2019].

[63] US Department of Energy (DOE). *All-Electric Vehicles*. 2022 [cited 2022; Available from: https://www.fueleconomy.gov/feg/evtech.shtml].

[64] Wilson, G. *Energy-charts dot org - Charting Great Britain's energy transition*. 2019 [cited 2022; Available from: https://energy-charts.org/].

[65] Office for National Statistics. *Dataset - Middle Super Output Area population estimates*. 2021 [cited 2022; Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/middlesuperoutputareamidyearpopulationestimates].

[66] Department for Environment, Food & Rural Affairs,. *Official Statistics - 2011 Rural Urban Classification*. 2021 [cited 2022; Available from: https://www.gov.uk/government/statistics/2011-rural-urban-classification].

[67] Office for National Statistics. *Dataset - Income estimates for small areas, England and Wales*. 2020 [cited 2022; Available from: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/datasets/smallareaincomeestimatesformiddlelayersuperoutputareasenglandandwales].

[68] National Energy Action and Energy Action Scotland, *UK Fuel poverty monitor 2019-20*. 2020.

[69] Department for Business, Energy & Industrial Strategy,, *National statistics. UK local authority and regional carbon dioxide emissions national statistics: 2005 to 2019*. 2021.

[70] Department for Business, Energy & Industrial Strategy,, *2020 UK greenhouse gas emissions, provisional figures*. 2021.

[71] Department for Business, Energy and Industrial Strategy,. *Provisional UK greenhouse gas emissions national statistics*. 2022 [cited 2022; Available from: https://data.gov.uk/dataset/9a1e58e5-d1b6-457d-a414-335ca546d52c/provisional-uk-greenhouse-gas-emissions-national-statistics].

[72] Solargis. *Solar resource maps of United Kingdom - Photovoltaic Electricity Potential*. 2020 [cited 2022; Available from: https://solargis.com/maps-and-gis-data/download/united-kingdom].

[73] Canet, A. and M. Qadrdan, *Zero 2050 South Wales project - Temporal and spatial heat demand profiles*. 2021.

[74] BMT, *South Wales Cluster De-Carbonisation WP1: Decarbonisation of Road Transpor*. 2020.

[75] Vivid Economics and Imperial College London, *Accelerated electrification and the GB electricity system*. 2019.

[76] Western Power Distribution, *Our Business Plan 2023-2028 - Final Submission*. 2021.

[77] Statista. *Median construction time required for nuclear reactors worldwide from 1981 to 2020*. 2022 [cited 2022; Available from: https://www.statista.com/statistics/712841/median-construction-time-for-reactors-since-1981/].