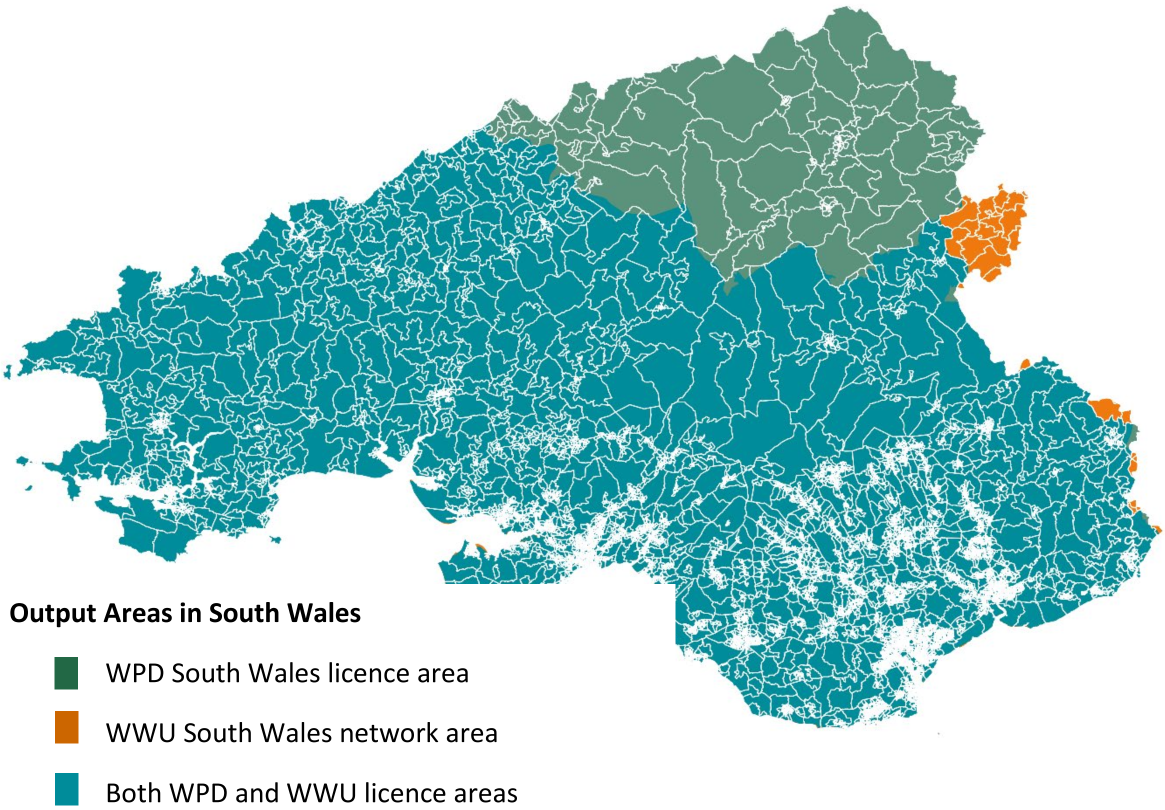
Net Zero South Wales 2050

A combined gas and electricity distribution network future energy scenarios (DFES) assessment for South Wales to 2050

Dataset companion report



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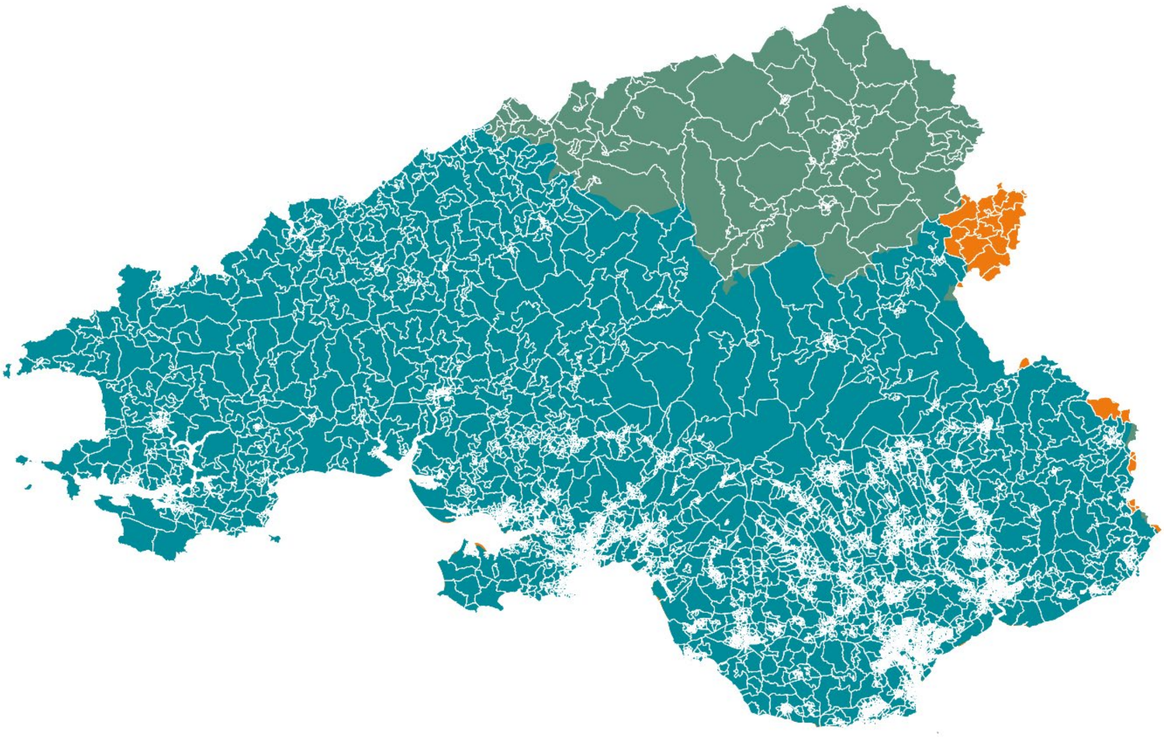
Contents

Glossary

Term/ Acronym	Definition
AD	Anaerobic Digestion
ACT	Advanced Conversion Technology
ASHP	Air Source Heat Pump
BEIS	Department for Business Energy and Industrial Strategy
CCC	Committee on Climate Change
CCGT	Combined Cycle Gas Turbine
CCUS	Carbon Capture Utilisation and Storage
CHP	Combined Heat and Power
DFES	Distribution Future Energy Scenarios
DSR	Demand Side Response
ESA	Electricity Supply Area
EPC	Energy Performance Certificate
EV	Electric Vehicle
FES 2019	National Grid Future Energy Scenarios published in 2019
GIS	Geographic Information Systems
GSA	Gas Supply Area
GSHP	Ground Source Heat Pump
HHP	Hybrid Heat Pump
kWh	Kilowatt-hour
Load	Load on the network from either a demand or supply source
Linepack zone	Pressure management zone on gas distribution network
LSOA	Lower Super Output Area (ONS geographic area)
MW	Megawatt
NIA	Network Innovation Allowance
OAC	Output Area Classification (smallest defined geographical area from Census 2011)
ONS	Office for National Statistics
PV	Photovoltaics
RHI	Renewable Heat Incentive
Scm	Standard cubic metre
South Wales	For the purpose of this study the area of South Wales is bounded by the extent of the two licence areas for gas (WWU) and electricity (WPD) distribution.
SMR	Steam Methane Reformation (for production of hydrogen)
WPD	Western Power Distribution
WWU	Wales and West Utilities

Section I: Executive summary and net zero insights



1. Executive summary

The Net Zero South Wales 2050 innovation project has been undertaken as a partnership between Regen, Western Power Distribution (WPD) and Wales and West Utilities (WWU) with funding from the Network Innovation Allowance (NIA) programme. This innovation project was about bringing two networks together, developing insights and value from an integrated approach to gas and electricity scenario planning. Bringing together the datasets and combined knowledge of the two networks meant the project was able to explore South Wales's potential net zero future at an increased depth and scope.

The main objective of the project was to create integrated distribution future energy scenarios (DFES) for the gas and electricity networks in South Wales and, as part of this, to develop a new methodology for conducting cross-vector scenario forecasting at a regional level. The project has also provided insights into how South Wales might transition to a net zero future under three net zero scenario pathways: **High Electrification**, **Core Hydrogen** and **High Hydrogen** along with a hybrid heat sensitivity.

The main output of the project is a DFES projection dataset provided to inform network planning and investment in WPD and WWU. The dataset covers energy demand and supply technologies that might be expected to connect to the gas and electricity distribution networks under the three scenario pathways. The data is projected annually from 2020 to 2035, and then at five yearly intervals between 2035 and 2050. Projections are provided at geographic levels relevant to each respective network, defined by Electricity Supply Areas (ESAs) and Gas Supply Areas (GSAs). Outputs from this project will also feed into the Zero2050 South Wales project being led by National Grid, which will also consider in more detail the interaction between the distribution and transmission networks.

This summary report accompanies the dataset and describes the approach taken in the analysis, the key assumptions and methodologies used in the scenarios for each different technology and sector and provides an overview and commentary of the results. A separate Learning Report has been produced that focuses on the learnings from developing an integrated approach to DFES.

The DFES dataset is the first stage in the network planning process for both networks. As illustrated in Figure 1-1, forecast data is an input used to create technology load profiles, peak load calculations or representative day models that can provide a snapshot of expected network requirements under certain conditions in future years[1]. This in turn informs network planning and investment appraisal.

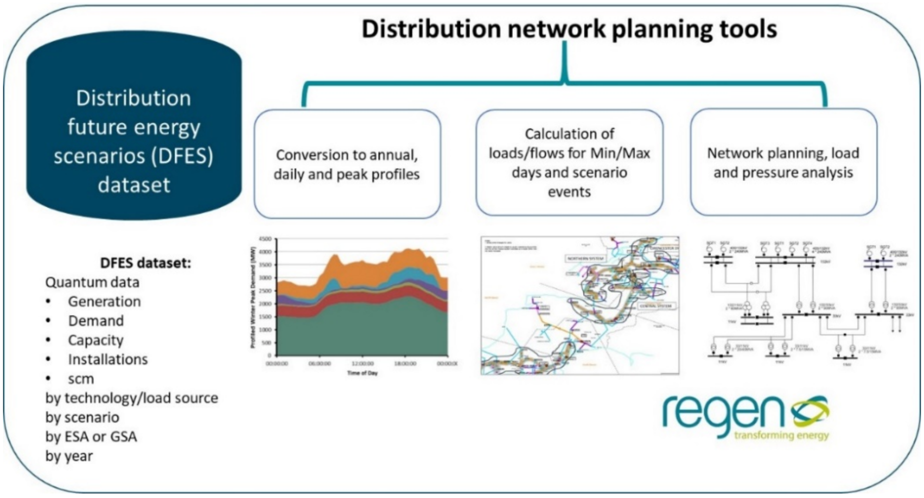
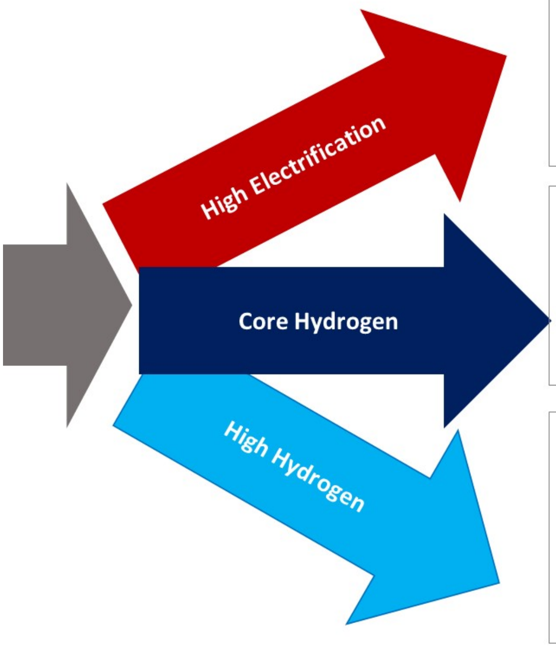


Figure 1-1 Network planning tools and relationship to DFES data

[1] For example: https://www.westernpower.co.uk/smarter-networks/network-strategy/strategic-investment-options-shaping-subtransmission

1.1. Introduction to the net zero scenarios

The project has considered three different scenario pathways to achieve net zero in South Wales by 2050, see Figure 1-2. Due to the divergent impacts on the distribution networks, the scenarios have been defined to focus on the different ways that the region may decarbonise heat, either mainly through electrification, or with a switch-over to hydrogen. In addition, a hybrid heat sensitivity was explored under the High Hydrogen scenario, looking at the impact of a higher uptake of hybrid heating solutions on electricity and gas demand.



In **High Electrification**, electrification is prioritised as the solution for heat. The majority of domestic and commercial heat needs are electrified, use low carbon heat networks or shared source heat pumps. Hydrogen use is focused on some high value sectors including heavy transport and for decarbonising the South Wales industrial clusters. This scenario is similar to the FES 2020 Consumer Transformation scenario.

In **Core Hydrogen**, a hydrogen network replaces the fossil gas network from 2035 in c. 57% of existing South Wales connections related to the densest areas of domestic and commercial demand. The remaining gas customers are electrified along with existing off gas areas during 2030s. Hydrogen also fuels industrial clusters, heavy transport and some peaking generation.

In **High Hydrogen**, the majority of the current gas network is converted to hydrogen from 2035 and users install a hydrogen boiler. Existing off-gas areas are electrified for heat. Hydrogen also fuels industrial clusters, heavy transport and some peaking electricity generation. This is similar to the FES 2020 System Transformation scenario. A **hybrid sensitivity** also explores the impact of hybrid heating systems replacing hydrogen boilers.

Figure 1-2 High level summary of the net zero scenarios used in this assessment

1.2. Summary of methodology

The DFES development uses a bottom-up process that prioritises stakeholder and local factors to identify an envelope of possible futures within a region. Key inputs include:

- The existing baseline of technologies and demand sources connected to the local networks.
- Near term pipeline projections developed using the pipeline of new applications for network connections.
- Local authority planning information such as new housing or commercial developments, as well as local and regional planning applications for energy projects.

Longer term scenario projections are then developed for each scenario which incorporate a number of factors including energy resources, geographical and land-use factors, historic growth and investment, regional policies and socio-economic factors. See Figure 1-3.

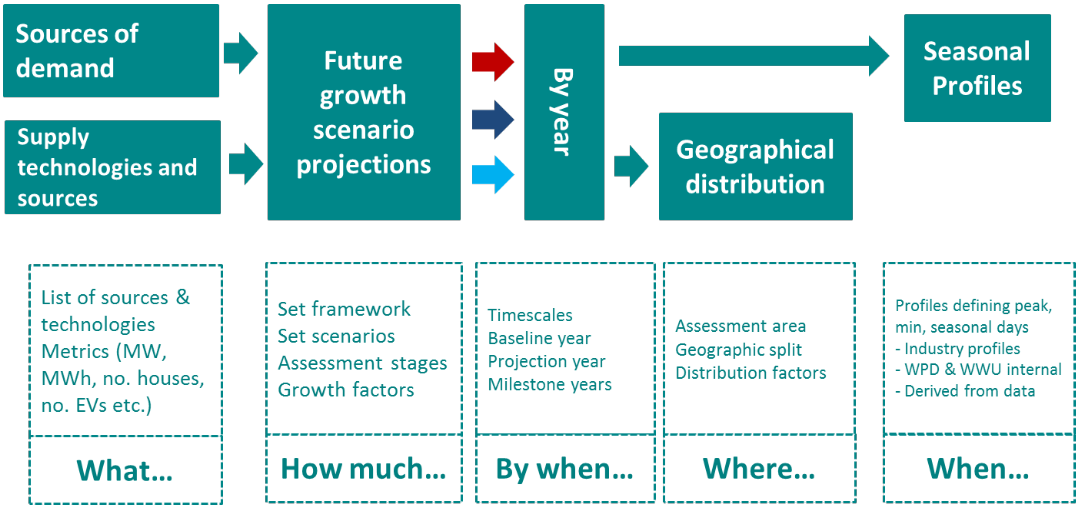


Figure 1-3 Overview of high level DFES phases

The future scenario analysis undertaken for each technology and sector involves a process of modelling baseline data and historic trends, which is then followed by known near-term pipeline analysis of projects in planning or those expected to connect in the next five years. This is followed by medium and then long term projections. This is illustrated in Figure 1-4.

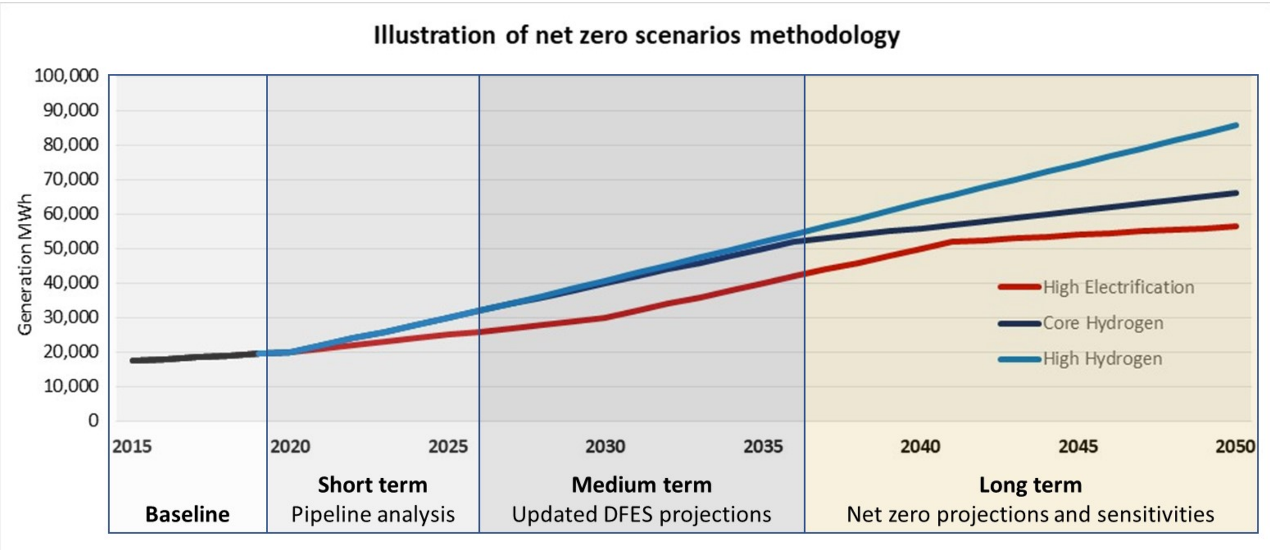


Figure 1-4 Illustration of the net zero DFES assessment method

In addition to the DFES projections, a seasonal day analysis was produced that modelled both demand and generation on a simulated summer and winter day as a baseline, 2035 and 2050. This analysis was based on profiles and operational data provided by WPD and WWU.

A key challenge for the project was to determine how the various technologies and sectors might typically behave during these simulated periods and how those behaviours might vary moving towards 2035 and 2050. A change in winter heating need and degree days as well as demand for summer cooling would also be expected over this period due to the shifting climate. Though these changes were not reflected in this study, it would be an important area for further analysis.

This project did not replicate the detailed planning processes for either network, instead this analysis was used to illustrate the potential intra-day flows of energy on these simulated summer and winter days on both networks, and to build a shared understanding of how the scenarios might typically impact electricity and gas distribution networks.

It was also useful to understand how the respective gas and electricity networks consider peak periods and to highlight areas of commonality and the inherent differences between the fuels and their respective networks. More information can be found in section 6.6.

1.3. Summary of results

Figure 1-5 illustrates how the make-up of energy use in South Wales changes by scenario over time and are expected to be mainly decarbonised by 2050. A key variable is the level of hydrogen consumption by 2050. There is over 15 TWh of hydrogen fuel consumption in the highest scenario, High Hydrogen. A smaller amount of hydrogen is consumed in the Core Hydrogen scenario and also in the High Hydrogen hybrid sensitivity, while in the High Electrification scenario hydrogen is used only for fuel in heavy transport and to supply industrial clusters.

In 2040, High Hydrogen initially has lower hydrogen usage than Core Hydrogen. This is due to the assumption made about longer timescale for a full hydrogen 'switch-over' date in the High Hydrogen scenario. This is due to the need to convert more of the gas network from fossil gas to hydrogen.

In all scenarios consumption of electricity increases for both transport and heating due to significant increase in the number of electric vehicles and electrically fuelled heating solutions.

Overall, energy consumption reduces across all scenarios. This is partly due to greater energy efficiency in buildings but also the comparative efficiency of using electricity for transport (compared to petrol/diesel) and the higher coefficient of performance of heat pump systems.

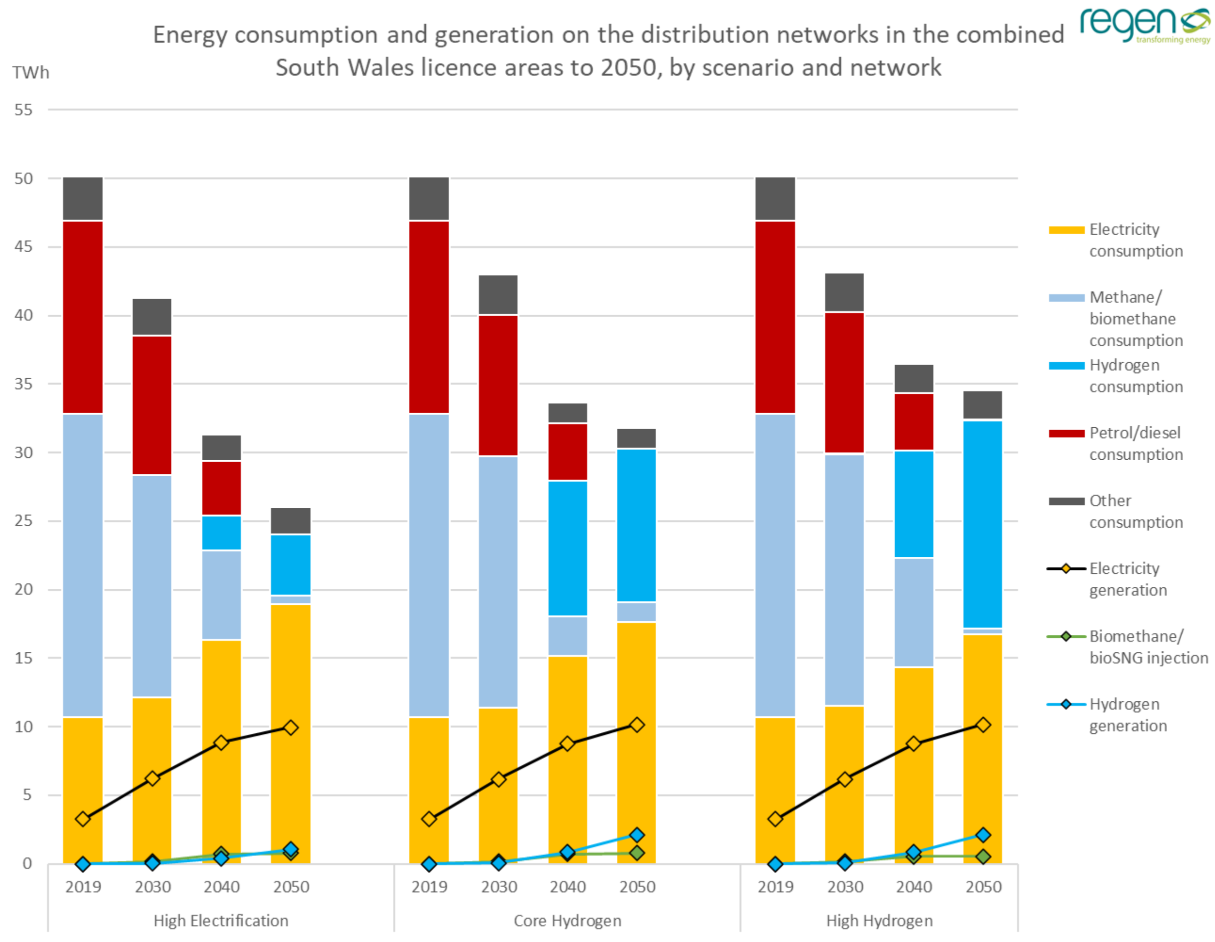


Figure 1-5 Overview of distribution network energy demand and supply out to 2050 by scenario

The graph in Figure 1-5 also shows that lowest energy is used overall in a High Electrification scenario. Although slightly more energy efficient buildings are projected in High Electrification (to support heat pump installations), this is mainly due to the energy efficiency of heat pumps themselves which are the primary heating technology for homes and businesses by 2050. Heat pumps are assumed to have a seasonal performance factor (SPF) of up to 300% by 2050. This takes a balanced view of potential improvements in heat pump performance due to technological advances, best practice installation and increasingly energy efficient housing[2]. Information about the High Hydrogen hybrid sensitivity can be found on page 26.

The projected amount of distribution network connected renewable electricity generation is the same across the scenarios and provides between 50% - 60% of the annual electricity demand of the South Wales network licence areas by 2050, compared to 30% in the baseline year. The balance is assumed to be provided through the transmission network. This could provide zero carbon electricity from a number of sources. Options would include transmission connected renewable generation or gas generation with CCUS either in South Wales, wider UK, or via interconnection to Europe.

It should be noted that this analysis projected distribution connected electricity generation, and as a result did not include significant projects that are likely to connect to electricity transmission network in South Wales. Transmission connected generation might include offshore wind and tidal range technologies, the largest onshore wind sites as well as CCGT plants which may continue to operate with fossil gas alongside carbon capture, utilisation and storage (CCUS) or hydrogen generation.

There are several ways in which hydrogen could be manufactured and distributed in a future energy system. In the scenarios production of hydrogen directly on the distribution network is assumed to be via electrolysis using between 16% and 32% of the 'excess' renewable generation connected to the distribution network., Higher production meets more of the local demand in the Core and High Hydrogen scenarios. However, in all scenarios hydrogen demand significantly exceeds distribution supply produced by electrolysis, see Table 2-1, and it is assumed that the balance will be imported via a hydrogen transmission network.

Production and consumption of biomethane is included in all the scenarios. The level of production and the level of demand are similar in both High Hydrogen and High Electrification. However, in Core Hydrogen the biomethane demand exceeds supply by around 45%. It is assumed again that the balance would be imported from outside the region or by plants connected to the transmission network. The logistics of segregating hydrogen transmission networks and biomethane networks is something that will be explored in the Zero 2050 National Grid project.

The scenarios framed in this analysis are only one set of possible net zero futures for South Wales and have been explicitly focused on different approaches to heat decarbonisation. Exploring the results and the comparisons between the scenarios can provide important insights into the implications, decisions and trade-offs that might feature in a net zero transition in South Wales, and across regions in the UK. These are explored further in the insights in Section 2 below.

[2] Field trials and modelling suggest that current standalone ASHPs have an SPF of 2.5-2.7 (https://www.gov.uk/government/publications/hybrid-heat-pumps-study) with many existing installations achieving SPFs over 3. The National Grid FES assumes a 36% improvement in ASHP coefficients of performance by 2050, from 2.8 to 3.8 (http://fes.nationalgrid.com/media/1440/fes-qaa-document.pdf)

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2. South Wales net zero insights

i) There is significant evolution on both networks by 2050.

Across all three scenarios, there is a significant transformation on the gas and electricity networks. The mix and capacity of connected loads on both the networks is radically different in 2050.

The statistics outlined below are striking and illustrate the systemic change and significant energy system and network investment needed over the next 30 years, to achieve net zero.

	Distributed solar and wind capacity increases by over 350% to 5.8 GW in 2050 in **all scenarios**. This provides over 50% of annual electricity demand in 2050.
	A huge number of domestic properties switch their heating technologies to a low carbon alternative by 2050. With c.860,000 properties switching to a type of heat pump under the **High Electrification** scenario and c.758,000 properties with a hydrogen heating system under the **High Hydrogen** scenario.
	Only low carbon vehicles will be on the road in South Wales by 2050. There will be c.1.3 million electric vehicles under the **High Hydrogen** scenario, adding c.2.7 TWh of demand in 2050.
	The amount of indigenous waste-derived biomethane and bioSNG being injected into the gas network reaches 802 GWh in 2050 in the **Core Hydrogen** scenario from a baseline of zero.
	Battery storage capacity significantly increases in all scenarios by 2050, reaching 599 MW under the **High Electrification** scenario.
	The production of green hydrogen through electrolysis of renewable electricity generation on the distribution network commences in South Wales in all scenarios, with capacity increasing to **482 MW_e** by 2050 in the **High Hydrogen** scenario, producing over 2 TWh of zero carbon hydrogen for heating, industry, transport and peaking generation.

ii) Decentralised energy supply meets an increasing proportion of annual demand.

In all three scenarios an increased proportion of South Wales' annual energy demand could be met by decentralised renewable energy sources by 2050 (see Table 2-1).

The scenarios project that between 50-60% of electricity and up to 36% of low carbon gases could be delivered from distribution connected indigenous energy resources in South Wales by 2050.

To note that as this is only distribution network connected projects, additional supply sources in South Wales could also be connected on the gas (hydrogen or methane) and electricity transmission networks.

Table 2-1 Comparison of South Wales distributed energy supply and demand in the three scenarios

Local supply compared to local demand in South Wales scenarios	Baseline	High Electrification		Core Hydrogen		High Hydrogen	
	2019	2030	2050	2030	2050	2030	2050
Annual distributed **renewable generation**, as a proportion of regional electricity demand	30%	51%	53%	54%	58%	54%	61%
Annual distribution-network-supplied **hydrogen and biomethane**, as a proportion of regional demand on the gas network	0%	1%	36%	1%	23%	1%	17%

iii) The pathway for decarbonising heat is the most significant variable in distribution net zero analysis.

Both distribution networks will be heavily affected by the pathways chosen for heat decarbonisation in any given location and region. This is likely to be the most significant variable to influence distribution network use out to 2050.

As summarised in Figure 2-1 for domestic properties, the network that will be needed to deliver heating energy varies significantly across the three scenarios by 2050.

As well as differences between heating technologies between each scenario, there will also be significant variance within each scenario between different areas of South Wales such as existing off gas areas and the homes and businesses inside or outside of the core urban areas. Given the long timescales required for both preparation for hydrogen switchover and electricity network investment, it is likely that key strategic decisions on the future of heat in South Wales will be needed by the middle of the 2020s to enable critical infrastructure investment to be planned.

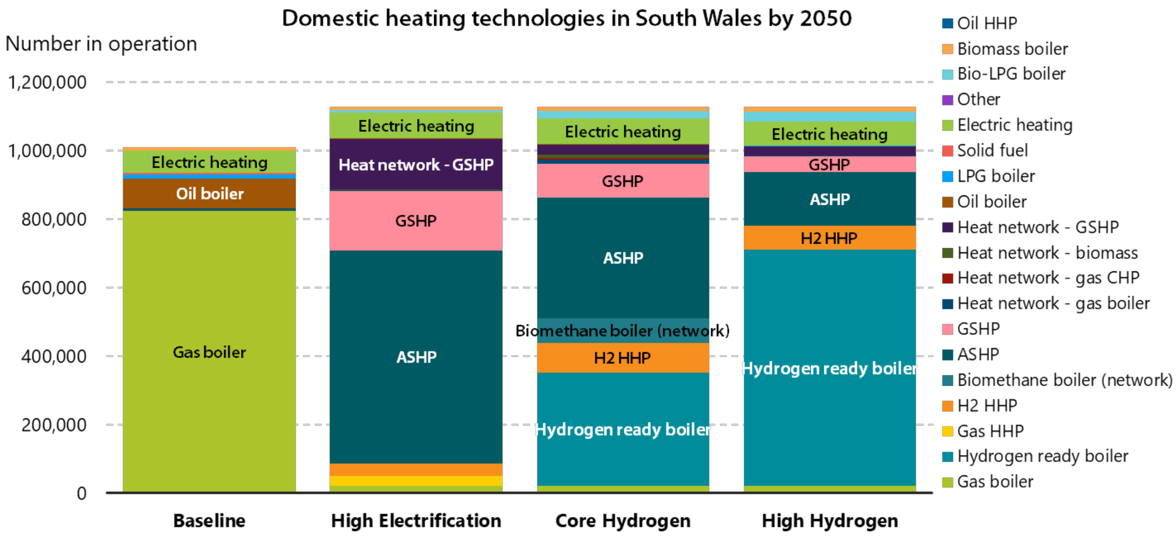


Figure 2-1 The number of domestic heating technologies in operation in South Wales in 2050, across the three net zero scenarios, against the 2019 baseline

iv) The scenarios have a wider range for distributed gas than distributed electricity.

The scenarios set out significantly divergent futures for South Wales and each have very different implications for the use of, and investment needed in, both the gas and electricity networks. The key factor for this divergence was the pathway for heat decarbonisation, which explored a range between near full electrification and full hydrogen network.

Analysis of the consumption results shows that the usage range on the electricity distribution network is potentially much less than that faced by gas networks (see Figure 2-2).

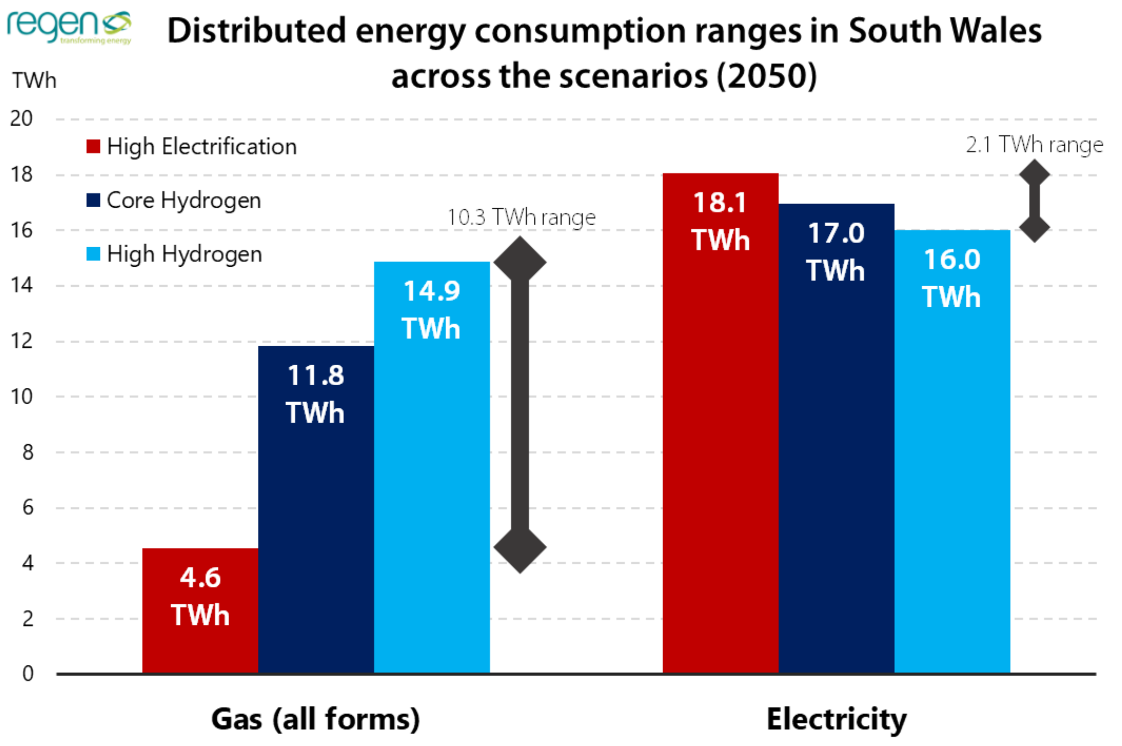


Figure 2-2. The range of projections across the scenarios for gas and electricity consumption on the distribution network in South Wales in 2050.

Over half of the demand range for the gas network is dependent on whether heat in buildings (domestic and non-domestic) decarbonises using low carbon gas, or electricity. Other significant elements are the extent to which industrial processes move away from gaseous fuels, and whether hydrogen is used to fuel some peaking plant electricity generation.

The demand range for electricity networks is a more nuanced by scenario; in High Electrification, electrified heat and industrial processes result in c.3 TWh additional demand for these consumers relative to the hydrogen focussed scenarios, however this is to some extent offset by c.1.5 TWh hydrogen electrolysis electricity demand which is halved in this scenario compared to the Core and High Hydrogen. Although the net demand range is significantly less for electricity, there is more variability in how electricity is used.

These net zero scenarios suggest that the electricity networks will most likely need to deliver increased volumes of energy towards 2050, with up to 45% of this increase coming from electrification of petrol/diesel vehicles. Whereas the amount of gaseous energy delivered could lie between 23% and 71% of the 2019 baseline, and be spread across a number of gas types and network formats.

v) Carbon emissions from heat decline at different times in different scenarios.

Though all pathways are significantly decarbonised by 2050, Figure 2-3 illustrates that carbon emissions from heat decline at different rates in the different scenarios.

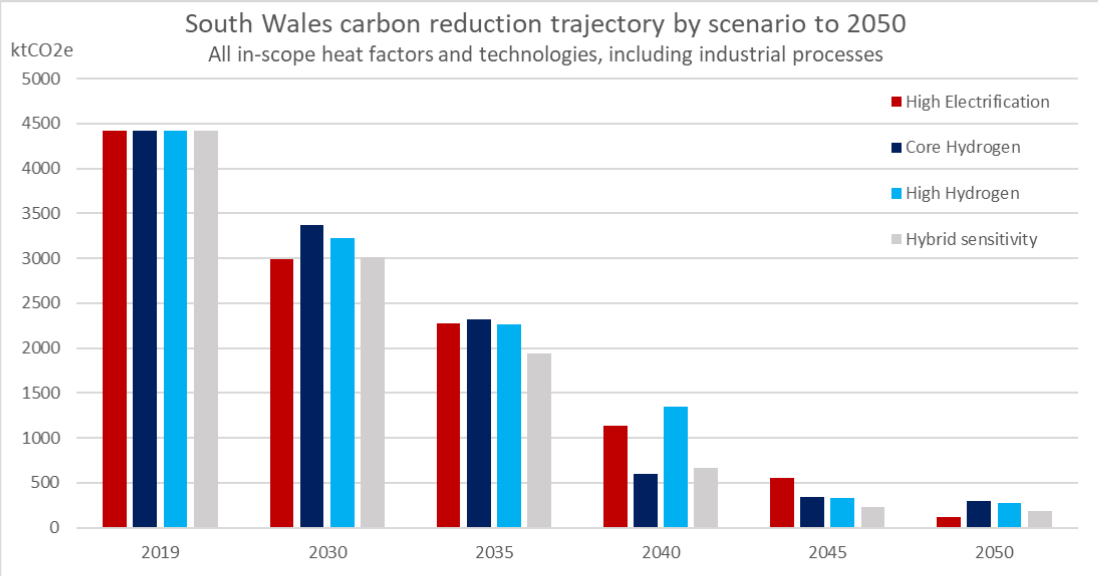


Figure 2-3: Carbon emissions by scenario to 2050 for in-scope heat factors and technologies

High Electrification emissions and hybrid sensitivity see the biggest declines by 2030. By 2040 both Core Hydrogen and the hybrid sensitivity show a sharp decline in heat emissions ahead of both High Hydrogen and High Electrification. This is because those scenarios benefit from a combined approach of electrification and a low-carbon hydrogen switchover.

High Electrification pathways shows a steadier, more consistent decline in emissions as homes are made appropriate for full electrified heat. There is still fossil gas in cities in the late 2030s and 2040s.

High Hydrogen has a later decline in emissions as all on-gas properties do not significantly decarbonise until the hydrogen switchover occurs in the late 2030s and early 2040s. Hydrogen ready boilers will still be burning fossil gas in the medium term and not be able to use hydrogen until it becomes universally available after a hydrogen supply 'switch-over'. See Table 2-2.

Table 2-2 Properties using low carbon heat in South Wales in 2035 by scenario

Proportion of properties using low carbon and electrified heat in 2035		
Scenario	**Number of domestic households**	**Number of non-domestic properties**
High Electrification	651,177 (60%)	61,876 (68%)
Core Hydrogen	436,446 (40%)	49,253 (54%)
High Hydrogen	331,979 (31%)	46,222 (51%)
High Hydrogen hybrid sensitivity	517,555 (48%)	54,853 (60%)

There are some key questions related to hydrogen networks and heating, which are currently the subject of research and innovation, this includes the planning and investment required in hydrogen production, storage, and distribution, along with updating of consumer appliances and domestic infrastructure, all of which will be needed before the fossil fuel supply is removed[3].

It is assumed in these scenarios that the hydrogen switch over for High Hydrogen would take longer than the switch over in Core Hydrogen where the network will be smaller and is focused on core urban areas. The analysis, which five yearly from 2035 assumed:

- Core Hydrogen 'switch over' completed in years between 2035 and 2040.
- High Hydrogen 'switch over' completed in years between 2035 and 2045. In this scenario switch over concludes later as it covers the whole existing network.

To note that though scenarios have been projected to be consistent with net zero, there is expected to be a low level of residual emissions from distribution energy by 2050 mainly as a result of hydrogen production via ATR. It is assumed that negative emission technologies would be used to remove these remaining emissions.

[3] Key areas for hydrogen transition are outlined in this report: https://www.theiet.org/media/4095/transitioning-to-hydrogen.pdf

vi) Distributed hydrogen production via electrolysis is likely to meet only a proportion of hydrogen demand. Further supply will require a strategy for large-scale hydrogen production, storage and transmission in South Wales.

Figure 2-4 illustrates that the local supply of 'green' hydrogen from electrolysis is not projected to meet the demand for hydrogen. A basic assumption has been made that the balance of supply would be provided through the transmission network. This will need to be validated by the Zero2050 South Wales project.

In all scenarios the main gas distribution network is assumed to no longer deliver fossil gas to the majority of customers by 2050, but in some small areas it may deliver gas with a significant biomethane blend. In the Core and High Hydrogen scenarios, the gas distribution network is repurposed to supply hydrogen. However, a few customers in South Wales, for example CCGT plants, large industrial users, or potentially large hydrogen Steam Methane Reformation (SMR) plants may wish to continue to receive fossil gas in 2050. But to have this option, these users will need to maintain a fossil gas supply, potentially through transmission and a reconfiguration of the gas distribution network.

Therefore crucial for the practicality of hydrogen networks in South Wales will be decisions on what the gas transmission network will be transporting, by when, and whether it is reasonable or practical to assume it could deliver both hydrogen, biomethane and/or fossil gas to different customers. This is explored further in section 7.1 and is a key question for further analysis.

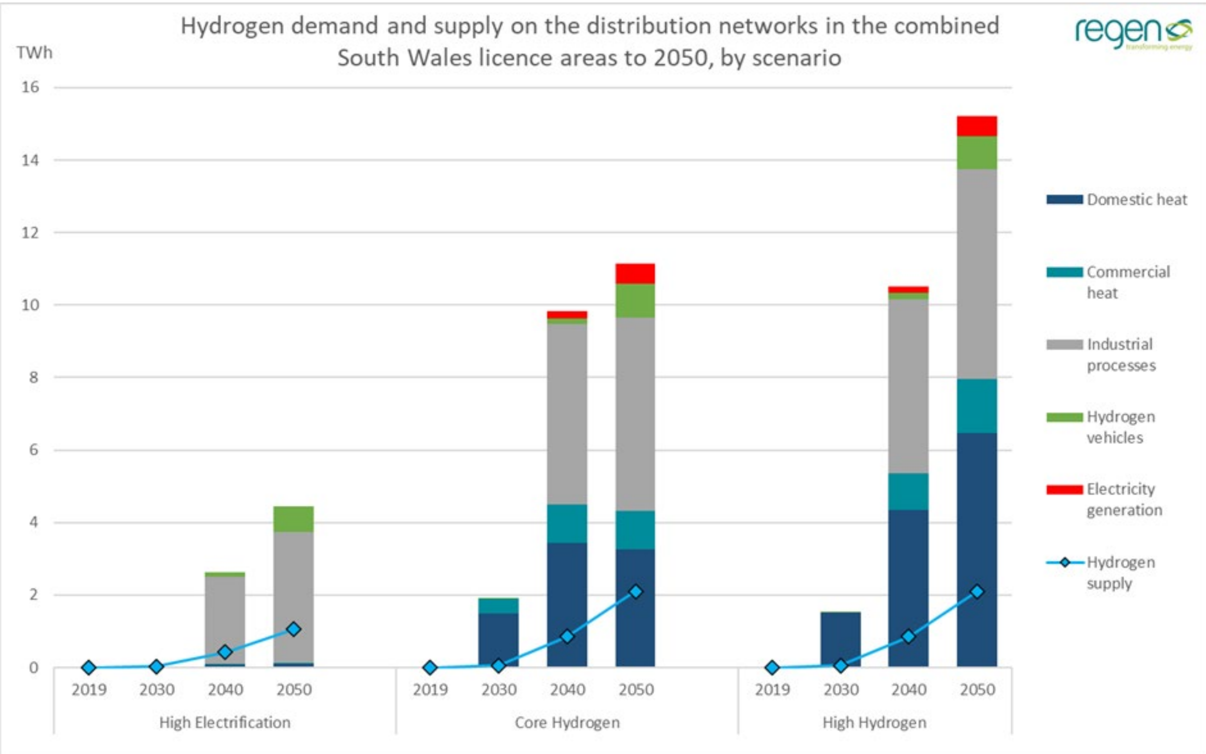
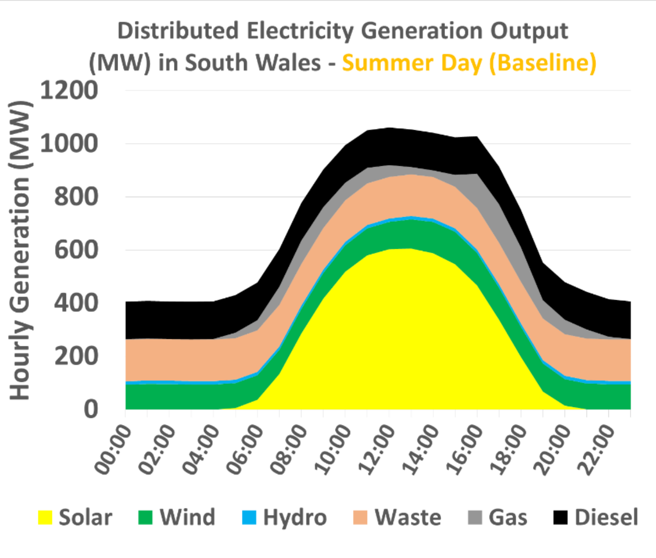


Figure 2-4 Hydrogen demand and supply by sector and scenario.

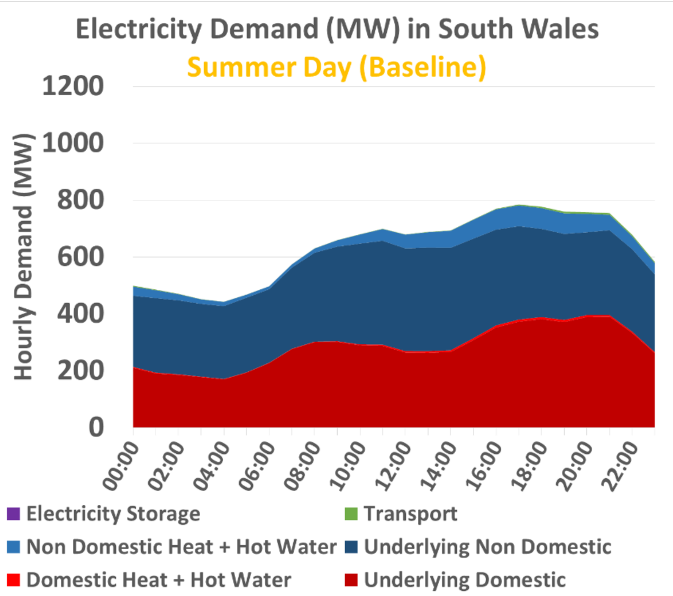
vii) Electricity demand and supply variance increases in both summer and winter, in all scenarios. Local and national balancing is likely to be increasingly important.

The seasonal day analysis suggests that, using existing known demand profiles, there is likely to be significant variance between electricity demand and decentralised electricity generation, in both the summer and winter. This reinforces the value of the UK electricity transmission system and efforts to match demand and supply locally, as well as highlighting the significant role of time of use tariffs, smart EV charging, more sophisticated heating control systems and Demand Side Response (DSR).

A simulated baseline summer day shown in Figure 2-5 illustrates that a strong solar and moderate wind day already potentially exceeds underlying domestic and commercial electricity demand in South Wales. This implies that the region could be exporting c.1.2 GWh of electricity generation across the day into the transmission system. The opposite is true for a simulated baseline winter day (Figure 2-6), even with high wind output, South Wales electricity demand would exceed supply by c.25 GWh across the day, where demand is over two and a half times the distribution connected supply.

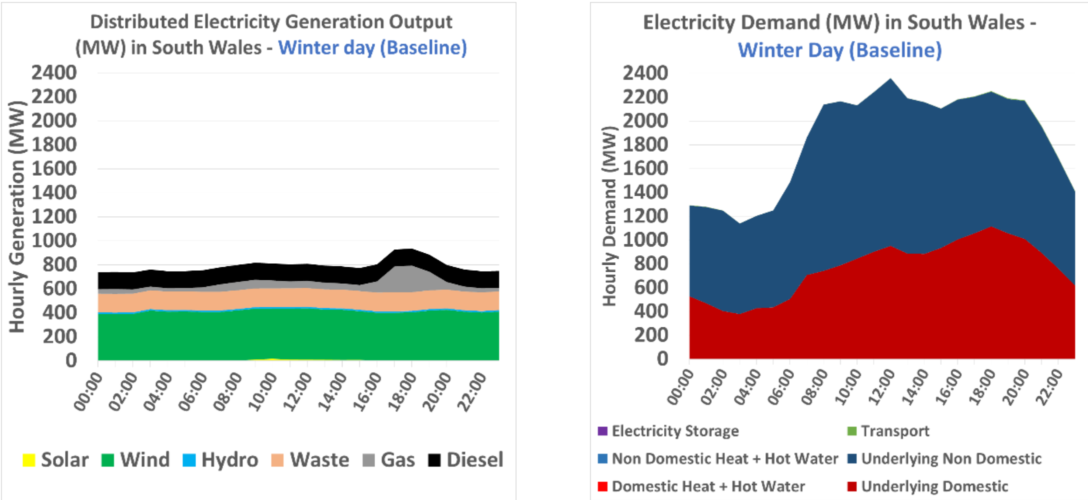


Summer Day Electricity Generation	
Max generation period	12:00
Max generation (MW)	1,062
Min generation (MW)	406
Daily energy (MWh)	16,454



Summer Day Electricity Demand	
Max demand period	18:00
Max demand (MW)	785
Min demand (MW)	443
Daily energy (MWh)	15,223

Figure 2-5 Simulated baseline summer day electricity generation and demand profiles in South Wales



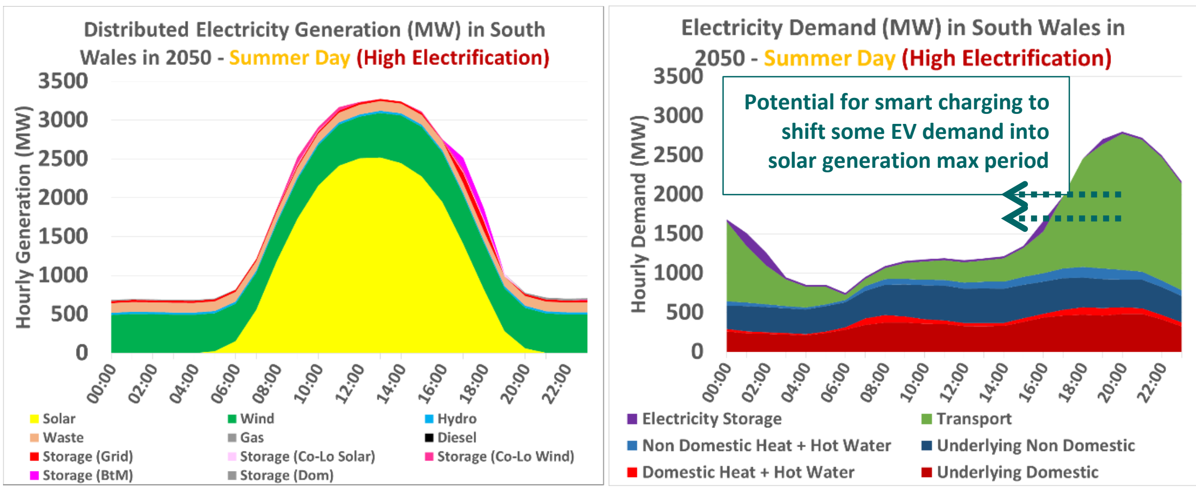
Winter Day Electricity Generation	
Max generation period	18:00
Max generation (MW)	936
Min generation (MW)	737
Daily energy (MWh)	19,016

Winter Day Electricity Demand	
Max demand period	12:00
Max demand (MW)	2,362
Min demand (MW)	1,140
Daily energy (MWh)	44,342

Figure 2-6 Simulated baseline winter day electricity generation and demand profiles in South Wales

Reviewing similar simulated seasonal days in 2050 under the High Electrification scenario suggests that, without applying time of use tariffs, smart EV charging or additional sources of flexibility, some of these over-supply and under-supply seasonal trends could be amplified in a net zero world.

In a simulated summer day in 2050 in the High Electrification scenario, electricity demand across the day has more than doubled, mainly due to EV charging. Despite this, there is a c.3 GWh electricity generation over-supply across the day and noticeably the peak generation and demand periods are separated by 7 hours. See Figure 2-7. As discussed in section 6.6, the profiling does not account for future behaviours, therefore the potential for smart EV charging and use of higher duration storage could realign a proportion of the demand and distributed generation supply.

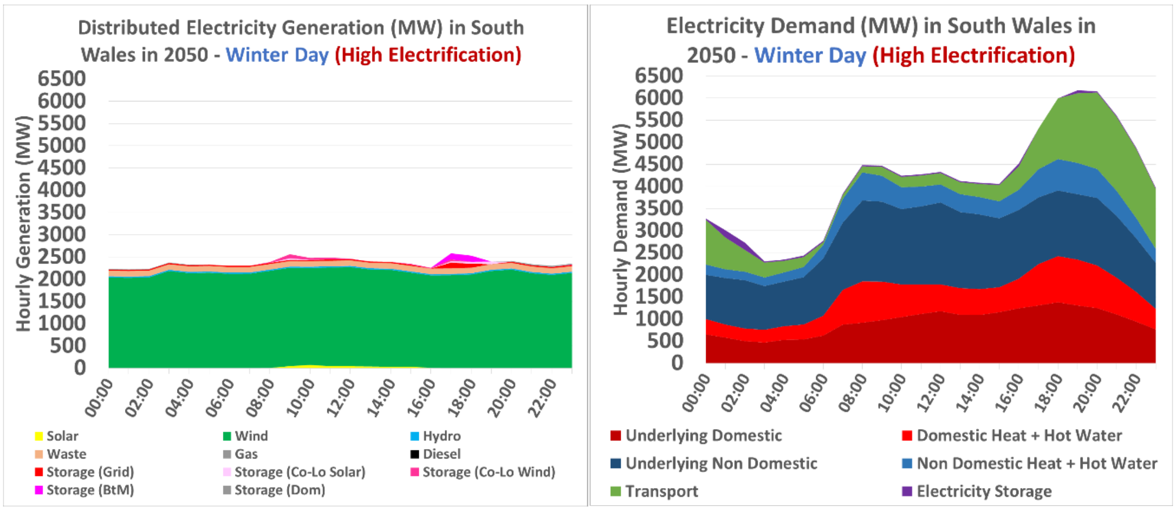


Summer Day Electricity Generation	
Max generation period	13:00
Max generation (MW)	3,273
Min generation (MW)	684
Daily energy (MWh)	40,578

Summer Day Electricity Demand	
Max demand period	20:00
Max demand (MW)	2,800
Min generation (MW)	750
Daily energy (MWh)	37,331

Figure 2-7 Simulated summer day distributed electricity generation and demand profiles in South Wales in 2050 under the High Electrification scenario

Figure 2-8 illustrates that, for a simulated winter day in 2050, due to the additional demand from heat pump installations in homes and businesses, overall daily electricity demand has doubled. Whilst distributed generation has also significantly increased (assuming a high wind day), South Wales demand now exceeds local supply by c.60 GWh (up from c.43 GWh in 2019).



Winter Day Electricity Generation	
Max generation period	17:00
Max generation (MW)	2,582
Min generation (MW)	2,223
Daily energy (MWh)	56,979

Winter Day Electricity Demand	
Max demand period	19:00
Max demand (MW)	6,716
Min demand (MW)	2,305
Daily energy (MWh)	99,365

Figure 2-8 Simulated winter day distributed electricity generation and demand profiles in South Wales in 2050 under the High Electrification scenario

Though it has not been modelled in this seasonal day analysis, there is significant potential to reduce the 'mismatch' in local supply and demand intra-day max through smart EV charging, DSR, use of hydrogen electrolysis and higher energy capacity battery storage on the distribution networks[4]. However, the role of a national transmission and balancing system, along with seasonal storage, is also clearly demonstrated.

In the interim years flexible gas fired electricity generation plant will play an important role in an increasingly variable energy system. The pipeline of gas peaking plant connections shows that this is a key area of near-term growth to help facilitate an increasing proportion of renewables in the electricity system.

In the long term, where unabated fossil fuel generation is not compliant with net zero, hydrogen peaking plant (as modelled to operate in the Core and High Hydrogen scenarios) could continue to play an important role, alongside electricity storage and other sources of flexibility.

It is likely that other gas-fired flexibility, in the form of CCGT and CCUS or BECCS, would be connected to the electricity transmission network, due the capital costs of CCUS technology.

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[4] https://www.theade.co.uk/assets/docs/resources/Flexibility_on_demand_full_report.pdf

viii) Biomethane has many valuable uses in a net zero scenario, not least in negative emissions. But with a limited supply, its role needs careful consideration.

Although in total energy terms bioenergy is expected to play a relatively small role in a future energy system, the multi-vector properties of biomethane and bioSNG, and the potential for them to provide negative emissions, will make bioenergy an extremely valuable energy source to achieve net zero.

Bioenergy can also provide additional economic benefits for the agriculture and waste sectors. Biomethane production has therefore recently been incentivised through the Renewable Heat Incentive and a new Green Gas Levy announced in the 2020 March Budget.

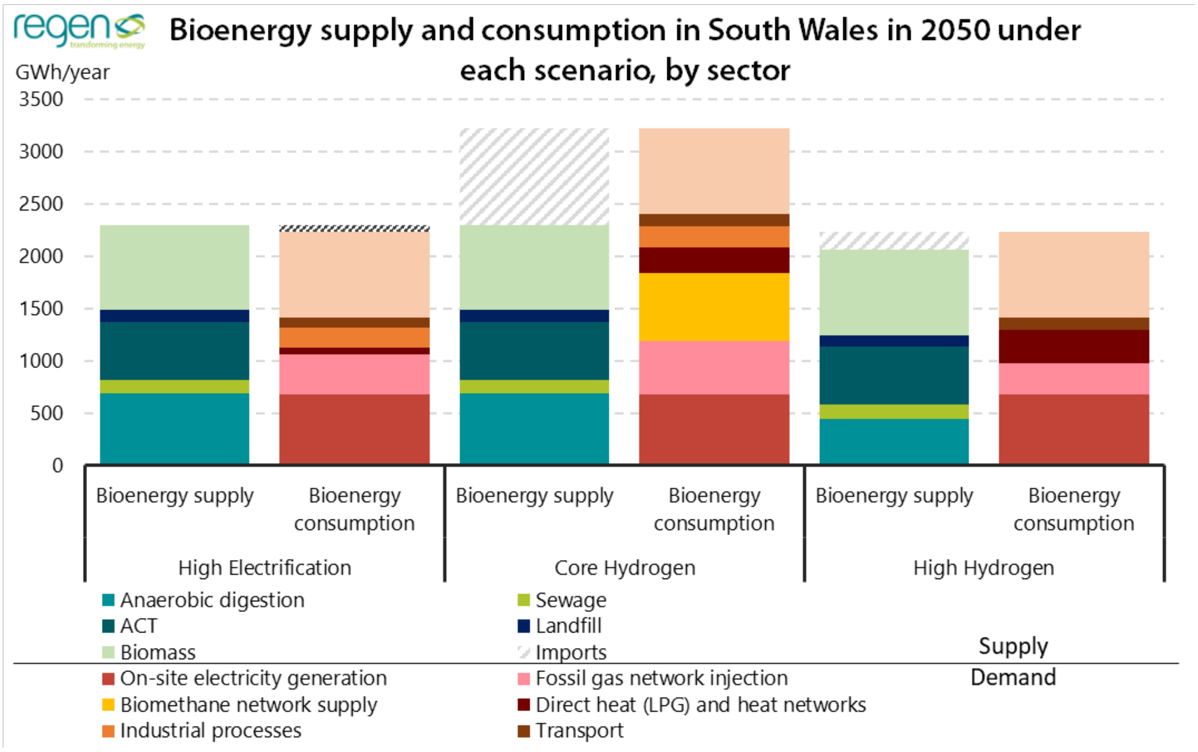

Figure 2-9: Bioenergy supply and consumption by scenario in 2050. 'Fossil gas network' relates to the existing methane gas network, which continues to supply a small number of properties, industrial sites and power stations in 2050, with a high proportion of blended biomethane and bioSNG.

The bioenergy supply and consumption within the scenarios, which are described in section 7.2 reflect just some of the many possible uses to which biomethane and biomass could be put, including industrial processes, heavy transportation and electricity generation. In the Core Hydrogen scenario biomethane is anticipated to also play an important role as a heating fuel for: domestic and commercial consumers not served by a hydrogen network, through local biomethane networks and heat networks. In all scenarios biomethane is a direct heating fuel for rural consumers and industrial areas that are currently not served by the gas network.

Increasingly it is expected that biomethane and biomass use in electricity generation and industrial processes will be accompanied by carbon capture and storage solutions to deliver negative emissions to offset those parts of the economy that are unable to fully decarbonise. However, the scenarios have not modelled a possible energy system in which negative emissions are prioritised, which could mean that bioenergy resources are actively channelled for use with carbon capture, thereby limiting their supply for transport and for domestic and commercial heating.

ix) By 2050, winter day electricity demand doubles in High Electrification, though High Hydrogen has highest total energy demand across both networks.

Winter day demand and winter day peaks are a key factor in both gas and electricity network cost and sizing. Electricity demand on a winter day more than doubles in High Electrification and increases by over 60% in High Hydrogen. The energy delivered across a 2050 winter day through the gas network is similar or lower than baseline levels. However, due to the lower energy density of hydrogen compared to methane[5], in Core and High Hydrogen, the network is likely to need to deliver a significantly higher volume of gas on a winter day than the current baseline, or deliver gas through the network at a higher pressure.

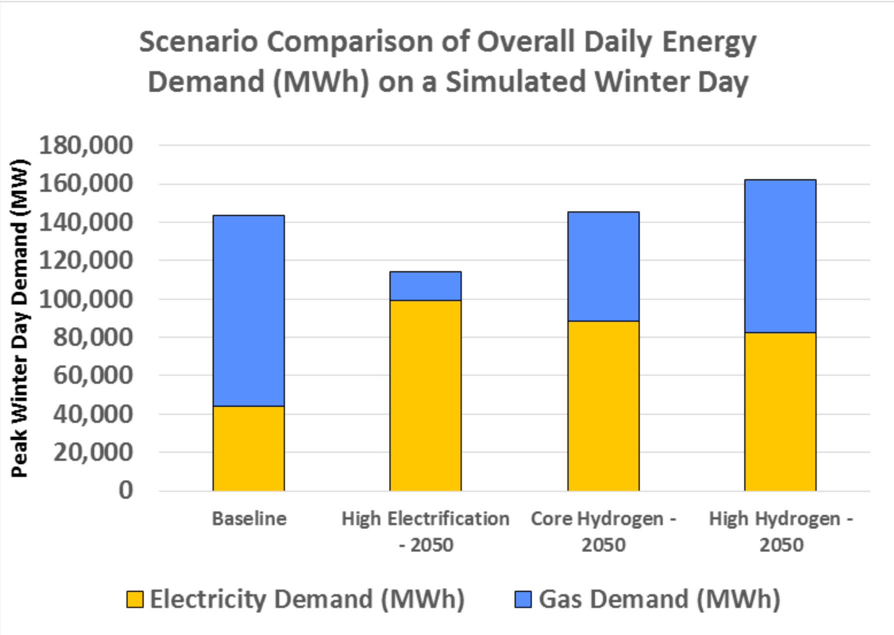

Figure 2-10 Electricity and gas distribution network total daily demand across a simulated winter day, baseline vs all scenarios in 2050 (not including CCGT)

In the High Hydrogen scenario, some 758,000 hydrogen boilers have been modelled to be installed across South Wales by 2050. When simulating a winter day in 2050 on both networks, this scenario shows the highest overall (electricity and gas) maximum network demand (MW) and daily network energy demand (MWh), see Figure 2-10 and Figure 2-11.[6] This is predominantly due to the much higher fuel-to-heat conversion efficiency (e.g. coefficient of performance) of heat pumps versus hydrogen boilers, which are seen in much higher numbers in the other scenarios.

This comparison also highlights that High Electrification could be the only scenario where overall winter day energy demand across the two networks in 2050 is notably lower than in 2019.

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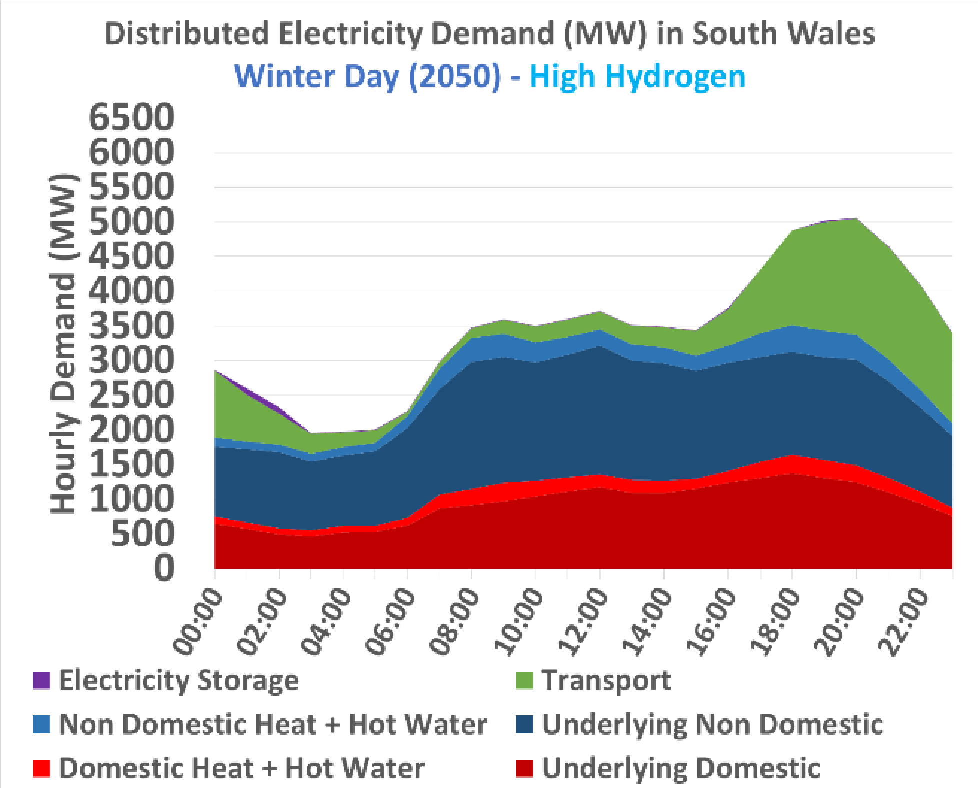
[5] By volume, gaseous hydrogen contains a third of the energy of the same volume of Methane. Source: Arup https://www.arup.com/perspectives/publications/promotional-materials/section/five-minute-guide-to-hydrogen

[6] It should be noted that the profiles that have been applied to the projections do not reflect more dynamic future profiles, e.g. smart EV charging, dynamic heat control systems and network flexibility and balancing actions. This limitation of the seasonal day modelling therefore places some uncertainty on the maximum values that are produced in the modelling and therefore they should be treated as illustrative only.



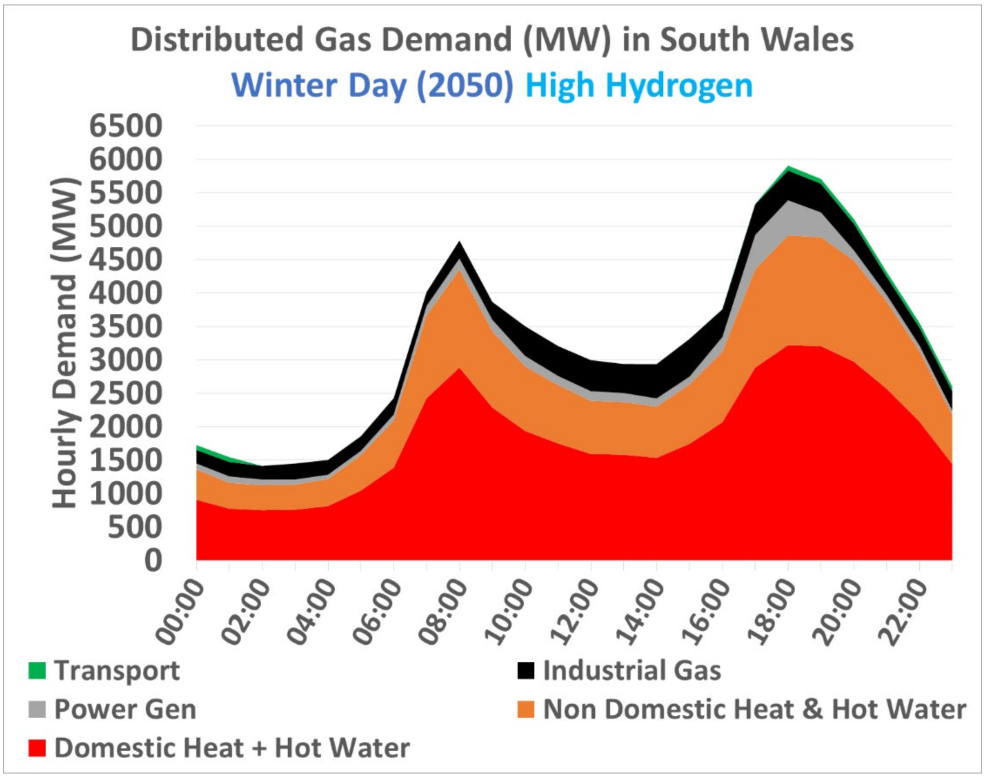


Figure 2-11 Simulated winter day electricity and gas distribution network demand profiles (not including CCGT plant) in South Wales in 2050 in the High Hydrogen scenario

x) A High Hydrogen hybrid sensitivity has similar levels of hydrogen demand by 2050 as Core Hydrogen. Though winter day demand looks similar to High Hydrogen.

A hybrid sensitivity was calculated from the High Hydrogen scenario for the analysis. The sensitivity assumed that hybrid hydrogen heating systems were installed instead of hydrogen ready boilers. This sensitivity could exist in a world where hydrogen has higher cost than assumed in High Hydrogen, and where electricity prices fluctuate significantly depending on supply and demand.

Table 2-3 and Figure 2-12 illustrate that the hybrid sensitivity assumptions reduce hydrogen usage for heating significantly to just under half. The project used benchmarks from Project Freedom[7] to assume a 70%:30% ratio for delivery of heat through the electricity and gas networks. The project also assumes a heat pump Seasonal Performance Factor of 300% by 2050.

Table 2-3 Total hydrogen and electricity demand South Wales in 2050 by scenario including hybrid sensitivity

Scenario	2019 fossil gas demand (TWh)	2050 hydrogen demand (TWh)	2019 electricity demand (TWh)	2050 electricity demand (TWh)
High Electrification	22.1	4.4	10.7	18.9
Core Hydrogen		11.1		17.6
High Hydrogen		15.2		16.7
High Hydrogen - **hybrid sensitivity**		11.4		17.8

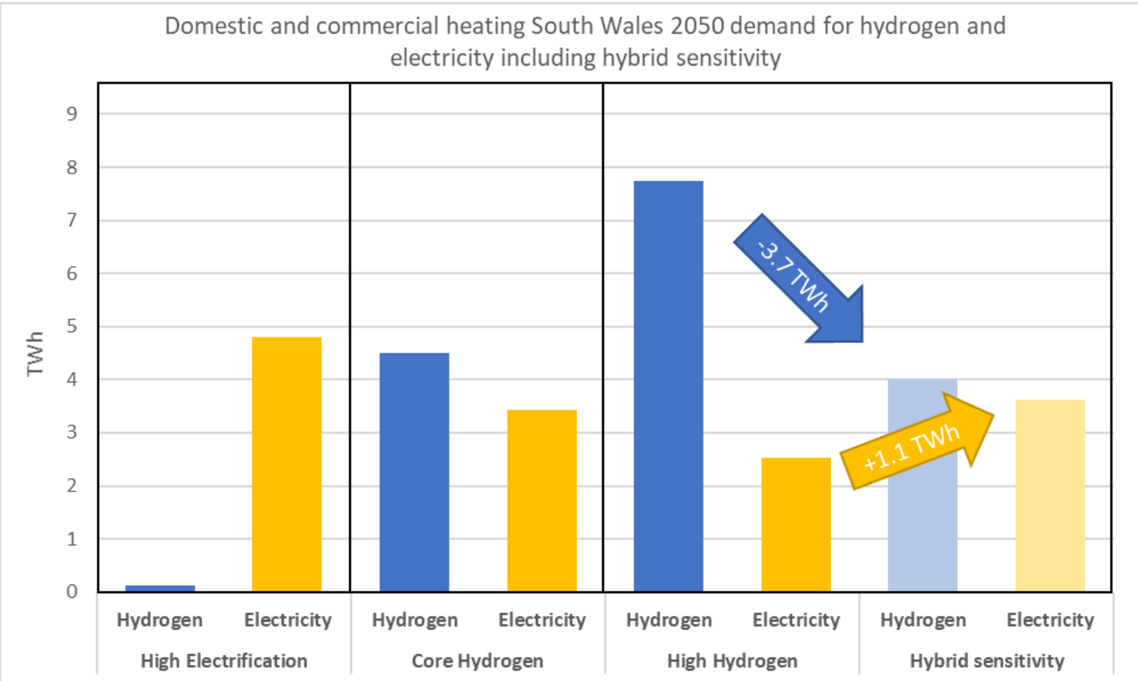


Figure 2-12 Hydrogen and electricity for building heat in 2050 by scenarios and hybrid sensitivity

[7] The analysis of the hybrid sensitivity used benchmarking information from Project Freedom conducted by WWU and WPD https://www.westernpower.co.uk/projects/freedom

There are some clear benefits to a hybrid solution, including:

- As with the High Electrification pathway, the hybrid sensitivity has the potential to support earlier heat decarbonisation due to the part decarbonisation of heat via electrification in 2020s and 2030s ahead of the hydrogen 'switch over' date. (See Figure 2-3).
- As explored in Project Freedom, the flexible and cross-vector nature of hybrids suggests there is potential to reduce network costs, in particular peak balancing costs for electricity[8]. For the consumer, assuming they face both high electricity and gas prices, it provides the opportunity to create value by switching fuels depending on relative price and/or local network conditions.

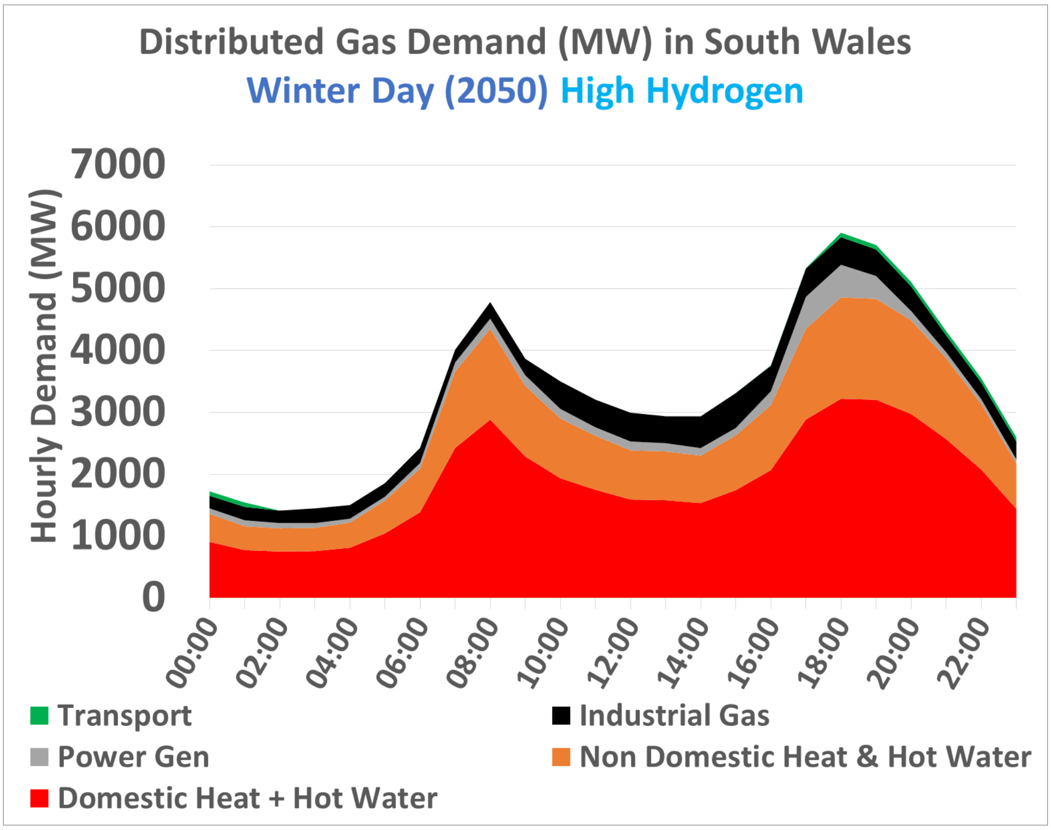
However, there are also some key challenges with a hybrid pathway:

- The cost of installing and maintaining two heating systems is likely to be a significant factor for consumers and by 2050 it is expected that many would choose either a hydrogen solution or an electrified solution, rather than maintaining two.
- The simulated winter day modelling in 2050 for the hybrid sensitivity suggests that although there are clearly some flexibility benefits for networks and consumers, the winter intra-day maximum hour and full day usage could be similar to High Hydrogen. See Table 2-4.

Table 2-4 High Hydrogen simulated maximum hourly and day usage compared to hybrid sensitivity. Not including CCGT plant.

Scenarios in 2050	Winter day max hr demand (MW)			Winter daily total energy use (MWh)		
	Electricity	Gas	Total	Electricity	Gas	Total
High Hydrogen	6,185	5,904	12,089	99,352	79,734	179,086
Hybrid sensitivity – percentage variance	-0.03%	0.1%	0%	4%	-16%	-5%

[8] See Project Freedom final report: https://www.wwutilities.co.uk/media/2829/freedom-project-final-report-october-2018.pdf



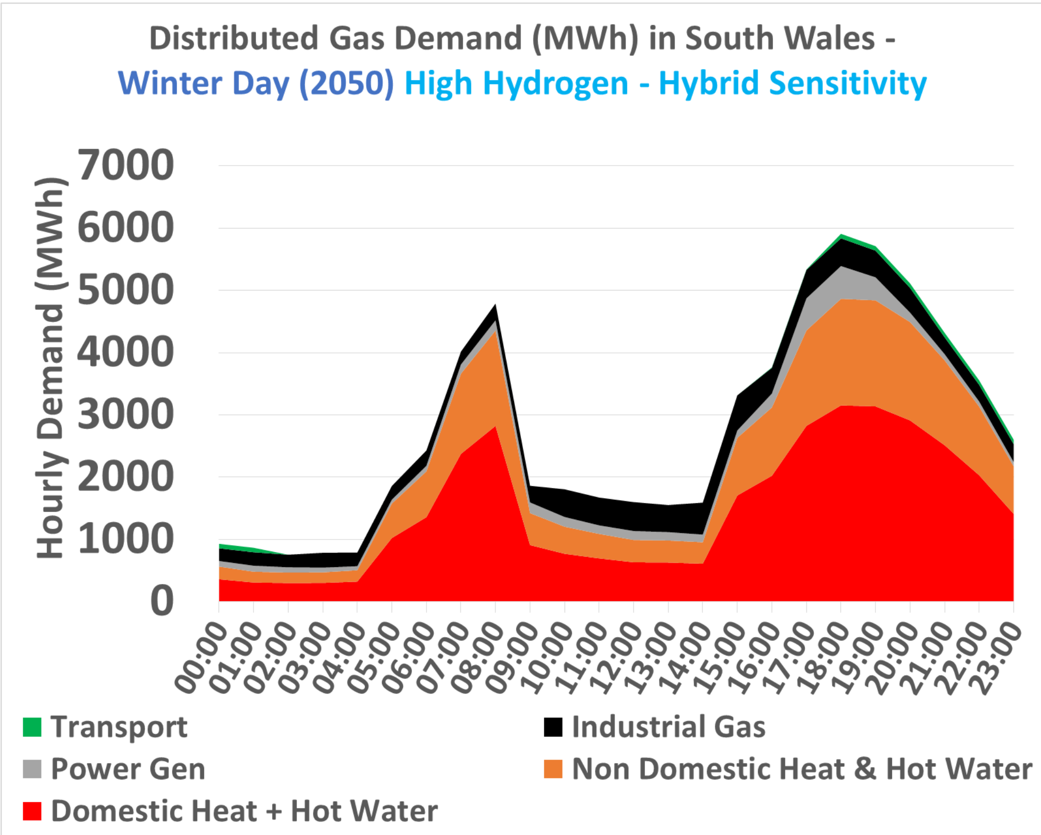
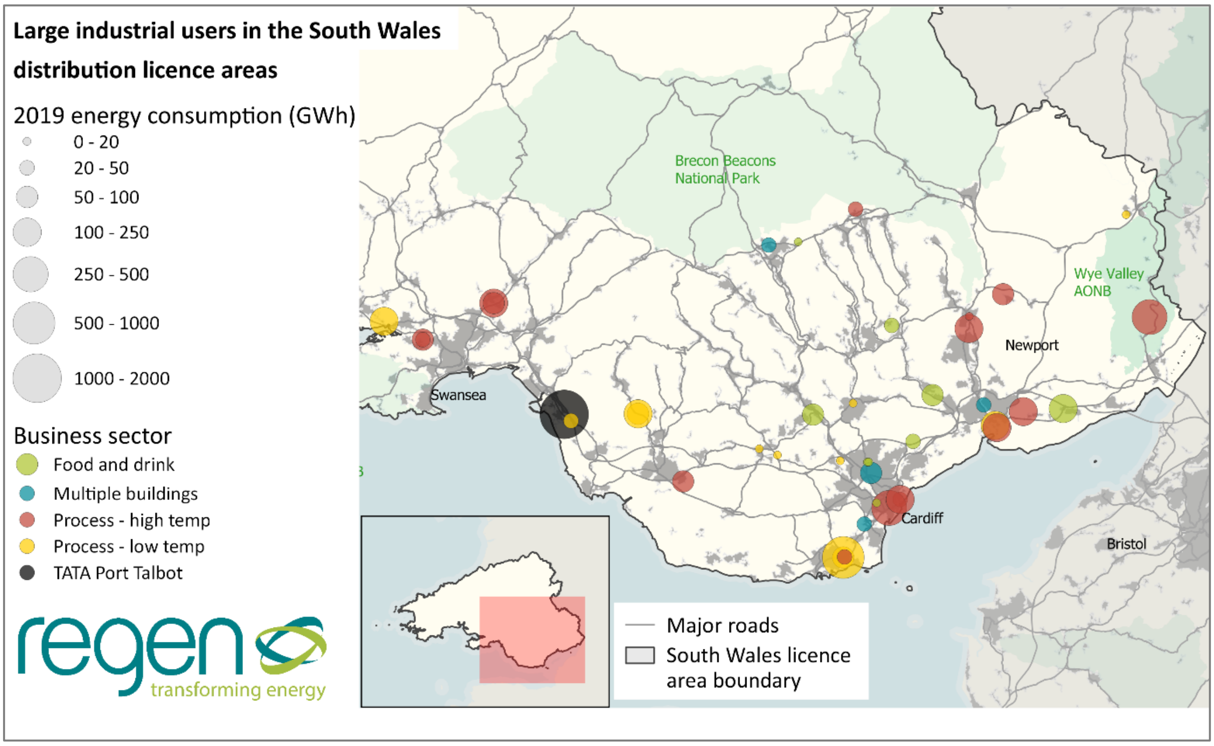


Figure 2-13 Distributed gas demand on a simulated winter day in 2050 in High Hydrogen and Hybrid Hydrogen sensitivity (not including CCGT)

Section II: Project overview and methodology



3. Net Zero South Wales Project

3.1. Introduction and background

Energy networks are fundamental to our energy system, delivering energy from where it originates to where it is needed. The UK's commitment to net zero by 2050 means that in 30 years' time little or no unabated fossil fuels can be burnt for energy. Removing the fuels which have been fundamental to our economy for over 100 years is a truly seismic change that will reinvent our relationship with energy.

In order for energy networks to plan for what will be needed from them in the future, both electricity and gas networks need to understand how a number of key transformational changes will impact their local networks in the short, medium and longer term.

These changes include:

- The decarbonisation of heat and transport
- The increase in renewable electricity generation at all scales
- The production, supply and use of low carbon gases such as hydrogen and biomethane

However, developing a local understanding of the future decarbonisation pathway is not straight-forward. Although all regions of the UK will contribute to the net zero targets, it is clear that not all regions will support the same technologies, pathways, or degrees of change.

In order to understand the impact of future energy scenarios on the distribution networks in different regions, it is important to rationalise the UK's net zero targets, technology pathways and future energy demand considerations, with the realities of regional networks, resources, politics and geography across the UK.

In addition, although there is some continuing uncertainty about how net zero will be delivered in the UK, it is clear that an efficient future energy system will need to be increasingly flexible and cross-vector, dynamically converting energy for use as power, heat or for transport. As a result, it is important that the different energy vectors become much more integrated, co-dependent and joined-up in their long-term planning, forecasting and operation.

Part of this transition will be seen in the increase in technologies that are flexible and able to react to system needs, and designed to directly utilise either, or both, the gas and electricity networks. These multi vector technologies include gas fuelled power generation, hydrogen electrolysis, hybrid heating systems, heat networks, new transport fuels, green gases and other forms of bioenergy.

The interaction between networks, which determined the Net Zero South Wales project scope, is illustrated in Figure 3-1.

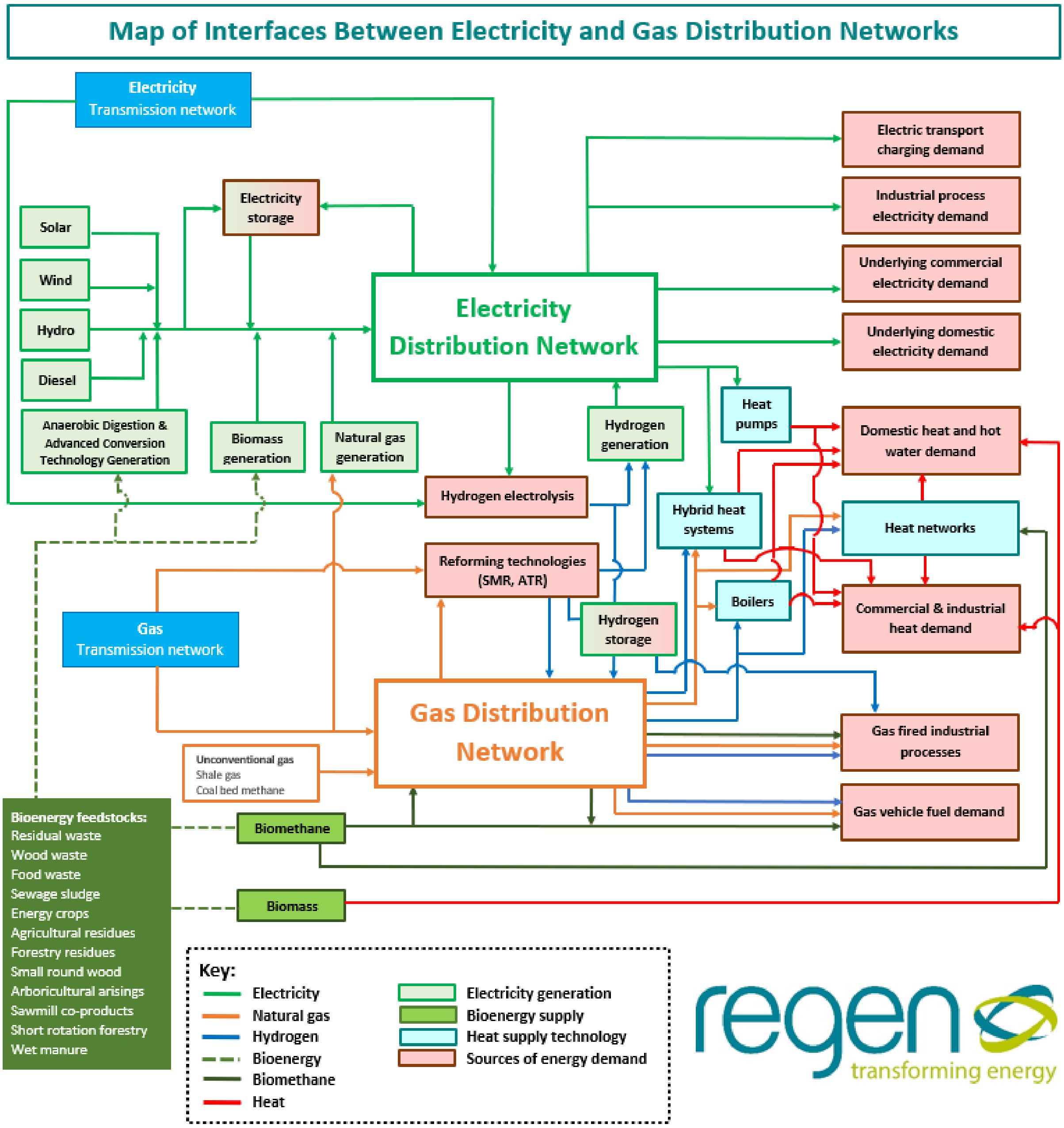


Figure 3-1 Map of interactions between gas and electricity distribution networks

This report summarises the outputs and development of a new cross-vector scenarios methodology for distribution networks, through exploring the WPD and WWU South Wales licence areas and the local implications of different decarbonisation pathways.

The main output of the analysis is a dataset that details for the three different scenario pathways the different technologies and sectors which might be expected to connect to different parts of the gas and/or electricity network out to 2050. This report accompanies that dataset and records the key assumptions and methodologies used in the scenarios.

These scenarios outputs are intended to help network gas and electricity operators to identify key impacts and areas for network investment, and to understand the most cost-effective pathways for different regions and the local areas within them.

3.2. Innovation objectives

The Net Zero South Wales 2050 project is an innovation partnership between Regen, WPD and WWU to develop distribution gas and electricity net zero scenarios in South Wales up to 2050. The work has been funded by the Network Innovation Allowance (NIA) programme.

Regen has worked with both WPD in 2018 and WWU in 2019 to undertake Distribution Future Energy Scenario (DFES) studies for their separate electricity and gas distribution networks in South Wales. A DFES process creates bottom-up, stakeholder led, locally relevant decarbonisation pathways for licence areas and regions. The DFES dataset produced can then be used by the distribution networks to plan how the network might need to evolve, and where and when network infrastructure investment, and non-network solutions, might be needed. As outlined in Figure 3-2, the scenarios are an important first step in a longer network planning and investment appraisal process.

This project brought together the outputs and methodologies of the two earlier DFES studies to create a new integrated DFES covering both networks. This involved working together with both networks to update, merge and consolidate the data, evidence and approaches developed for previous single network studies. The project also used trajectory and milestone analysis to extend the previous medium-term scenarios from 2035 to achieve a 2050 net zero outcome for South Wales.

There were two key innovation and learning objectives for the project:

1. To develop a detailed understanding of the net zero implications on energy networks at a licence area and distribution network level. South Wales was chosen as a region that faced some unique challenges and opportunities in decarbonisation pathways. These are outlined further in section 3.

2. To develop new processes and methodology for a cross-vector DFES study. Working together with both WPD and WWU to combine their respective knowledge, data and network information to provide DFES outputs that could be utilised to support both gas and electricity network development. A separate report has been produced that outlines the key learning points from this methodology process.

The project analysis and outputs were cognisant of the increasing cross-vector challenges faced by distribution networks. Within this, it was important to develop a shared understanding of the increase in deployment, operation and role of key disruptive and cross-vector technologies such as hybrid heat solutions and hydrogen networks.

In order to extend learning about the cross-vector technologies, the project also produced an illustrative 'simulated' day analysis in both summer and winter, in the years 2035 and 2050. This allowed the project to explore further project learnings about the separate network processes that use and process DFES data to produce network load analysis. The methodology for this simulated day analysis is summarised in section 566.6 while some of the headline results are shown in section 8.

This summary report has been developed to outline the approach, methodology and assumptions made to produce the scenarios dataset in WPD and WWU South Wales licence areas, as well as the insights that relate to South Wales. It is intended as a companion report to explain the dataset results and analysis. This report also touches on some of the challenges and innovation involved in the process.

A separate **Learning Report** has been produced that expands these areas and focuses on the methodology and innovation related to DFES itself and the process of undertaking integrated network scenarios and analysis.

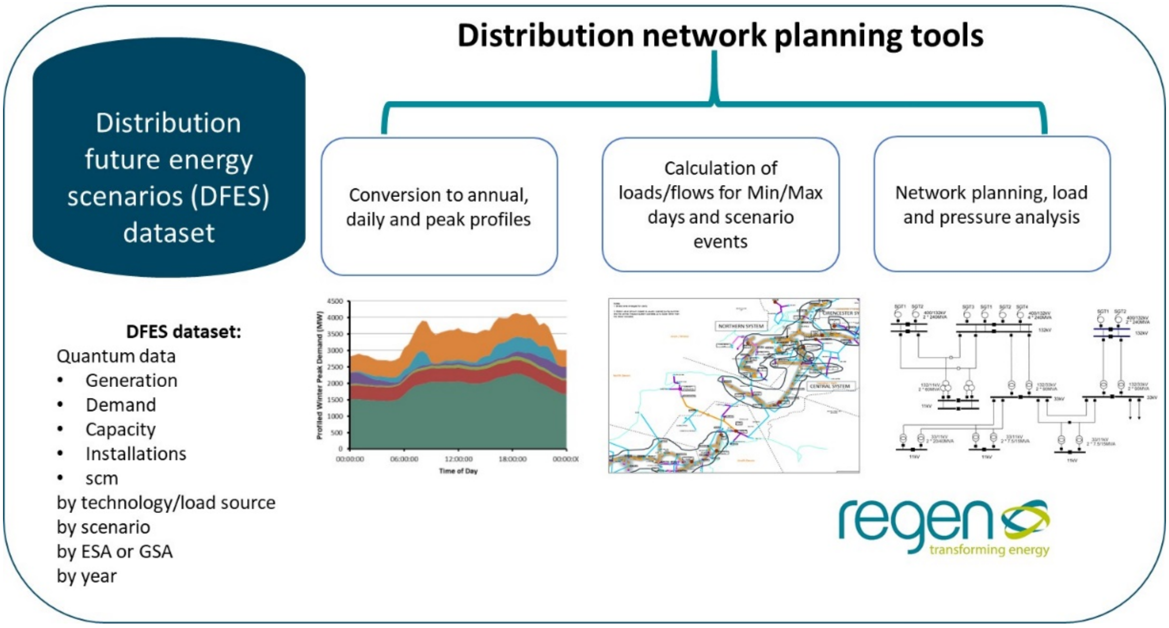


Figure 3-2 Network planning and use of DFES data by networks

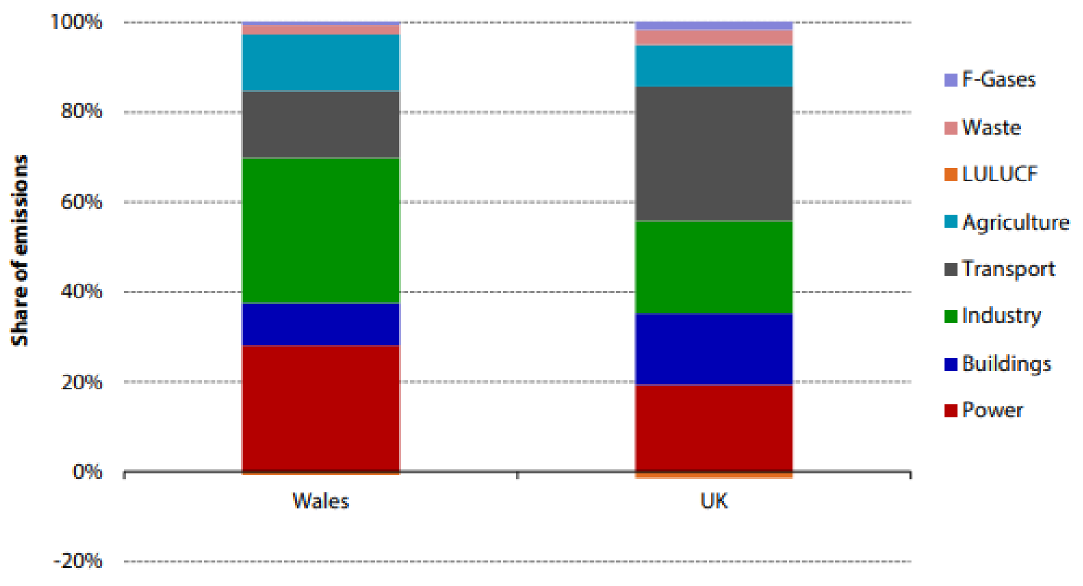
4. South Wales context

A key objective of the project was to explore the implications of the new net zero target on distribution energy networks in a specific licence area. The scenario projections have been evidenced by bottom-up research that includes geographical, socio-economic and political factors. South Wales was chosen as an area where the gas and electricity licence areas broadly corresponded, but also as a unique part of the UK, where decarbonisation has strong political support, along with high renewable energy potential and resources.

South Wales also faces significant challenges with decarbonising the very high energy demand and carbon emissions of its industrial base, including Tata Steel works at Port Talbot, which is primarily powered by fossil fuels. These relative differences to the UK average sector emissions are illustrated by the Committee on Climate Change analysis of Welsh carbon emissions shown in Figure 4-1.

The region is also already facing some significant constraints on new generation capacity connecting to the electricity network, with lack of capacity on both transmission and distribution network. These constraints are likely to continue to impact new generation connections in the short and medium term.

Sectoral shares of emissions in Wales and the UK (2015)



Source: NAEI 2017.
Notes: Transport includes emissions from international aviation and shipping.

Figure 4-1 Welsh share of emissions compared to the UK average share, Source: Committee on Climate Change. https://www.theccc.org.uk/wp-content/uploads/2017/12/CCC-Building-a-low-carbon-economy-in-Wales-Setting-Welsh-climate-targets.pdf. P.29

4.1. Energy use in South Wales

With over 1 million households and 2.3 million people, South Wales is home to over 80% of the Welsh population and the three biggest urban areas: Cardiff, Newport and Swansea. In South Wales 82% of the population live in areas served by the mains gas network.

Average household electricity use is 5% lower than the UK average. However South Wales has relatively high non-domestic energy use per capita at 14,000 kWh per year, compared with just 8,000 kWh in the UK[9]. Although this figure does not include the usage for the largest industrial users such as Tata Steel, it still reflects the continued energy demand of South Wales's large industrial base.

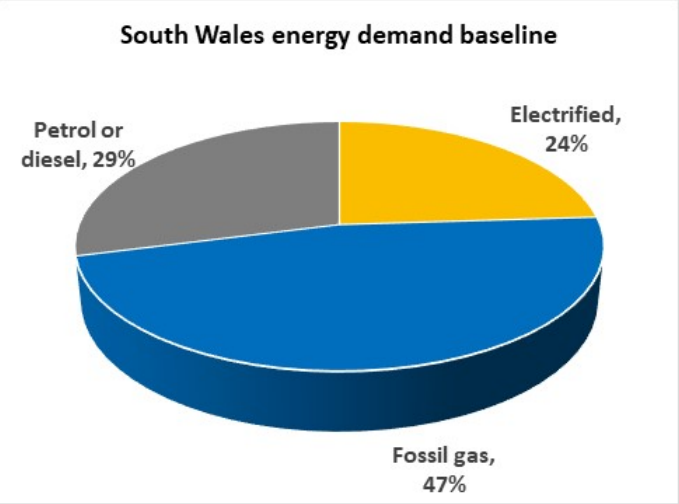


Figure 4-2 South Wales baseline proportion of energy demand by sector. Source: BEIS

Annual energy demand in South Wales has reduced and this is projected to continue to 2050. Despite a 6% population increase between 2005 and 2017, in the same period total energy use in South Wales reduced across all local authority regions, from a total of 86.9 TWh in 2005 to 67.5 TWh in 2017: a reduction of 22% over a 12-year period[10]. The energy delivered by the South Wales gas distribution network fell by 13%, from 33 TWh to 29 TWh[11], with a slightly smaller reduction in electricity but only a very small (1.6%) reduction in transport energy use.

Given that productivity and population have increased over the same period, it is assumed that energy efficiency improvements to buildings have been important in reducing demand for electricity and gas and are likely to continue to do so. The Welsh Government's Warm Homes Programme through Nest[12] and Arbed[13] support this objective by providing funding for energy efficiency improvements to low-income households and deprived areas in Wales.

The UK government has stated an intention to bring all homes in England and Wales to an Energy Performance Certificate (EPC) 'C' rating by 2035[14]. The Welsh Government also commissioned a report in 2019 that recommended moving to EPC rating of A by 2050[15].

[9] Source: BEIS sub-national energy statistics 2017
[10] Source: BEIS sub-national energy statistics 2017
[11] Source: Wales & West Utilities 2019 Long Term Development Statement: https://www.wwutilities.co.uk/media/3166/2019-long-term-development-statement.pdf
[12] Nest website: https://nest.gov.wales/en/
[13] Arbed website: http://www.arbedambyth.wales/arbed-am-byth---our-services.html
[14] https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/1730/173005.htm
[15] https://gov.wales/sites/default/files/publications/2019-07/independent-review-on-decarbonising-welsh-homes-report.pdf

4.2. Welsh Government and regional energy strategy

South Wales has considerable renewable energy resource potential, and the Welsh Government has set ambitious decarbonisation targets to encourage new project development. In May 2019, the National Assembly for Wales was the first parliament in the world to pass a Climate Emergency and has now put an emissions reduction target of 95% by 2050 into law[16]: a level recommended by the UK Committee on Climate Change in recognition of the agricultural and industrial base. The Welsh Government has been supporting this by developing specific energy targets, with a target for Welsh renewables to generate electricity equal to 70% of Wales' consumption by 2030 (the 2019 level is 50%) as well as a target for 1 GW of locally owned renewable energy projects.

The Welsh Government have also recognised the importance of the energy networks and systems in the transition. The Welsh Government's 'Prosperity for All: A Low Carbon Wales'[17] noted the system benefits of cross-vector hybrid heating systems as well as the potential for low carbon gas and biomethane to play a key part in decarbonisation.

There have already been important steps taken to turn these Welsh targets into action. The Welsh Government Energy Service has been working in partnership with the Carbon Trust and Regen to develop regional energy strategies to 2035 for each of the four regions of Wales. For the Swansea Bay City Region, the development of the strategy builds on previous work by Regen for the Institute of Welsh Affairs' Re-energising Wales project on decarbonising the region's energy system[18].

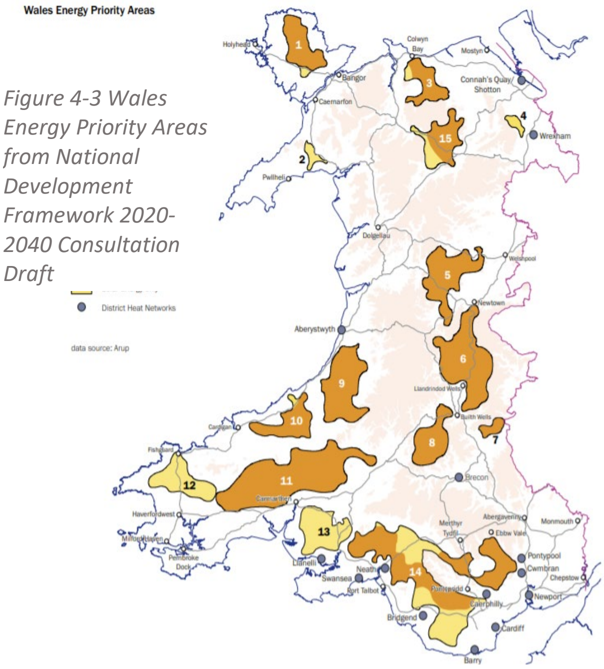


Figure 4-3 Wales Energy Priority Areas from National Development Framework 2020-2040 Consultation Draft

The Welsh Government has also taken a significantly different approach to planning for renewable generation compared to the one adopted in England. They recently consulted on updating its wind and solar planning policy through the draft National Development Framework (NDF). The draft NDF sets out Priority Areas for solar and wind energy where there is a presumption in favour of development and where the principle of landscape change is accepted[19]. Outside of the Priority Areas there is also considerable potential resource and projects will also be considered, where they demonstrate local social, economic and environmental benefits, and no unacceptable adverse effects.

As a result of the supportive policy and approach, South Wales has experienced a significant growth in distributed renewable generation in the last decade, although this has slowed in the last few years.

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[16] https://gov.wales/sites/default/files/publications/2019-10/energy-generation-in-wales-2018.pdf

[17] https://gov.wales/sites/default/files/publications/2019-06/low-carbon-delivery-plan_1.pdf

[18] https://www.regen.co.uk/publications/swansea-bay-city-region-a-renewable-energy-future/

[19] Welsh Government (2019) *National Development Framework 2020-2040 Consultation Draft: 7 August – 1 November 2019* https://gov.wales/sites/default/files/consultations/2019-08/Draft%20National%20Development%20Framework.pdf

With renewed UK policy support recently being announced[20], South Wales is now likely to see an increase in installations of renewable generation and other low-carbon technologies.

4.3. Industrial usage

The plan for decarbonising the industrial base will be crucial for South Wales. Industrial usage accounts for over 30% of carbon emissions in the South Wales region. Port Talbot steelworks on its own represents around 50% of industrial emissions and 16% of total emissions in Wales[21].

This presents both a challenge and an opportunity for decarbonisation pathways in South Wales. The big industrial loads have the potential to provide base loads for developing hydrogen networks for example, and initiating the investments needed to decarbonise other sectors.

The South Wales Industrial Cluster project[22] is currently working on a roadmap for decarbonising its big industrial users including the steel works. The industrial sector has been modelled separately to other commercial demand and different pathways for net zero decarbonisation have been developed from information provided by the industrial clusters.

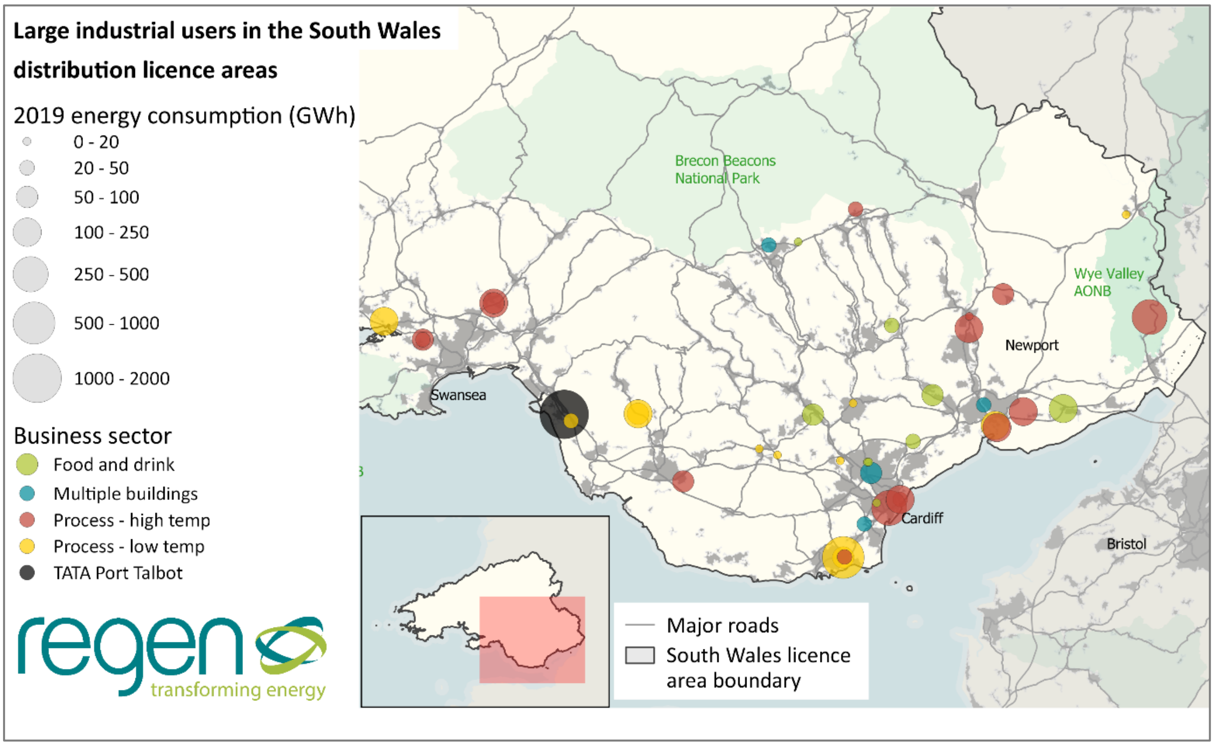

Figure 4-4 Location and sector of large industrial energy users in South Wales

Although over the last 12 years industrial and commercial energy demand has dropped significantly (31% fall in energy demand between 2005 and 2017), a modelling assumption has been made that the total level of industrial activity remains static during the scenario period. Reductions in demand from

[20] https://www.current-news.co.uk/news/onshore-wind-brought-in-from-the-cold-as-government-announces-pot-1-cfd-auction

[21] Source: Committee on Climate Change. file:///C:/Users/pmaltby/Downloads/CCC-Building-a-low-carbon-economy-in-Wales-Setting-Welsh-climate-targets.pdf

[22] https://www.swic.cymru/

the baseline are therefore due to fuel switching, new processes, and efficiency rather than deindustrialisation.

More details on the approach taken to both small-scale and large-scale industrial processes in the scenarios can be found in section 7.4, with further information in the appendix pages 84-132.

4.4. Network investment and constraints

The rapid shift in how energy is used and generated at transmission and distribution levels has already caused significant challenges to energy networks. South Wales already has 1400 MW of renewable generation connected and with its distributed electricity network now reaching capacity, further connections are likely to require further network upgrades and increased flexibility.

To address this, WPD currently has two Active Network Management zones in the South Wales region, Swansea North and Pembroke, and a further two in development in Rassau and Aberthaw. In these network zones, new connections can be offered a lower connection cost in return for a constrained connection where the service can be interrupted if the network is under stress[23]. WPD's flexible power initiative is also looking to procure demand management services in eight zones to the north and west of the region.[24]

The area is also subject to a transmission network constraint:

"The South Wales region has seen unprecedented growth in levels of embedded generation of all types, and specifically plant that is to be used for supplying energy at peak demand times. Unlike other areas of the Transmission Network, which have recently seen significant closures large thermal generation, there have been none in South Wales. These factors, together with small reductions in levels of demand in the area, has in the short term, reduced the capacity available for some types of generation connections in the South Wales Group." (National Grid Letter to WPD, 19 May 2016)

Pending upgrades to the transmission network, expected sometime between 2026 and 2028, new projects for controllable electricity generation technologies (that can run at peak times) are not currently able to connect to the network in the South Wales region. This connection embargo does not include onshore wind or solar, or technologies under 1 MW. It has however, impacted on the short and medium term development of battery storage, along with gas generation and technologies such as energy from waste or bioenergy that generate electricity.

The 1,560 MW Aberthaw Coal Power Station officially closed at the end of March 2020. The owners are investigating a range of options for the site's redevelopment and/or sale. The impact of the closure on the transmission and distribution networks and the current transmission statement of works embargo will depend on what happens to the site going forwards.

[23] https://www.westernpower.co.uk/Connections/Generation/Alternative-Connections/ANM-Further-Info.aspx
[24] https://www.flexiblepower.co.uk/map-application

4.4.1. Off gas network areas

As illustrated in Figure 4-5, the region also has many areas where customers are not connected to the distribution gas network, mainly to the north and west of the region. These areas have fewer pathways for decarbonising heating specifically and are therefore treated separately in the scenario modelling. The size of these off gas areas is expected to expand towards 2050, the extent of this varies depending on the scenarios and whether any new hydrogen network is widespread or restricted to “core” demand areas.

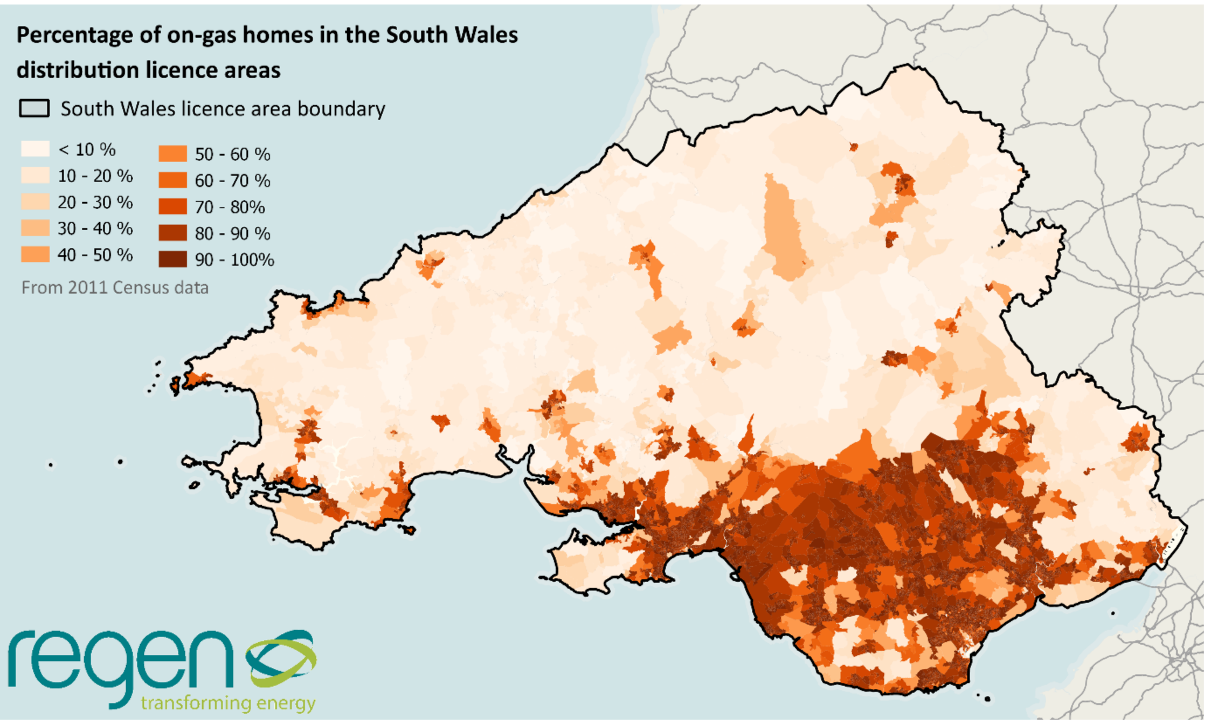

Figure 4-5 South Wales, proportion of households on and off-gas grid in 2019

4.5. New housing and commercial developments

The location of new domestic and commercial developments is also important for the DFES analysis to identify where new households and business demand might arise, but also where new technologies (such as heat pumps, heat networks or solar rooftop PV) are more likely to be installed. The Welsh Government have committed to clean energy sources for all new homes from 2025[25].

To understand where these new developments are likely to be located, data was updated from the earlier WWU and WPD DFES studies that had been collected from local plans to identify the locations, sizes and build trajectories of planned new developments. To update the analysis, each local authority was contacted in early 2020 to review the previous data with a focus to ensure that the projections were correct for the largest strategic sites.

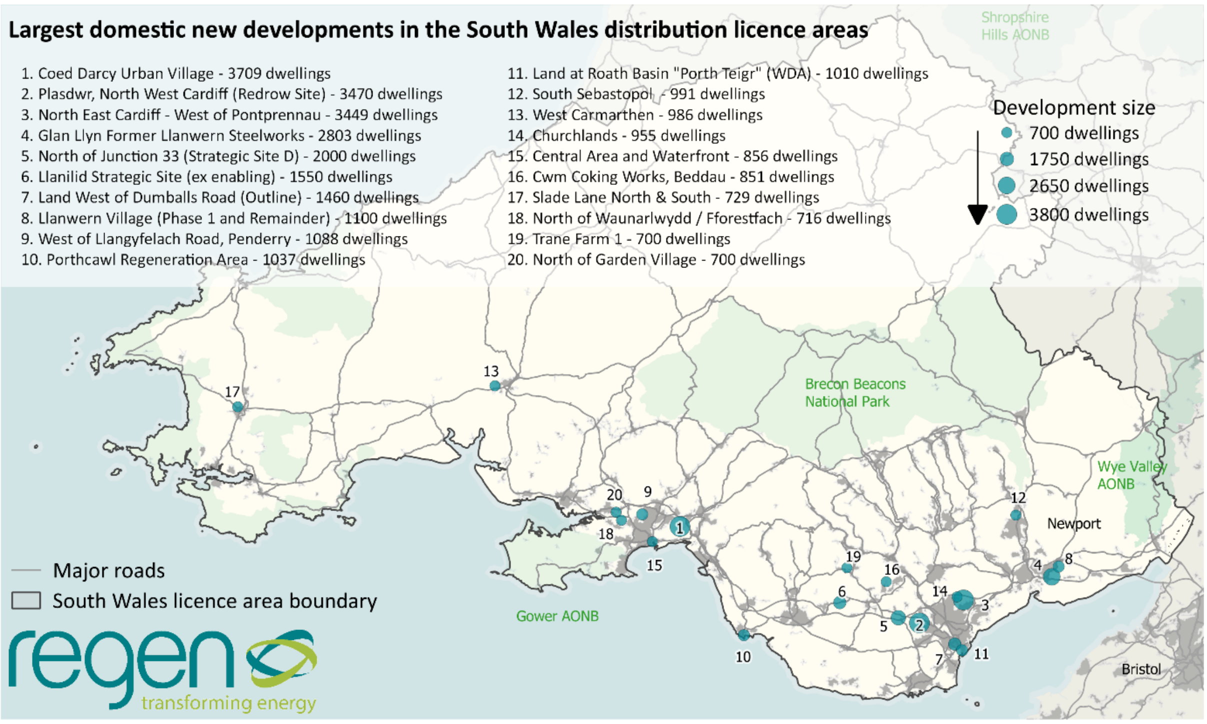

Figure 4-6 Largest domestic new developments in South Wales

The actual locations of developments are important for a medium term DFES analysis, however extending the analysis to 2050 meant that projections needed to be made for developments considerably beyond the normal planning period horizon (typically 10 – 15 years). To do this, Office of National Statistics (ONS) projections of households per local authority were used to provide trajectories to 2041, and a linear extrapolation of these ONS projections was then used to extend the trajectories to 2050. A small number of local authorities see a decrease in households in the ONS data; this was not reflected as a decrease in dwelling numbers.

As the ONS projections only provide data to local authority level, an updated methodology was developed using historic trends and distribution analysis to identify more granular geographical areas within the region where new developments were likely to occur.

[25] https://gov.wales/all-new-homes-wales-be-heated-and-powered-clean-energy-sources-2025

Analysis of planned developments and EPCs registered for new build properties since 2009 evidenced that areas which were peripheral to existing urban or development areas, with a density of 5-50 dwellings per hectare, were particularly likely to host strategic developments, although all areas of existing housing saw an underlying level of house building.

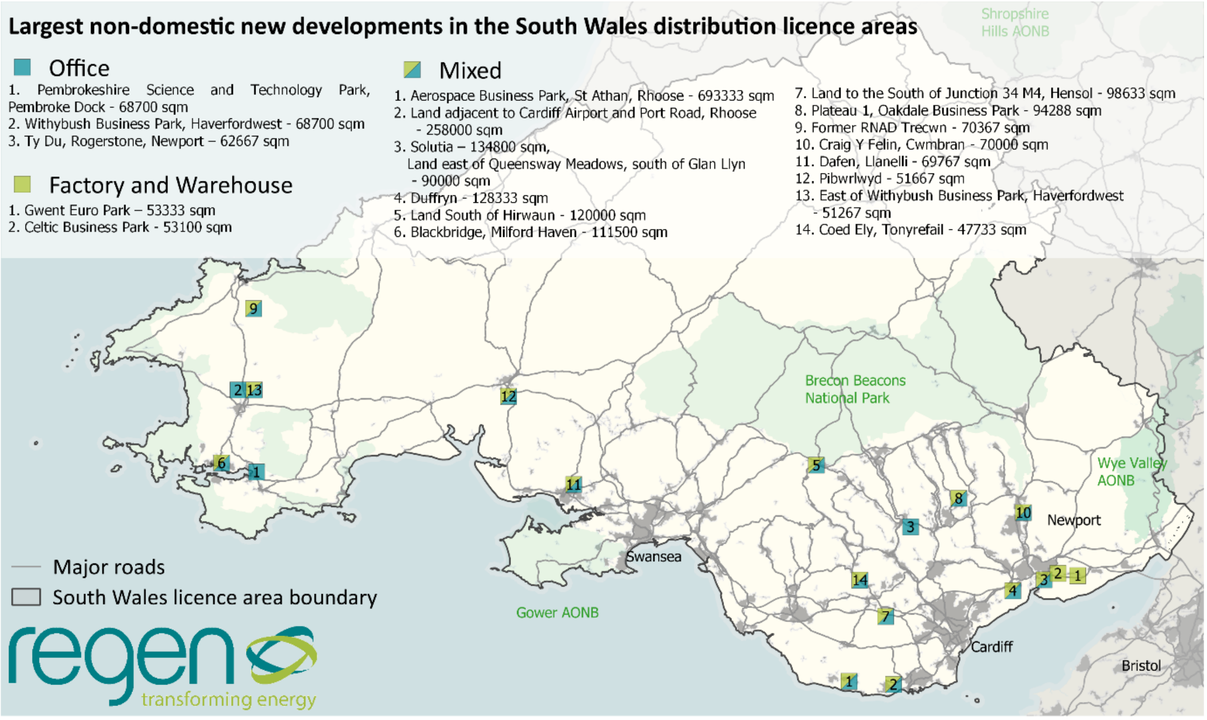

Figure 4-7 Largest non-domestic new development sites in South Wales

5. Framing of scenario pathways

The DFES process normally uses the annual National Grid Future Energy Scenarios as a guide and structure for scenario trajectories, however the latest available version, FES 2019, did not contain all the data and information required to steer the net zero trajectories needed for this project as it was based on the older 80% carbon reduction targets.

Therefore, in order to project a series of credible net zero pathways, the project used a number of sources to set parameters and steer the projections. These included the FES 2019 net zero sensitivity[26] and early information from National Grid about the future FES 2020 structure, along with information from the Committee on Climate Change Future Ambition scenario[27]. It was clear from all of the source reports that a net zero target provides the UK with fewer potential pathways by which the country will be able to fully decarbonise. Unlike the previous 80% decarbonisation target, no sector will be able to remain as "business as usual". To achieve a net zero carbon outcome there is no possibility for unabated burning of fossil fuel for heat for buildings or power in any sector.

These studies also showed that in some sectors the decarbonisation pathway is more consistent and certain, for example it is increasingly likely that domestic and small vehicles will have a mainly electrified pathway. However, in other sectors, such as heat, there remain some critical decisions about the future pathway and preferred technology routes. These decisions are likely to be specific to different regions and highlight the importance of whole system and local area energy planning. To note that though the levels distribution level technologies and demand have been projected to be consistent with net zero, the scenarios project a small amount of residual emissions by 2050. It is assumed that negative emission technologies would be used to remove these remaining emissions.

The supply and use of hydrogen is the greatest area of potential divergence. Hydrogen seems set to become an important fuel for some forms of transport and industrial processes, however whether it will become a ubiquitous heating fuel in commercial and domestic buildings will depend on its cost compared with electrical solutions. This will in turn will depend on the cost of feedstock, production processes and their efficiency, along with carbon capture and storage costs. There will also be seasonal and daily hydrogen storage and distribution costs.

In order to reflect this varying level of certainty, the project created a series of scenarios that focused on particular cross-vector 'variable' areas. This meant keeping some 'core factors' the same across the scenarios, for example electrification of domestic vehicles and heating in existing off gas properties. Projections for technologies which only directly impacted one network, such as the level of renewable generation, were also set to be consistent with net zero but not varied across the scenarios.

This meant that the analysis was then able to focus the scenarios, learnings and insights on 'cross-vector variables' such as heat, industrial processes and heavy transport. Different pathways for these sectors were explored in different scenarios and combined with core factors to create three discrete scenario pathways. A core assumption is that, given the expectation of higher heating fuel costs for both electricity and hydrogen, compared to fossil gas, greater levels of building and process energy efficiency will be required, as well as more efficient heat pumps, boilers and other heating technologies. This analysis approach to net zero is outlined in Figure 5-1 .

[26] http://fes.nationalgrid.com/
[27] https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/

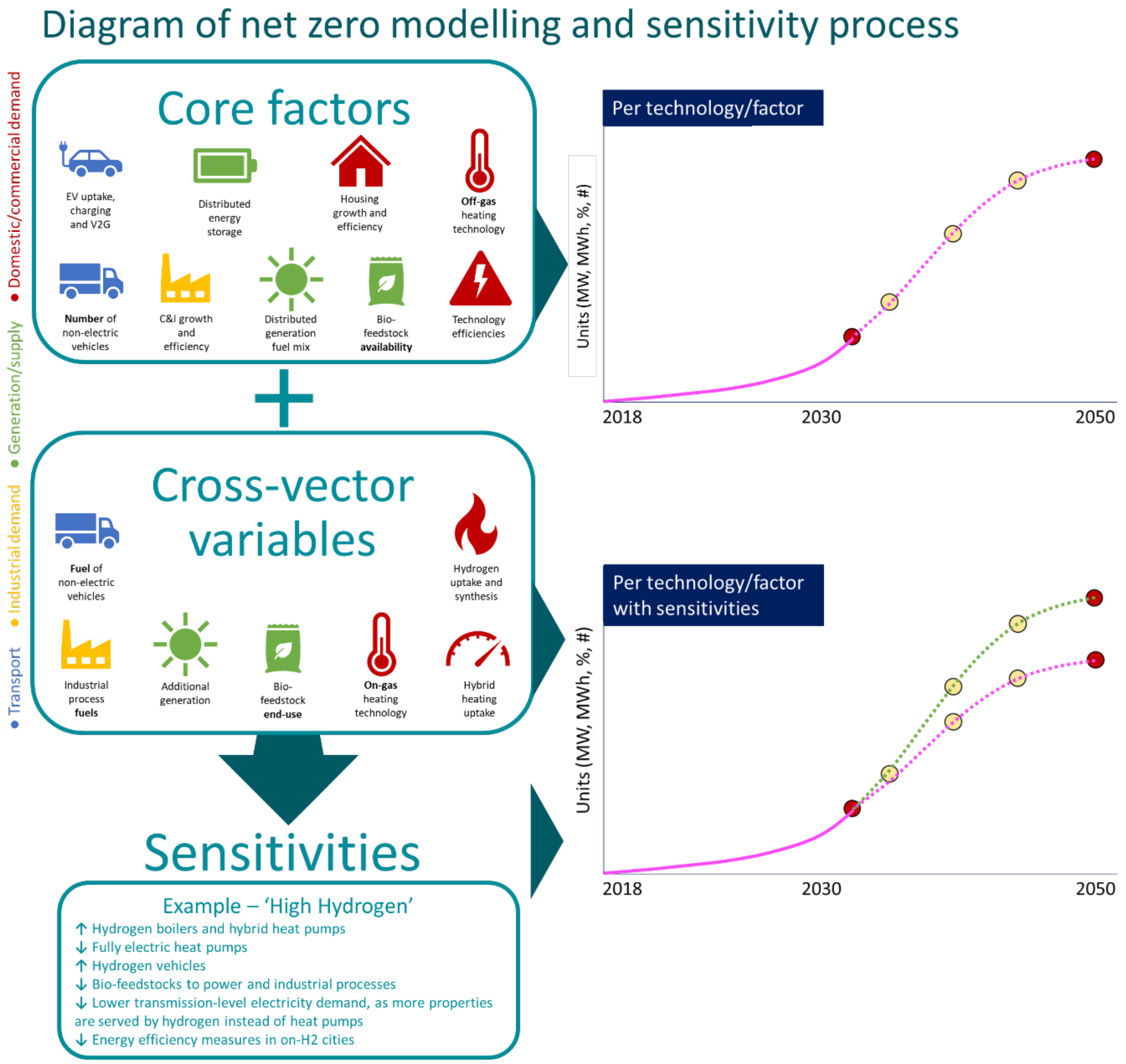

Figure 5-1 Core factors and cross-vector variables

5.1. Introduction to the scenarios

The project used this core factor and variable process to define three different scenario pathways to achieve net zero in South Wales by 2050. The key factor in each scenario was the different ways that the region might primarily choose to decarbonise domestic and commercial heat, either through electrification, or with a switch-over to hydrogen. This was also guided by the scenarios expected in FES 2020[28].

In all scenarios the critical factor considered was the availability and relative cost of hydrogen by the mid-2030s, the point where final decisions will need to be made about the pathway for heat decarbonisation. Across the scenarios, the assumption was made that, due to energy efficiency, increased costs and manufacturing constraints, consumption of low carbon gas would be less than the current consumption of fossil gas. It was assumed for the purposes of modelling that the majority of low carbon gas is hydrogen, with biomethane used mainly for rural consumers, industrial clusters and discrete biomethane networks.

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[28] http://fes.nationalgrid.com/media/1460/introducing-the-fes-2020-scenarios.pdf

Scenario	Description of energy use and generation in 2050
High Electrification	With the exception of a few large consumers, fossil gas is no longer delivered through the distribution network. The great **majority of domestic and commercial heat is electrified** through heat pumps and/or ultra-energy efficient homes using electrical resistive heating, a small number of off-gas homes are heated through bio-LPG. Some urban areas have low carbon heat networks serving clusters of domestic and commercial buildings. There is also a small number of local biomethane gas networks. **Hydrogen distribution is limited to members of the industrial cluster** who cannot feasibly electrify their processes. Low carbon gas (either hydrogen, biomethane or syngas) also has an important role in larger (HGV) transport. All low carbon and **renewable electricity generation in the area reaches optimum capacity** while a proportion of generation (modelled excess assumed to be 16%) is electrolysed to manufacture hydrogen. Waste and bioenergy plants primarily produce biomethane for heating, heavy transport and industrial processes but also act as peaking generators as required. There is also a high level of battery electric storage to manage peaks. This scenario description is similar to the yet to be published **FES 2020 Consumer Transformation scenario.**
Core Hydrogen	With the exception of a few large industrial consumers who have carbon capture technologies, fossil gas is no longer delivered through a generally available gas distribution network. The densest areas of the existing gas network, in the greater urban **areas around Cardiff and Swansea, are converted into discrete networks to deliver low carbon hydrogen.** The majority of hydrogen heating is delivered through hydrogen boilers, with a small number of hybrid systems combining heat pumps with a hydrogen boiler back-up. In some areas outside the hydrogen network, there are discrete biomethane gas networks, but the **majority of the remaining gas customers are electrified** during 2030s along with pre-existing off gas areas. A small number of off gas homes are also heated through bio-LPG. Low carbon gas (either hydrogen, biomethane or syngas) also has an important role in larger transport. All low carbon and **renewable generation in the area reaches optimum capacity** with a proportion of generation (modelled excess assumed to be 32%) is electrolysed. Waste and bioenergy plants primarily produce biomethane for heating, heavy transport and industrial processes but also act as peaking electricity generators as required. There is also a medium level of battery electric storage to manage electricity peaks. This scenario envisages hydrogen demand for heat at levels similar to **FES 2019 Net Zero sensitivity.**
High Hydrogen **(with hybrid sensitivity)**	This third scenario explores a future where **the majority of the gas network is converted to hydrogen and hydrogen** is available at relatively low cost. With the exception of a few large consumers, fossil gas is no longer delivered through the distribution network. The majority of **hydrogen heating is delivered through hydrogen boilers**, with a smaller number of hydrogen hybrid boilers. Most off gas homes have electrified heat, through some also use bio-LPG. Low carbon gas (either hydrogen, biomethane or syngas) also has an important role in larger transport. All low carbon and **renewable generation in the area reaches optimum capacity** with a proportion of generation (modelled excess assumed to be 32%) is electrolysed. Waste and bioenergy plants primarily produce biomethane for heavy transport and industrial processes but also act as peaking generators as required. There is also a medium level of battery electric storage to manage electricity peaks. This scenario envisages higher hydrogen demand and is similar in description to the, yet to be published, **FES 2020 System Transformation scenario.** In this scenario an additional **hybrid sensitivity** has been developed to look at the implications on both networks of a shift from hydrogen boilers to hybrid heat solutions.

5.2. Infrastructure and system costs

In modelling, the project **did not** assess the likely infrastructure and network costs related to the scenarios. However, it is clear that these system costs will be significant and will form a key part of planning for an optimal net zero system in South Wales. An indicative assessment has been made below as to the likely magnitude of the cost for each key area, relative to each other. These are illustrated in Table 5-1.

Table 5-1 Indicative assessment of different infrastructure costs associated with the three scenarios

Indicative assessment of distribution system costs	High Electrification	Core Hydrogen	High Hydrogen
Cost of upgrading electricity network to support electrification	• Higher	• Medium	• Lower
Magnitude of electricity system demand peaks and cost of balancing	• Higher	• Medium	• Lower
Investment required in switchover to hydrogen network for building heat	• None	• Medium	• Higher
Hydrogen transmission network and / or hydrogen storage required to meet winter peak	• Lower	• Medium	• Higher

The first area is system costs associated with upgrades of electrical cables and substations to support the higher electricity demand and generation across the network associated with electrification of heating and transport. Cost is expected to be highest in High Electrification, but some costs will still be incurred in the Core and High Hydrogen as a result of increased renewable generation and transport electrification.

The second area is the likely relative magnitude of the electricity system balancing costs such as the cost of providing flexibility or peaking generation to meet demand. There will be changes to electricity usage across the scenarios that will increase this cost, the variance within the scenarios relates specifically to managing the winter heating demand peak. This would be highest in High Electrification where most heating is electrified. In a Core Hydrogen scenario there would still be an electric heating winter peak associated with c. 40% of households of which most will be heated electrically. The system cost and associated peak is assumed to be lowest in the High Hydrogen scenario where hydrogen boilers replacing existing fossil gas.

There are also implications for the gas distribution network which vary by scenario. The distribution gas network is expected to be able to carry hydrogen but at present there is no large scale hydrogen network in operation that delivers hydrogen for heating. A hydrogen switchover will therefore require significant research and innovation in order to ensure the system can deliver hydrogen safely into homes and businesses. Sunk costs related to redundant gas network infrastructure were not considered in this context.

The final area is related to the development of hydrogen transmission network and/or local storage that might be needed to meet winter peak heat demand in South Wales for hydrogen. With the lower energy density of hydrogen, in High Hydrogen particularly this may require significant levels of hydrogen storage. This cost is assumed to be highest in High Hydrogen.

6. Methodology

The Net Zero South Wales 2050 innovation project was undertaken as a partnership between Regen, Western Power Distribution and Wales and West Utilities with funding from the Network Innovation Allowance programme. Outputs from this project will also feed into the Zero2050 South Wales project being led by National Grid. More information can be found on this project here: www.zero2050.co.uk

The main objective of the project was to create integrated distribution future energy scenarios (DFES) for the gas and electricity networks in South Wales and, as part of process, to develop a new methodology for conducting cross-vector scenario forecasting at a regional level. The project also looked to provide insights into how South Wales might transition to a net zero future under three net zero scenario pathways: High Electrification, Core Hydrogen and High Hydrogen. A shared scenario approach is expected to aid understanding of the impacts of net zero on the two networks, and the local approaches and investments that might be required to achieve the scenario pathways.

The main output of the project is a DFES projection dataset provided to WPD and WWU to inform network planning and investment. The dataset covers key technologies, both demand and supply, that might be expected to connect to the gas and electricity distribution networks under the three scenario pathways. The data covers each year from 2020 to 2035 and then five yearly intervals between 2035 and 2050. Projections are provided at geographic levels relevant to each respective network, these have been defined as Electricity Supply Areas (ESAs) and Gas Supply Areas (GSAs).

Regen has been working since 2015 with WPD to produce DFES projections of short and medium-term capacity growth of new and disruptive technologies connecting in their four licence areas[29]. This analysis has been used by the DNO to identify areas where network constraints may be triggered and therefore in need of strategic network investment or a non-network flexibility solution. In 2019, Regen worked with WWU to develop equivalent gas distribution network scenarios to 2035[30].

The first step in the analysis was to merge and consolidate the approaches developed for previous single network (electricity and gas) scenarios conducted for both WPD and WWU in 2018 and 2019 respectively. It also extrapolated medium-term scenarios from 2035 to 2050 net zero outcomes for South Wales, using trajectory and milestone analysis.

In order to maximise the learning, the analysis also developed an illustrative simulated day's analysis (see section 6.6) to illustrate demand and supply over two typical summer and winter days, using typical demand profiles and design demand factors used by WWU and WPD network planners. The resulting methodology and approach are explained in more detail in the sections below.

Table 6-1 Source DFES analysis by sector

Net zero sector models	Source DFES (to 2035)
Gas and diesel generation	WWU & WPD
Domestic and non-domestic heat	WWU
Industrial processes	WWU
Transport and electric vehicles	WPD & WWU
Waste and bioenergy technologies	WPD & WWU
Renewable energy	WPD
Electricity storage	WPD

[29] https://www.westernpower.co.uk/smarter-networks/network-strategy/strategic-investment-options-shaping-subtransmission

[30] https://www.regen.co.uk/project/wales-and-west-utilities-regional-growth-scenarios-for-gas/

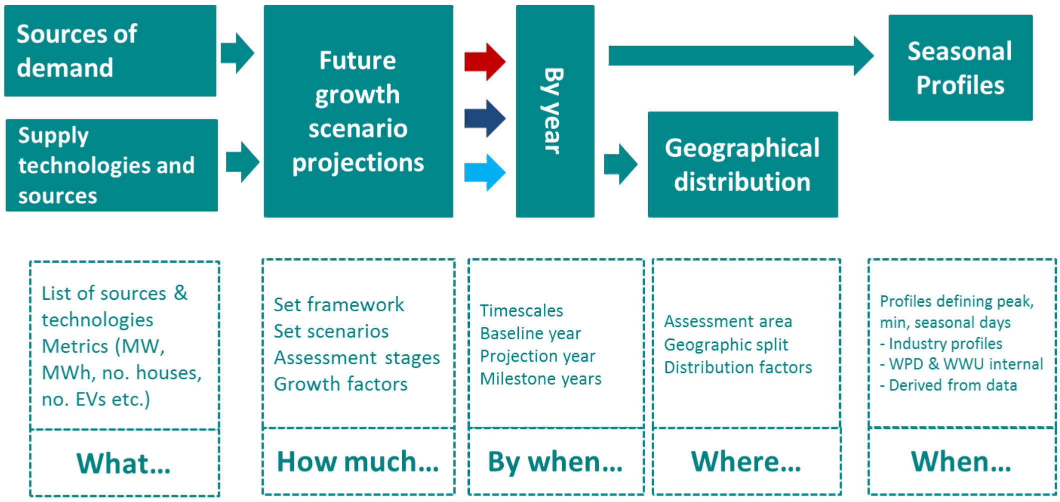


Figure 6-1 Overview of high level DFES phases

6.1. Framing the analysis outputs and inputs

Although the cross-vector approach covered both sources of distribution demand and distribution energy supply in the South Wales region, the analysis did not attempt to match demand and supply of energy in South Wales at a distribution level. The supply of energy was constrained by an assessment of likely local resource, however no constraint was put on the use of energy in whatever vector as a result of local availability. The results do however note the proportion of energy or gas use that is produced locally.

Energy use in scope

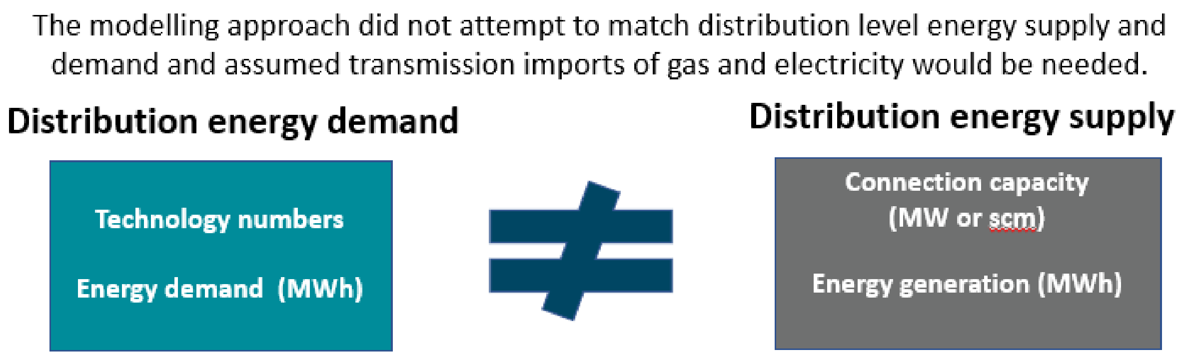
All connections to the gas and electricity distribution network were included in the scope of the projections, with the exception of electricity demand for existing domestic and non-domestic customers not related to heat or transport, such as appliances and lighting. This element was not in scope for previous DFES studies for WPD. However in order to collate the projections into a full distribution model, basic assumptions on the trajectory for underlying (non-heat) electricity demand were made using FES 2019 trajectories to 2050.

The scope of the study did not include connections at the gas and electricity transmission level such as Pembroke Power Station. It also did not include energy uses which are not on the distribution gas or electricity network, such as use of coal for industrial processes or fuel use for aviation and shipping. Where off-network energy use has been important for the modelling, such as petrol and diesel consumption for road transport, or Bio-LPG for off gas homes, this has been included.

Capacity factors

The single vector DFES studies produced outputs that were relevant for either electricity or gas distribution networks. The cross-vector analysis meant that these outputs needed to be made comparable across the energy vectors. In practice this meant an additional step in the analysis converting connection capacities usually specified in megawatt of capacity into a measure of energy generated in megawatt hours. This was particularly important for cross-vector technologies such as anaerobic digestion where the biogas could either be injected into the gas network or burnt to produce electricity.

As a result, the capacity factors for each technology became of primary importance. Where metered data was available, capacity factors were directly derived. Where actual factors were not available, the project also used FES 2019 factors for Community Renewables scenario where available. BEIS capacity factors[31] were used where the FES data was not available or insufficiently granular.



Flexible and cross-vector technologies

Technology	Gas demand	Electricity demand	Gas supply	Electricity supply
Gas fired generation	✓			✓
Hydrogen electrolysis		✓	✓	
Battery electric storage		✓		✓
Hybrid heat pumps	✓	✓		
Waste and bioenergy			✓	✓

Figure 6-2 Illustration of analysis framing with cross-vector and flexible technologies

[31] BEIS source: https://www.gov.uk/government/collections/renewables-statistics

6.2. Geographic analysis - merging gas and electricity supply areas

A key challenge for the project was to define a set of geographical areas for spatial analysis that would be relevant for both the gas and electricity networks in South Wales. In addition, the project sought to produce analysis that would also be useful for local authorities, city regions and other key stakeholders who might have a different geographical view of the data.

Though the WWU and WPD network areas predominately overlap, small sections on the east of the region are in the WWU South Wales network area but are in the WPD West Midlands licence area. There is also a larger area to the north which is part of WPD South Wales licence area but is part of WWU North Wales gas network area.

To deal with this the analysis covered the 'greater' South Wales region, but the results have been presented to the networks covering only their defined South Wales network areas.

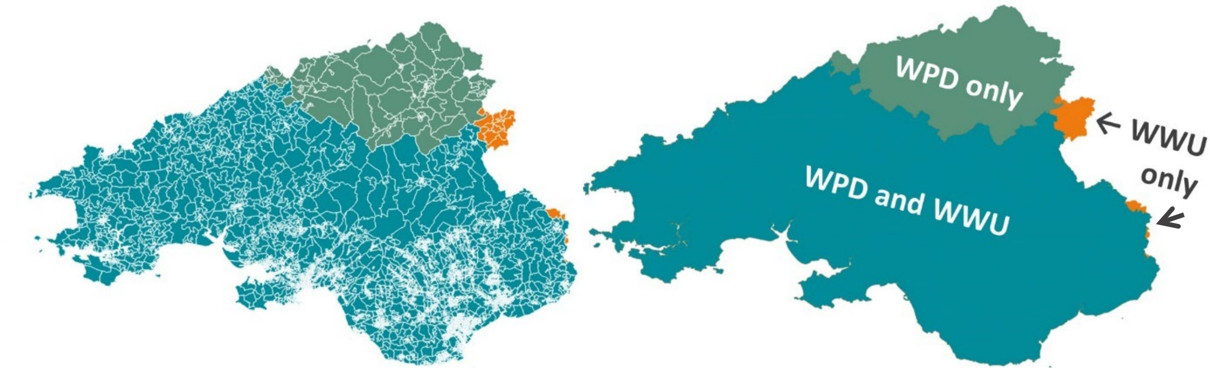


Figure 6-3 The two network areas in South Wales and output areas

The scenarios information is presented to WPD and WWU as a dataset broken down into either Electricity Supply Areas in the region or Gas Supply Areas.

These areas are defined as geographic areas served by the same network infrastructure. Regen, WPD and WWU have created these by mapping geographical data onto network points, linepack zones and local authority boundaries using Geographic Information System (GIS) software.

- There are 24 GSAs across WWU's South Wales network area which combines three gas linepack zones with local authority boundaries.
- There are 56 ESAs across WPD South Wales licence area, these are based on Bulk Supply Point substations.

In order to produce the information at different geographic levels, the analysis has been disaggregated to Output Area Classification (OAC). These are the smallest units for census data and cover approximately 125 households. This level of granularity allows the scenarios analysis to be aggregated to either ESA, GSA, or to LSOA and local authority, as required.

Further complexities for the combined studies included situations where some connections were distribution connected for gas but connected to electricity transmission, for example CCGT plants and potentially for future technologies such as hydrogen electrolysis sites. This was dealt with by developing specific 'gas only' output areas for power station and CCGT sites, ensuring this would only be included in the gas network output data, in a similar fashion to the output areas only in one of the two network's South Wales distribution areas.

6.3. Process for developing net zero scenarios

The DFES development uses a bottom-up process that prioritises stakeholder and local factors to identify an envelope of possible futures within a region.

- The existing baseline of technologies and demand sources connected to the local networks.
- Near term pipeline projections developed using the pipeline of new applications for network connections.
- Local authority planning information such as new housing or commercial developments as well as local and regional planning applications for energy projects.

Longer term scenario projections are then developed for each scenario which incorporate factors including energy resources, geographical and land-use factors, historic growth and investment, regional policies and socio-economic factors.

The analysis undertaken for each technology and sector involved the following stages illustrated in Figure 6-4 .

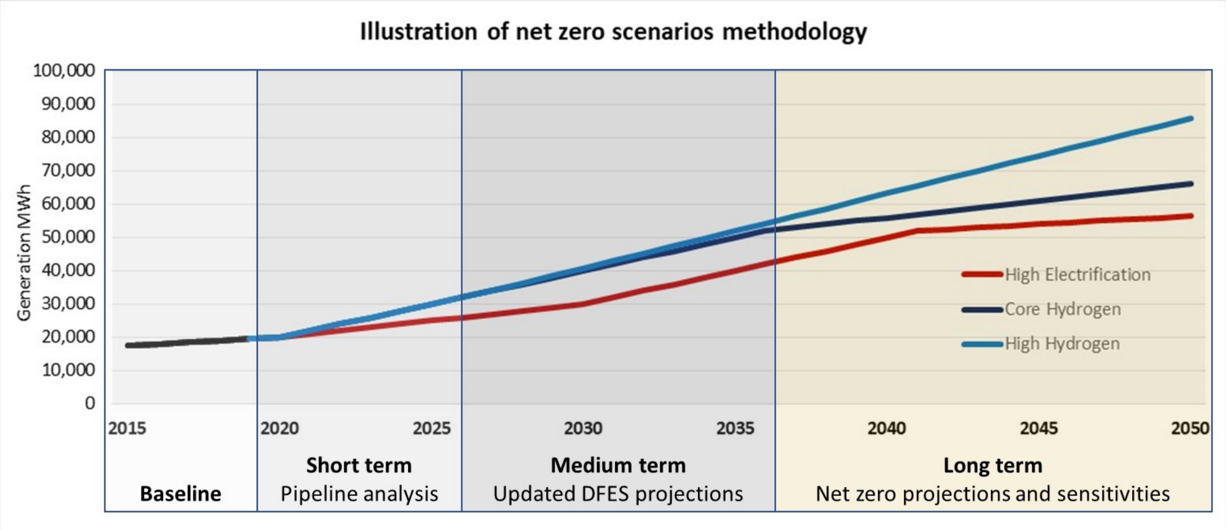


Figure 6-4 Summary of scenario methodology

Stage 1: Baseline

Technology baselines for installed electrical and injection capacity are calculated from WPD and WWUs network connection databases. This identified historic ‘high’ installation levels as well as historic trajectories that steer future growth.

This information was then reconciled with Regen’s project database and further desktop research is undertaken to address any identified inconsistencies.

Stage 2: Short-term pipeline – 2020 to 2025

The short-term projections are driven, where possible, by projects with network connections which have been accepted by the networks but are not yet connected. The pipeline connection database from WPD and WWU was then reconciled and augmented with data from the Renewable Energy

Planning Database[32], Department for Transport, ONS and other relevant data sources, along with telephone and internet research and understanding of the current market conditions and the net zero trajectories. The project also used analysis and stakeholder engagement recently undertaken for the Welsh Government and the development of regional energy strategies.

This allowed an assessment of which projects may go ahead and on what short term timescale. The domestic scale generation and demand technologies do not have a pipeline because they do not require a connection agreement.

Stage 3: Medium term – 2025 to 2035

The medium term projections were steered primarily by the earlier separate DFES analysis completed for WPD and WWU where stakeholder engagement helped build credible medium term trajectories. These existing projections were updated for the most recent information and then merged.

In addition, locational data from various data sources and GIS analysis was used to understand the geographical distribution, local attributes, constraints and potential for technologies to develop within the region in the next 15 years.

Stage 4: Long term – 2035 to 2050

The long term stage was an additional stage developed for this analysis as it extended 15-18 years further than the DFESs previously developed for WPD and WWU. Long term projections required a further bottom-up assessment of maximum potential of certain key technologies and sectors based on local resource, geography and other trends. For example, the amount of household waste produced provides a theoretical maximum for Energy from Waste or syngas generation and the trajectory to 2050 needs to account for significant expected declines in residual waste production over time.

A process of defining the optimum potential was calculated for each technology and steered the total generation and capacity expected by 2050. As well as referring to trajectories in FES 2019 sensitivity and Committee on Climate Change, the project also collated and reviewed stakeholder feedback from both WPD and WWU regional assessments, with specific relevance to future net zero trajectories

[32] See: https://data.gov.uk/dataset/a5b0ed13-c960-49ce-b1f6-3a6bbe0db1b7/renewable-energy-planning-database-repd

6.4. Technologies and sectors

This project presents credible scenarios for the potential changes in technology installations, use and take-up that have an impact on the electricity and gas distribution networks between 2020 and 2050 in the South Wales region.

Covering both electricity and gas networks within the DFES, as well as producing a representative day analysis, meant that the envelope of technologies needed to be larger than those analysed for each individual network. In order to complete a full analysis, the projections needed to cover the whole of energy use at distribution network level rather than the individual technologies that impact one network or another. For example, it was necessary to analyse the heat sector as a whole rather than covering individual heat technologies such as heat pumps or electric heat in isolation.

A 2050 scenario timeline also meant new technologies were needed to reflect the shift to hydrogen, or other low carbon gas. These included both demand from heating or peaking generation and hydrogen electrolysis.

Figure 6-5 summarises the sectors and technologies covered in the analysis and modelling along with assumptions made in the three scenarios. This illustrates that there are a number of shared assumptions across the scenarios, such as renewable generation and some waste technologies.

Further information on all the technologies and sectors modelled can be seen in the appendix which contains the methodology and summary sheets by technology and sector.

Figure 6-5: Summary of scenario assumptions and approaches by sector

Sector	Sub-sector	High Electrification	Core Hydrogen	High Hydrogen
Renewable generation	Onshore wind, solar and hydropower	Distribution resource potential is maximised as per Welsh Energy Strategy. Broadly aligned to FES 2019 Community Renewables.		
Heat	Existing off gas grid - Domestic and commercial	Majority electrified earlier than on gas. By 2025 low carbon alternatives are more attractive than off-gas fossil fuels		
Heat	Existing on gas grid - Domestic and commercial	Majority electrified with higher number of heat networks and small domestic biomethane networks. By 2030 low carbon alternatives are more attractive than gas and boilers are replaced at an increasing rate due to incentives.	A hydrogen network replaces gas network in core urban areas between 2040 and 2045 covering c. 57% of existing connections. Properties outside the hydrogen network are mainly electrified with a small number of domestic biomethane neworks	Hydrogen replaces the majority of the gas network between 2045 and 2050. The majority of heating is provided by hydrogen boilers with a small number of hydrogen hybrid systems installed.
Gas fired power	Natural gas generation	Small number of industrial sites have natural gas supply with CCUS by 2050.	No fossil fuels generation at distribution network level by 2050 (all hydrogen & green gas).	
Gas fired power	Distribution gas fired capacity trajectory	Investment and replacement slows from 2035	Investment and replacement slows from 2030.	
Gas fired power	Future of CCGT (electricity transmission but gas distribution)	CCGT plant remains generating using natural gas with CCUS.		
Gas fired power	Flexibility and peaking	No unabated fossil peaking generation at distribution by 2050. A few gas fired peaking with CCUs at industrial sites.	No unabated fossil peaking generation at distribution by 2045. Small hydrogen peaking plant growth at industrial sites.	
Industrial usage	Large-scale industrial cluster sites	Largest consumers and sites that cannot be electrified switch to hydrogen, remainder are electrified or install carbon capture and storage.	Majority of gas-fired processes switch to hydrogen, combined with process efficiencies to mitigate increased cost.	
Industrial usage		Cluster begins to develop in late-2030s and is limited to the largest consumers of natural gas.	Cluster begins to develop in mid-2030s around core anchor loads, expanding throughout the 2040s.	
Hydrogen electrolysis	Hydrogen manufacturing	Electrolysis produces hydrogen in industrial cluster areas using 16% of renewable generation. SMR assumed to be gas transmission connected.	Electrolysis produces hydrogen in industrial cluster areas using 32% of renewable generation SMR assumed to be gas transmission connected.	
Transport	Light and domestic vehicles	Fully electrified		
	Light goods vehicles	Near-fully electrified	Mainly electric, ~10% hydrogen	
Transport	Heavy goods vehicles	~70/10/20 hydrogen/green gas/electrified	~80/10/10 hydrogen/green gas/electrified	
Transport	Buses and coaches	~15/5/80 hydrogen/green gas/electrified	~25/5/70 hydrogen/green gas/electrified	
Bio Energy	Anaerobic digestion	Capacity is higher than High Hydrogen due to higher value of biomethane. Three additional plants provide biomethane for local networks.		Capacity increases over time and maximise export of biomethane with network injection where possible.
Bio Energy	Biomass	No new capacity on distribution network in south Wales. Existing sites remain generating electricity		
Waste	Energy from Waste (incineration)	Incineration capacity reduces to zero by 2050.		
Waste	Energy from Waste (ACT)	Sites run to maximise export of syngas and injection where possible.		
Waste	Landfill gas	Capacity reduces over time linked to the reduction seen in FES 2019.		
Waste	Sewage	Maximise biomethane export over electricity		
Battery storage	Storage capacity	More required due to more peaking required due to heat electrification.	Less required at distribution due to hydrogen heating and industrial demand served by hydrogen.	
Battery storage	Technology type	Batteries only – alternative technologies not viable on distribution network in South Wales. Energy to power ratio taken from FES 2019		

6.5. Geographical distribution

Once regional projections are made for increased capacity or installation numbers, these projections are then distributed to Output Area Classification (OAC) level. Each relevant technology is analysed to understand the factors impacting likely future deployment locations, through:

- **Baseline geography** – where existing capacity or currently installations are expected to have a greater impact in the short and medium term. For example, electric vehicle registrations are correlated with affluent households with off-street parking.

- **Pipeline trends** – pipeline location is used mainly for generation technologies that have sites identified by WPD that are expected to connect in the short term.

- **Planning evidence and portals** – Planning information is analysed for potential sites and locations for generation technologies. This includes current sites in planning that may not yet be in WPD's connection data but also previous rejected or abandoned sites which are likely to have good resource and potential for growth in the medium and long term.

- **Previous stakeholder engagement events** – evidence gained from stakeholder engagement events for both WPD and WWU DFES was used to understand locational drivers and geographical constraints in South Wales network areas.
- **Direct engagement with stakeholders** – this includes both conversations with developers for pipeline generation sites or sites in planning and other relevant stakeholders such as Welsh Water for plans for sewage plants and industrial cluster members for decarbonisation plans for Port Talbot for example.
- **Local plan data** – to understand locations for new developments for commercial and domestic sites, consultation is undertaken with local authorities directly as well as local plan information and supporting documents. These sites are expected to be higher for new technology installations.
- **Datasets** – demographic, socio economic and geographical data by OAC is used including MCS, census, AddressBase, GIS and others.

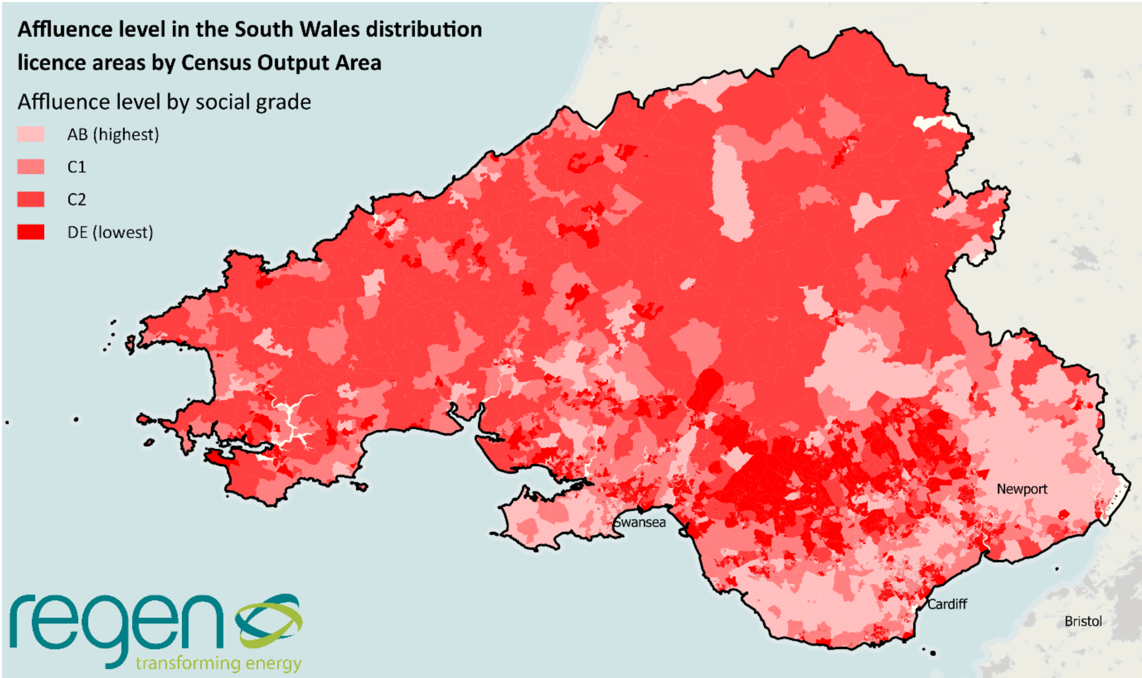


Figure 6-6: Affluence, based on NRS Social Grade, in South Wales at Output Area Classification level

- **Assumptions detailed in the National Grid FES** – modelling assumptions that are detailed in the National Grid FES, such as the types of housing most suited for different low carbon heating technologies.

The above factors, along with desk based research is used to characterise each geographical area. This is then inputted into Regen's Distributor model to calculate the potential uptake of each technology in each area by scenario pathway.

This is then collated by GSA and ESA to create scenarios for analysis by the distribution networks.

Figure 6-7 Example of Addressbase data

6.6. Seasonal day methodology

A simulated day analysis was completed as part of the study to build further understanding and learning on how the scenarios might impact the electricity and gas distribution networks in South Wales. For this, demand and generation (e.g. distributed electricity generation and distributed gas entry) was modelled on a simulated baseline summer and winter day and equivalent seasonal days in 2035 and 2050, for each scenario. The methodology for this analysis is outlined below.

An initial consideration was that each network has their own methodology to model and identify potential stress periods on their networks. These methodologies and approaches differ as a result of the very different nature of the energy vectors and infrastructure involved. This project did not attempt to replicate the critical planning processes for either network. Instead the project worked to define two simulated seasonal days on the energy networks using a combined set of existing demand and generation profiles including those used by WPD and WWU network planners to build a shared understanding between the networks.

The modelling sought to illustrate what future seasonal day energy demand and distributed generation would look like on the gas and electricity networks, with known existing profiles applied. The modelling therefore simulated future demand without future behaviour change, time of use tariffs, smart EV charging or more sophisticated heating control systems applied to the profiles. How the two seasonal days were defined is outlined in Table 6-2.

Table 6-2 Energy characteristics of simulated seasonal days

Simulated summer day	Simulated winter day
High solar generation	Low solar generation
Medium/Low wind generation	High wind generation
Gas generation variable / flexible operation	
Other thermal generation assumed to have flat 100% output	
Heating demand assumed to be zero (some underlying hot water demand)	Heating demand assumed to be high (moderately higher hot water demand)
Fairly generic diversified EV charging profile (not reflecting smart charging)	
Seasonally reflective industrial demand	

By modelling these two seasonal days on the networks, it was possible to assess the potential intra-day flows of energy (distributed supply and demand), as well as determining illustrative intra-day supply and demand maximum periods on both networks. Note that the demand from distribution connected CCGT plant was not included in the gas demand profiles, as this site exports to the electricity transmission network and was therefore deemed out of scope for the purpose of this as a distribution network assessment.

The scenario projections of growth in connected capacity of generation technologies, electricity storage and various sources of gas and electricity demand were applied their equivalent seasonal day profiles shown in Table 6-3.

Whilst some profiles were adjusted for 2035 and 2050 (e.g. fuel conversion efficiency improvements for heating technologies or increased capacity factors etc.), the majority of the load profiles remained unchanged, and thus did not reflect more significant changes in behaviour or incentives that may shift demand or generation into different times of day. Developing more reflective future profiles for sources of demand, storage and flexible generation technologies that can be applied to DFES projections, is an area that would benefit from further analysis, engagement, and development.

6.6.1. Detailed seasonal day methodology

The method outlined in Figure 6-8 was adopted to assess and model seasonal days on the networks:

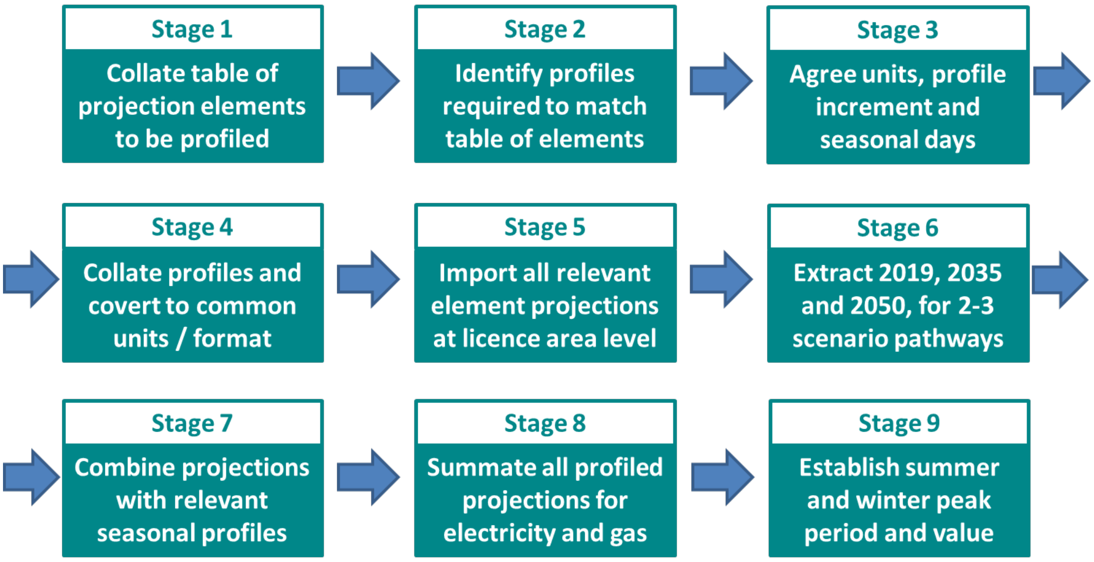
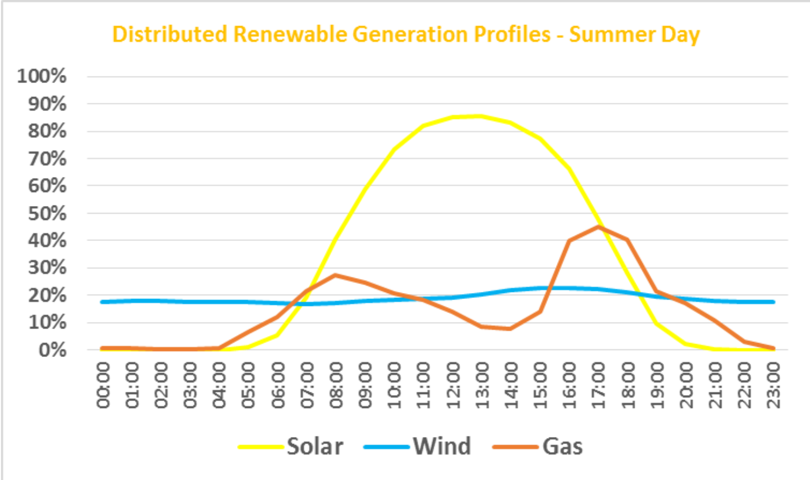
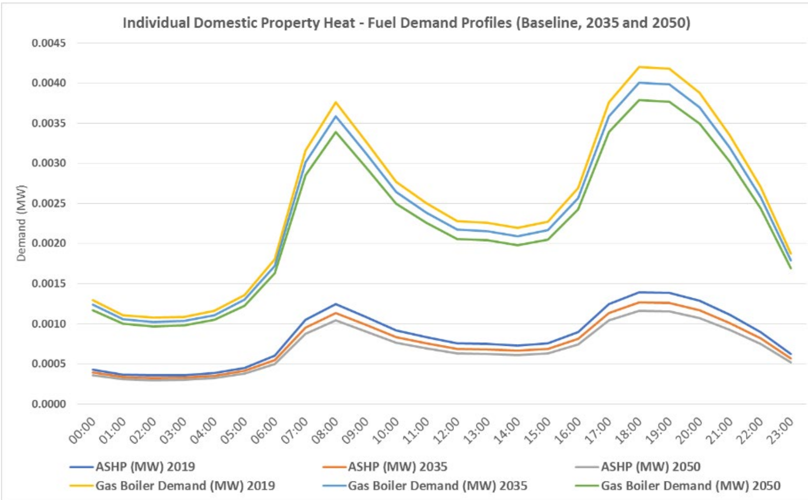


Figure 6-8 Seasonal day profiling methodology at a high level

For each stage, a summary of the approach can be described as follows:

Profiling method stage		Summary of approach / outcome
1	**Collate table of projection elements to be profiled**	The first stage of the analysis was to understand what projections needed to be profiled and what metrics to use. These were: **Electricity network elements:** • All distributed electricity generation technologies • All electricity storage asset classes (import and export) • Underlying domestic electricity demand • Electricity fuelled domestic heat demand • Underlying non-domestic (C&I) electricity demand • Electricity fuelled non-domestic heat demand • Electric vehicle charging demand **Gas network elements** • Distributed biomethane gas injection • Gas fuelled domestic heat demand • Gas fuelled non-domestic heat demand • Gas demand for gas fired electricity generation (not including distribution connected CCGT) • Gas fuelled industrial process demand • Gas vehicle fuelling demand
2	**Identify profiles required to match table of elements**	Regen was provided with a number of pre-defined typical profiles from WPD and WWU, ranging from seasonal renewables profiles, diversified EV and heat demand profiles, heat technology profiles (boiler and heat pumps) and underlying domestic and commercial demand. A number of other profiles were also derived based on operational data provided by WWU, including industrial gas use (categorised by industry sectors), hybrid heating 'switching' profiles, as well as samples of biomethane injection and gas fired generation operational data.

<table>
<tr><td>3</td><td>Agree units, profile increment and days</td><td>The profiles were unified to be 24 x hourly increments.
The profile units were also unified to be % if the element projections were in MW or equated to MW if the element projections were dimensionless (e.g. no. properties or no. EVs etc.)</td></tr>
<tr><td>4</td><td>Collate profiles and covert to common units / format</td><td>A modelling spreadsheet was developed to capture all key demand, storage charge/discharge and generation profiles, examples below:



</td></tr>
<tr><td>5</td><td>Import all relevant element projections at licence area level</td><td rowspan="2">The cumulative total licence area level projections for all elements listed in stage 1 were collated for the three snapshot years, 2019, 2035 and 2050 and under all three scenarios (High Electrification, Core Hydrogen and High Hydrogen), totalling some 620 snapshot projections used in the seasonal day profiling.</td></tr>
<tr><td>6</td><td>Extract 2019, 2035 and 2050 projections for 2-3 scenario pathways</td></tr>
<tr><td>7</td><td>Combine projections with relevant seasonal profiles</td><td>In order to combine the profiles identified in stage 4 with the projections, some elements first required future efficiency gains to be applied e.g. generation technology conversion efficiency, industrial process efficiencies or heat technology fuel efficiency. Once these were applied, the projections in each snapshot year, for</td></tr>
</table>

8	**Summate all profiled projections for electricity and gas**	each scenario, were multiplied by their equivalent summer and winter seasonal profiles to create a set of 72 individual aggregated profiles. These aggregated profiles were collated into 4 categories: • Distributed electricity generation • Distribution network electricity demand • Distribution network gas injection • Distribution network gas demand
9	**Establish the winter and summer maximum periods on both networks**	Analysis was undertaken to determine the maximum period (hour) and maximum value (MW) on both networks in all years and scenarios, for the four aggregated categories identified in stage 8. The variance between the two networks and between the years was assessed, to determine an energy vector balance in the region. The summation of the seasonal maximum values on both networks was also identified to provide an indication of total seasonal day demand across the energy system at distribution network level.

6.6.2. Seasonal day profiling sources

Developing profiles that could provide a valuable indicative seasonal day analysis has been a challenging area for the project. Though there were profiles available that described technology behaviours seen on the networks today, a key issue is that some of these profiles will likely become less representative of 2035 and 2050 behaviours. As the seasonal days were intended to be an illustrative of the capacity growth projection results, rather than the focus of the study. A further issue was whether the profiles provided were comparable both in metrics, units, intended use and geography.

The nature of gas molecules and electrons has produced a different set of priorities and focus for peak day load analysis. For gas network planners, the key objective is to maintain a daily gas pressure, using the inherent energy storage within the network as an intra-day balancing mechanism, thus gas networks are particularly interested in the peak hour or peak 6 mins within a peak day, with regards to extremity pressures and governor capacity. Whereas WPD network planners are concerned with the instantaneous peak demand (within a time period) that must be balanced by instantaneous generation. Gas profiles therefore tend to focus more on a worst case peak demand day, whereas electricity profiles focus on the worst case, or more accurately the 90th percentile, design demand required for each individual demand period.

As an example, gas network planners would not assume that gas electricity generation peaking plant would be running at full capacity for a full day (48 concurrent half hour periods). WPD network planners however have to assume that, during a peak day, gas generators could be running at full capacity during any of the 48 half hour periods within the day.

Table 6-3 summarises the source and method to determine the indicative profiles used in the analysis. The majority of the profiles were sourced from project partners WPD and WWU along with some pre-existing Regen analysis.

Table 6-3 Method to determine indicative seasonal profiles for all key elements

Element	Network	Source of seasonal profiles	
		Baseline (2019)	Future (2035 & 2050)
Renewable generation	Electricity	WPD subtransmission profiles	WPD subtransmission profiles
Thermal generation	Electricity & Gas	WPD subtransmission profiles WWU gas flow data	WPD subtransmission profiles
Battery storage	Electricity	WPD & Regen energy storage operating mode profiles	
Underlying domestic electricity demand	Electricity	WPD subtransmission profiles	WPD subtransmission profiles
Underlying C&I electricity demand	Electricity	WPD subtransmission profiles, augmented by floorspace	WPD subtransmission profiles, augmented by floorspace
Electrically fuelled domestic and non-domestic space heating	Electricity	Base diversified heat demand per property (sourced from WWU pathfinder gas boiler demand), converted to heat technology-specific demand using current conversion efficiencies	Base diversified heat demand per property (sourced from WWU pathfinder gas boiler demand), converted to heat technology-specific demand using future conversion efficiencies projected in 2035 and 2050
Electric vehicle charging	Electricity	WPD ‘Electric Nation’ diversified profile for 7kW battery EVs	

Biomethane injection	Gas	WWU operational flow data (specific to summer and winter)	WWU operational flow data uplifted to higher 'post-commissioning' injection rates
Gas fuelled domestic and non-domestic space heating	Gas	WWU Pathfinder diversified heat demand, converted to gas demand using known average gas boiler efficiency	WWU Pathfinder diversified heat demand, converted to gas demand using future gas / hydrogen boiler conversion efficiencies projected in 2035 and 2050
Gas fired industrial processes	Gas	WWU gas flow data for key industrial sectors	WWU gas flow data for key industrial sectors, augmented with future industrial process efficiencies projected in 2035 and 2050
Gas vehicle fuelling demand	Gas	WWU CNG filling station gas flow data converted to a per vehicle demand using current numbers of gas vehicle classes	

6.6.3. Limitations of the seasonal day modelling

Some of the key limitations of the seasonal day profiling are outlined below. All of these areas would benefit from further analysis and development.

- The project used detailed solar and wind generation profiles from WPD, however there were no equivalent dynamic profiles for other low carbon technologies such as hydro, biomass, and electricity from anaerobic digestion. Therefore, these technologies have been assumed to be at 0% or 100% for all periods during the simulated day.
- Battery storage profiles were not adjusted to reflect the longer battery storage duration (e.g. MWh storage capacity) that will evolve out to 2050. Shorter duration battery profiles were therefore used for all three snapshot years.
- Heat technology profiles in 2035 and 2050 were flexed based on an assumed efficiency improvement on 2019 diversified heat demand profiles, in reality smarter controlled heat technologies may affect the profile shape across a winter day in later years. Similarly the impact of energy efficiency measures on the heat demand was not separately applied.
- Non-domestic heat technology profiles were not available, therefore a generic assumption of multiplying the domestic heat technology profiles by ten was applied.
- Underlying electricity demand (domestic and non) profiles reflect a Bulk Supply Point (BSP) level of demand diversification. Licence area level diversity could potentially be different.
- Underlying non-domestic electricity demand profiles includes some direct transmission demand sites that are connected/fed via WPD's distribution network.
- Domestic summer time cooling load from Air Conditioning was applied using an assumed 1% of homes having Air Conditioning taken from the FES 2019 data workbook.
- Non-domestic summer cooling from Air Conditioning was applied using an assumed 12% of commercial properties having Air Conditioning from Regen's analysis of EPC and DEC data.
- Distributed gas fired power generation was only profiled for 2019, as a system reactive technology, the profile for generation behaviour in 2035 and 2050 was felt to be too uncertain. Also the distribution connected CCGT site was not included in the gas fired power generation profiles either as a source of gas demand or electricity generation export.
- The EV charging profiles do not consider significant smart charging adoption in 2035 or 2050.
- The demand and supply from hydrogen electrolysis is not included in this analysis due to lack of available profiles.
- Hybrid heating technologies are treated as a dual-fuel technology, but essentially have two individual heating technology components that are fuelled from each network. The demand

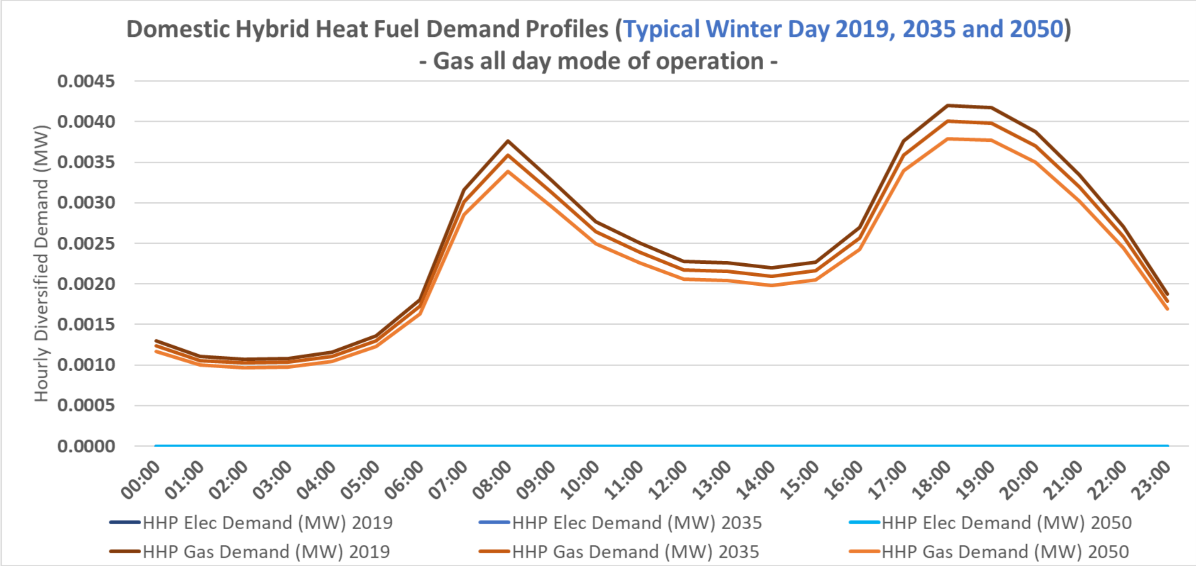
for electricity and gas on a winter's day is however highly dependent on a number of key factors that were external to this analysis.

- The sizing of the heat pump and boiler components of the hybrid heating system
- The control philosophy that determines when each technology cuts in and out
- The thermal efficiency of the home/property with the hybrid heating installed

Two basic diversified profiles were therefore adopted in the seasonal day profile modelling, to provide an indicative view of seasonal day demand on the networks from hybrid heat. These hybrid heat profiles are summarised in Table 6-4 and shown in Figure 6-9.

Table 6-4 Generic hybrid heating profiles used in seasonal day modelling

Profile	Mode of operation	Description
Hybrid Heat Profile 1	**Gas all day**	The boiler component of the hybrid system provides heat all day due to temperature
Hybrid Heat Profile 2	**Hybrid switcher**	Using a 2kW heat demand threshold, the heat pump component provides any hourly demand below 2kW and the boiler component cuts in to supply heat at 2kW or above



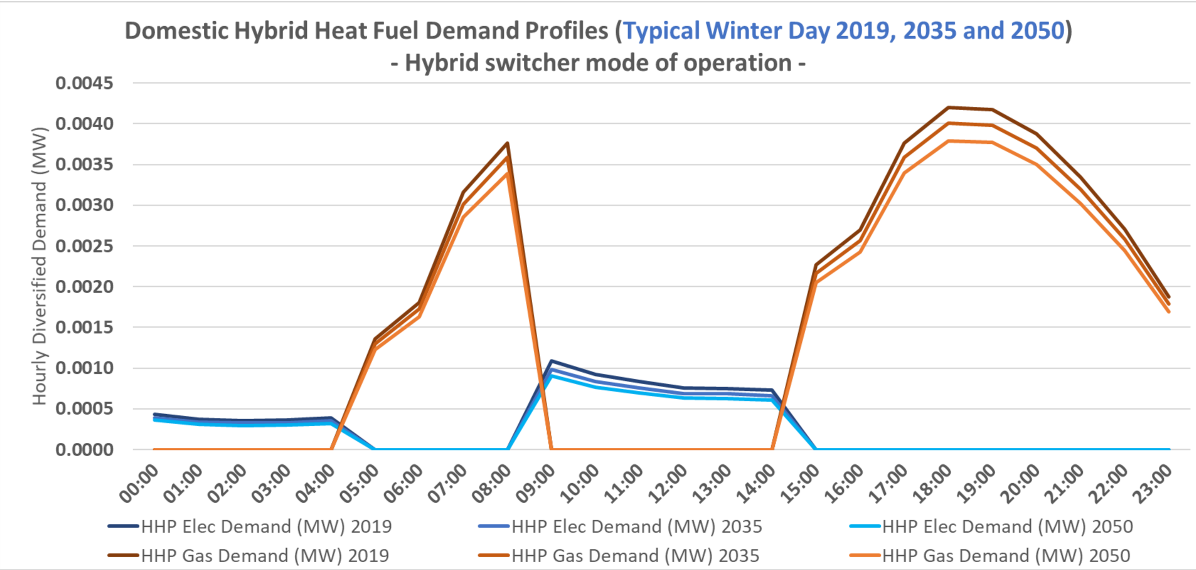
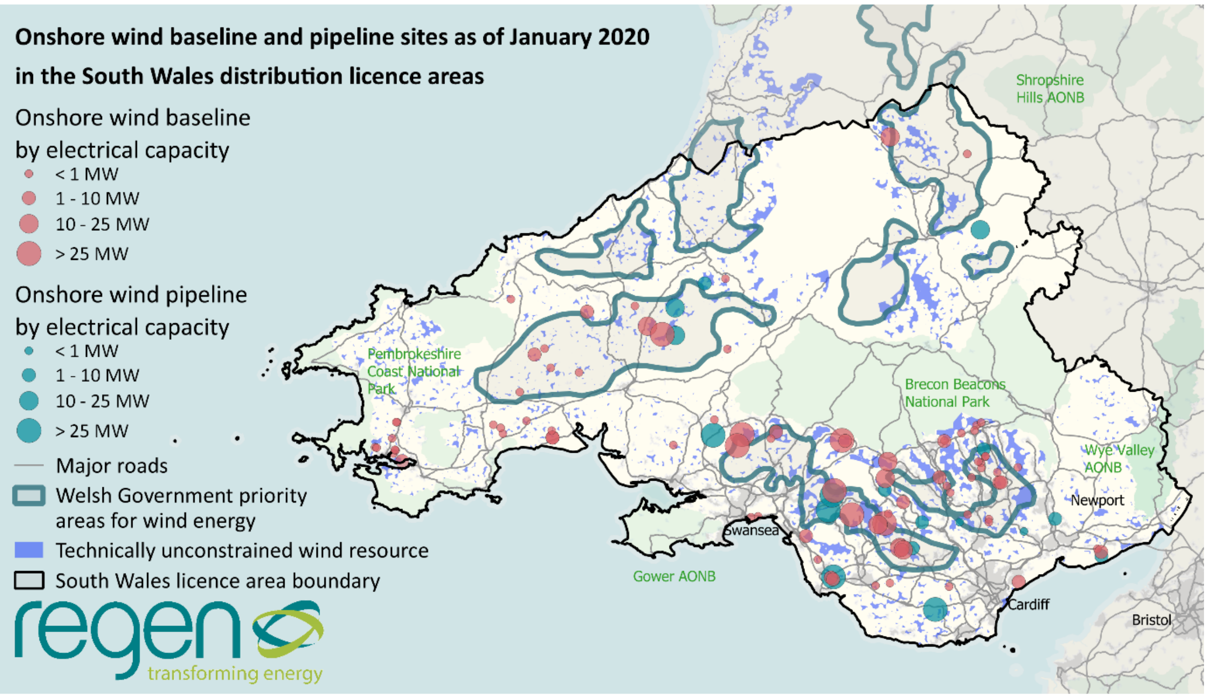


Figure 6-9 Diversified hybrid heat fuel demand profiles used in seasonal day modelling, reflecting several aggregated properties and converted to a single house profile

Section III: Scenario results summary



7. Summary of results

Figure 7-1 illustrates how the make-up of energy use in South Wales changes by scenario over time. A key variable is the level of hydrogen consumption by 2050. There is over 15 TWh of hydrogen used in the highest scenario, High Hydrogen. A smaller amount of hydrogen is consumed in the Core Hydrogen scenario and also in the High Hydrogen hybrid sensitivity, while in the High Electrification scenario hydrogen is used only for fuel in heavy transport and to supply industrial clusters.

High Hydrogen initially has lower hydrogen usage than Core Hydrogen in 2040. This is due to the assumption made about a longer timescale for a full hydrogen 'switch-over' date in the High Hydrogen scenario. This is due to the need to convert more of the gas network from fossil gas to hydrogen.

In all scenarios consumption of electricity increases for both transport and heating as a result of significant growth in the number of electric vehicles and electric heating solutions. Overall energy fuel consumption reduces across the scenarios. This is partly due to greater energy efficiency in buildings but also the comparative efficiency of using electricity for transport (compared to petrol/diesel) and the coefficient of performance of heat pump systems.

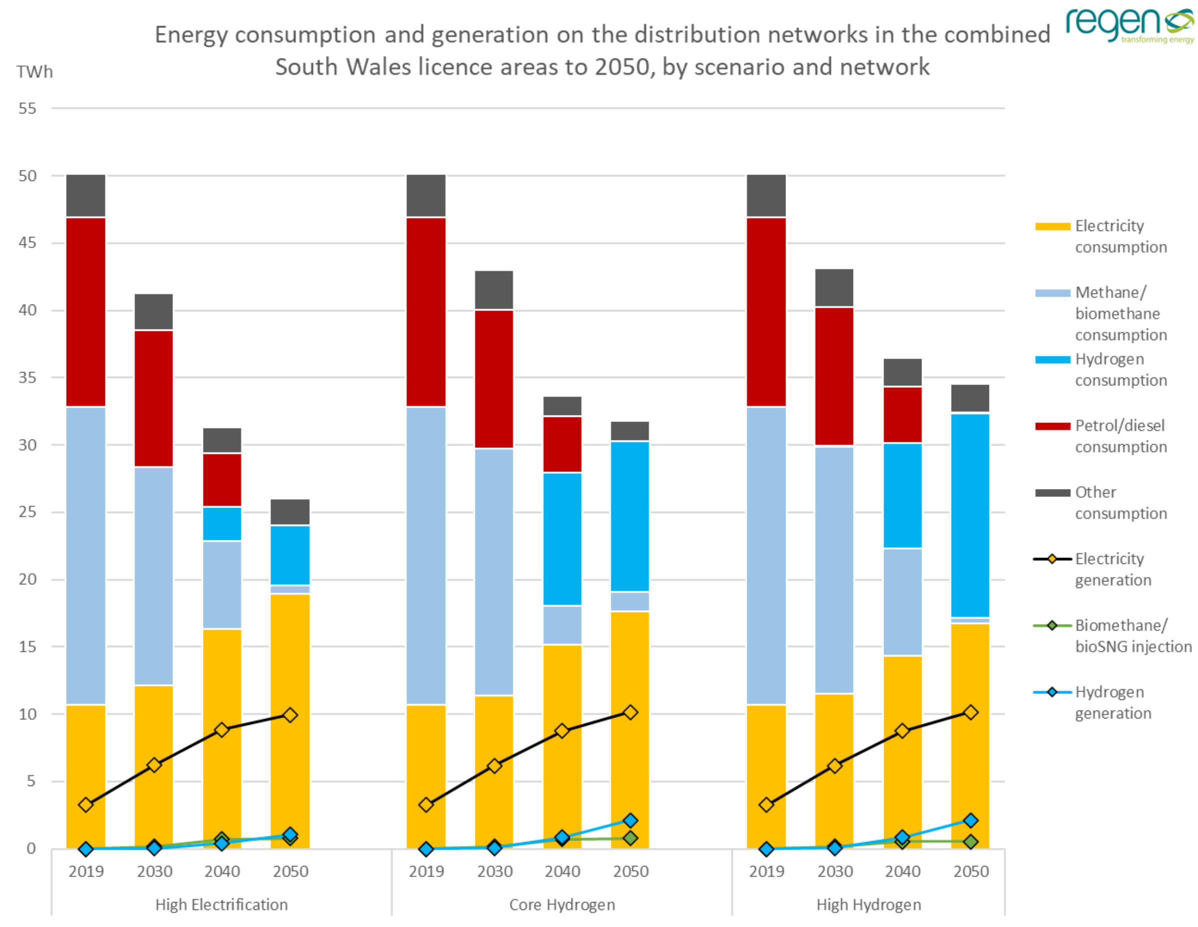


Figure 7-1 Overview of distribution network energy demand and supply out to 2050 by scenario

Figure 7-1 also shows that lowest energy is used overall in a High Electrification scenario. Although slightly more energy efficient buildings are projected in High Electrification (to support heat pump installations), this is mainly due to the energy efficiency of heat pumps themselves which are the primary heating technology for homes and businesses by 2050. Heat pumps are assumed to have a seasonal performance factor (SPF) of up to 300% by 2050. This takes a balanced view of potential improvements in heat pump performance due to technological advances, best practice installation and increasingly energy efficient housing[33].

The projected amount of distribution network connected renewable electricity generation is the same across the scenarios and provides between. 50% - 60% of the annual electricity demand of the South Wales network licence areas by 2050, compared to 30% in the baseline year. The balance is assumed to be provided through the transmission network. This could provide zero carbon electricity from a number of sources. Options would include transmission connected renewable generation or gas generation with CCUS either in South Wales, wider UK and via interconnection to Europe.

It should be noted that, this analysis projected distribution connected electricity generation and, as a result did not include projects likely to connect to transmission network. Transmission connected generation might include offshore wind and tidal range technologies and the largest onshore wind sites as well as CCGT plants which may continue to operate with fossil gas alongside carbon capture, utilisation and storage (CCUS) or hydrogen generation.

Production of hydrogen via electrolysis is also shown to increase over time and production is higher in Core and High Hydrogen in order to meet more of the local demand. However, in all scenarios hydrogen demand significantly exceeds distribution supply by electrolysis and it is assumed that the balance will be imported via a hydrogen transmission network. The supply of hydrogen in South Wales is explored further in section 7.1.

There is also some production and consumption of biomethane across the scenarios. The level of production and the level of demand are similar in both High Hydrogen and High Electrification. However, in Core Hydrogen the biomethane demand exceeds supply by around 45%. It is assumed again that the balance would be imported. The biomethane supply and consumption in the scenarios are explored further in section 7.2.

Sections 7.3 to 7.8 present a high level summaries of the approach and results by sector and technology group. More details about the approach and assumptions made are shown by technology can be found in the assumption and summary sheets which are contained in the appendix.

[33] Field trials and modelling suggest that current standalone ASHPs have an SPF of 2.5-2.7 (https://www.gov.uk/government/publications/hybrid-heat-pumps-study) with many existing installations achieving SPFs over 3. The National Grid FES assumes a 36% improvement in ASHP coefficients of performance by 2050, from 2.8 to 3.8 (http://fes.nationalgrid.com/media/1440/fes-qaa-document.pdf)

7.1. Focus area: Hydrogen supply

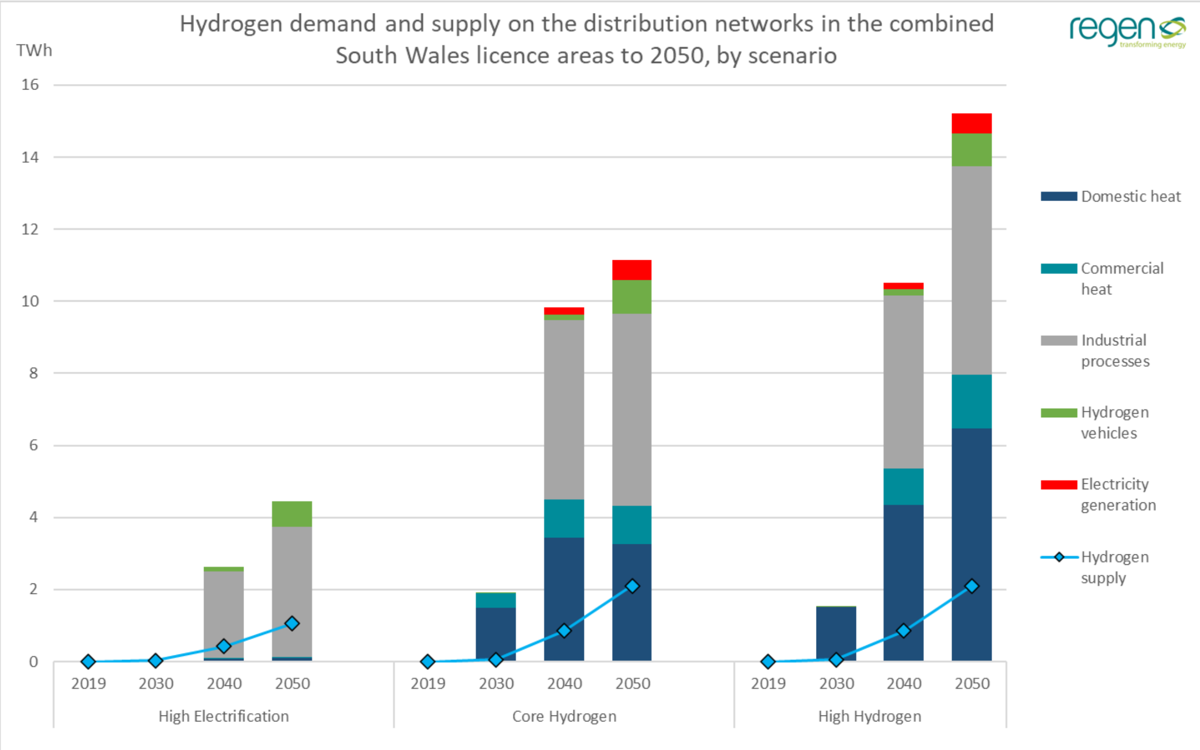


Figure 7-2 Hydrogen demand and supply by sector by scenario.

Hydrogen electrolysis is a new area for DFES analysis and there is a high degree of uncertainty about this technology. Some models assume that distribution network connected electrolysis plants will use very low cost "excess" electricity at times of high renewable generation, which implies that plants will be running at a relatively low capacity factor but could provide an important service to reduce renewable generation constraints at periods of high generation and low demand. Other studies have indicated that electrolysis plants need to be operating at near full capacity in order to reduce levelized costs of hydrogen production[34].

The project used FES 2019 net zero sensitivity data to create a benchmark assumption that just over 16% of renewable energy generation[35] in 2050 might be converted into 'green' hydrogen[36]. This figure was used in the **High Electrification** scenario and, in the **Core and High Hydrogen** scenarios**,** this figure was doubled to reflect the higher hydrogen demand. In reality hydrogen production is not limited by this factor and is likely to reflect the availability and cost of electricity across the GB energy system and connected European electricity market.

Process efficiencies were then used (increasing from 60% to 70% by 2050) to estimate that South Wales might produce between 1-2 TWh of green hydrogen from distribution connected renewable generation by 2050**.** For simple modelling purposes, an assumed capacity factor of 50% was applied

[34]Hydrogen Capacity factors are explored in this report by Irena https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Sep/IRENA_Hydrogen_from_renewable_power_2018.pdf

[35] The FES 2019 net zero sensitivity uses 68 TWh of electricity for hydrogen in 2050. This is c.16% of electricity generated by renewables in that scenario. http://fes.nationalgrid.com/fes-document/

[36] Green hydrogen is defined as hydrogen created from renewable generation and therefore has no associated carbon emissions. This is in contrast to other processes to create hydrogen from SMR using fossil gas for example which are described as 'blue' hydrogen.

to estimate that 241 MW capacity of electrolysis plants would be required to process this electricity in High Electrification and 482 MW in Core and Hybrid Hydrogen. In all scenarios the electrolysis plants were located near commercial transport fuelling hubs and close to industrial areas, where there would be demand for high quality 'green hydrogen'. For more information, see technology summary sheets: **Hydrogen electrolysis.**

Figure 7-2 illustrates that locally produced green hydrogen at these levels meets a relatively small proportion of projected local demand by 2050. In High Electrification, 1 TWh is just under a quarter of demand and the higher output of 2 TWh is 14% of demand in High Hydrogen.

Table 7-1 shows the key results on hydrogen supply and use by scenario and also estimates the amount of electrolysis capacity (with a 50% capacity factor) that might be required to provide all of the South Wales hydrogen demand. In the High Hydrogen, this would require 3.5 GW of electrolysis. This is nearly double the 2019 winter peak distributed electricity demand for the whole of South Wales. This will be explored further in the Zero 2050 South Wales project.

Table 7-1 Local hydrogen supply by electrolysis and demand in 2050, by scenario

Hydrogen in scenarios by 2050	Hydrogen demand (MWh)	Hydrogen supply (MWh)	Electrolysis capacity (MW)	Assumed capacity factor	% of local supply	Est. electrolysis capacity for 100% supply (MW)
High Electrification	4,437,994	1,055,221	241	50%	24%	1,014
Core Hydrogen	11,141,234	2,110,442	482	50%	19%	2,545
High Hydrogen	15,221,704	2,110,442	482	50%	14%	3,476

7.1.1. The role of gas transmission network

Although capacity factors for electrolysis may be higher than 50%, it is likely in any net zero scenario there will be a considerable gap between the production of distribution network connected 'green' hydrogen and overall hydrogen demand. In South Wales there are a number of options to source additional hydrogen supply:

- Increasing hydrogen SMR capacity in South Wales either linked to the gas distribution or transmission network.
- Importing hydrogen from other parts of the UK via a repurposed hydrogen transmission network.

However, if using the transmission network to transport hydrogen into the region, there is an additional question on whether it is feasible to also source fossil gas from the same or a parallel transmission network. In all scenarios the gas distribution network is assumed to no longer deliver fossil gas to the majority of customers by 2050. In the Core and High Hydrogen scenarios, the gas distribution network is repurposed to supply hydrogen.

However, a few customers in South Wales, for example CCGT plants, large industrial users, or potentially large hydrogen Steam Methane Reformation (SMR) plants may wish to continue to receive fossil gas for use in conjunction with CCUS technology. But to have this option, these users will need to maintain a fossil gas supply, potentially through a direct spur from the gas transmission network.

Therefore, the scenarios reveal a key uncertainty about whether the option to import hydrogen from the transmission network would make a continued supply of fossil gas to the region impossible.

Some possible options for additional South Wales hydrogen supply along with associated positives and challenges are outlined in Figure 7-3.

Figure 7-3 Options for South Wales hydrogen supply with associated positives and challenges.

South Wales options for hydrogen supply	Positives	Challenges
Distribution network electrolysis to produce 'green' hydrogen	• Lower reliance on gas transmission strategy • Potential to retain transmission fossil gas supply for industry	• Significant electrical demand in South Wales • Potentially very high cost of hydrogen • Some hydrogen storage required
Produce 'blue' hydrogen through SMR on distribution network	• Lower reliance on gas transmission strategy • Potential to retain transmission fossil gas supply for industry	• Potentially removes option to import hydrogen from transmission gas network • Purity of hydrogen may not meet industrial or transport needs • Requires local CCUS capacity along with hydrogen storage
Produce 'blue' hydrogen via reforming technologies (e.g. ATR) at Milford Haven (on transmission gas network)	• Some reliance on transmission strategy (for Wales in particular)	• Potentially removes option to import fossil gas from transmission gas network • Purity of hydrogen may not meet industrial or transport needs • Requires South Wales CCUS capacity along with hydrogen storage
Import 'blue' hydrogen via transmission gas network from elsewhere in UK	• Removes local CCUSs requirement	• Potentially removes option to import fossil gas through transmission gas network • Reliance on transmission strategy

A more complete analysis of the interaction between the distribution and transmission networks is expected to be undertaken by the Zero2050 South Wales project being led by National Grid.

7.2. Focus area: Biomethane, bioenergy and waste

In total energy terms biomethane[37] is expected to play a relatively small but very important role in a future net zero energy system. The importance of bioenergy to achieve net zero stems from:

- The multi-vector potential of biomethane which includes providing energy for transport, electricity generation and industrial processes, and for heat in both on and off gas grid areas and through heat networks.
- The potential to use biomethane, and other bioenergy sources such as biomass, alongside carbon capture and storage technology to create negative carbon emissions or Bioenergy CCUS (BECCUS)[38].
- The co-benefits of bioenergy in respect to use of waste resources (food and sewage, crop residues), to support afforestation and biodiversity and to provide an additional revenue stream for farmers and food processors in the agricultural sector.

Estimates of potential biomethane production in the UK have varied greatly under a number of different scenarios. A 2020 ENA pathways analysis estimated that 194 TWh biomethane could be produced in the UK[39]. A 2017 market review[40] produced for Cadent identified a low and high range of between 21 TWh and 124 TWh of annual biomethane production by 2050, with a 55 TWh mid-range scenario. This is more conservative than previous studies[41]. Further analysis of the Cadent 2017 review undertaken by WWU suggested a bio energy resource potential for Wales of up to 8.7 TWh made up of 2.9 TWh of "wet resources" such as food waste, sewage and animal waste, and 5.8 TWh of "dry" resources such as energy crops and wood waste that could be converted to bioSNG gas.

Part of the reason for the very broad estimate ranges are different assumptions around imports, the many types of biomethane feedstocks, their variable commercial viability and the alternative uses to which those resource could be put.

In 2018, the UK produced 34.6 TWh[42] of biomethane from landfill, sewage sludge and anaerobic digestion, of which the majority, 28.9 TWh, was used for electricity generation with 4.7 TWh being used for heat. Landfill gas has been declining since 2010/11 and will continue to do so. Sewage sludge gas production has increased slightly due to increasing population and process improvements. The biggest growth has been in anaerobic digestion of food and farm waste which accounted for 14.8 TWh in 2018, supported by electricity and more recently Renewable Heat Incentive (RHI) subsidies.

Gas to grid injection remains a relatively low but increasing proportion of biomethane usage. Incentivised under the RHI, network injection increased in 2018 to around 2 TWh. When blended into the GB gas distribution network this accounts for around 0.4% of the energy delivered.

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[37] Biomethane is used as a catch all term to refer to a variety of biomethane, biogas, bioSNG gas. The biggest likely growth area is biomethane gas from "wet" sources via anaerobic digestion and "dry" sources via gasification

[38] The Committee on Climate Change "Further Ambition" scenario includes a projection of 89 MT of negative CO2 emissions https://www.theccc.org.uk/publication/net-zero-technical-report/

[39] https://www.energynetworks.org/assets/files/gas/Navigant%20Pathways%20to%20Net-Zero.pdf

[40] https://cadentgas.com/nggdwsdev/media/media/reports/futureofgas/Cadent-Bioenergy-Market-Review-TECHNICAL-Report-FINAL-amended.pdf

[41] An earlier CCC study in 2011 had a range of between 38TWh and 98TWh, a 2009 E&Y report for National Grid had a range of between 5,625 and 18,432 million cubic meters by 2020

[42] DUKES 2019

Biomethane production and the potential for gas to grid injection is not evenly distributed across the UK. WWU South West distribution area, for example, has a higher concentration of agricultural and food processing industries and now has 18 gas injection sites with potential injection flow rate of 16,450 scm/h. In 2018, WWU has estimated that these sites injected an estimated 536 GWh into the gas distribution network, a level where gas network operators need to start investing and innovating to ensure that the gas network can be operated and controlled with high levels of green gas injection, such as with the WWU and Cadent Optinet project[43].

Biomethane production and gas to grid injection rates have been significantly less in Wales and there is currently only one operational biomethane injection to gas grid site in North Wales, located at a Five Fords Sewage Treatment Works in Wrexham, operated by Dwr Cymru (Welsh Water), and no injection sites in South Wales.

South Wales does have a total of 13 anaerobic digestion projects for electricity generation totalling an electrical capacity of 9 MW. The largest plant is the 3 MW Stormy Down plant in Bridgend which processes commercial and domestic food waste. There has been no increase in capacity since 2016 and currently none of the projects export biomethane for transport or into the gas network.

The lower bioenergy potential in South Wales[44], which is due to a number of factors including the nature of Welsh agriculture and availability of other feedstocks, is reflected in all the Net Zero South Wales scenarios. A key aspect and learning from the Net Zero South Wales project has been to better understand the potential sources of biomethane in South Wales and how that resource could be used under different net zero scenarios.

7.2.1. Net zero biomethane and bioenergy supply

The Net Zero South Wales analysis combined the approaches previously taken in WPD and WWU's DFES scenarios to produce a combined model that projected both low carbon gas injection and electrical generation. Underpinning the projection of biomethane production rates required an additional analysis[45] to determine potential availability of feedstocks for each technology type out to 2050.

For example, assumptions within the modelling were made about the volume of residual household waste declining 3% per year over the scenario period. These volumes then influenced the capacity projected for both incineration and ACT.[46] The total expected volume produced, and associated residual waste used in ACT and incineration are illustrated in Figure 7-4.

[43] See collaborative NIA project between Cadent and WWU, project OptiNet: https://www.smarternetworks.org/project/nia_wwu_052/documents

[44] See further analysis see Regen WWU DFES https://www.regen.co.uk/wp-content/uploads/WWU-Regional-FES-Phase-3-Wales-Results-Report.pdf

[45] Regen conducted an updated assessment based on food waste, biomass, farm waste, sewage and residue waste streams.

[46] 3% is the annual decline seen in recent trends. Declining levels of food and residual waste were calculated using stats wales information. https://statswales.gov.wales/Catalogue/Environment-and-Countryside/Waste-Management/Local-Authority-Municipal-Waste

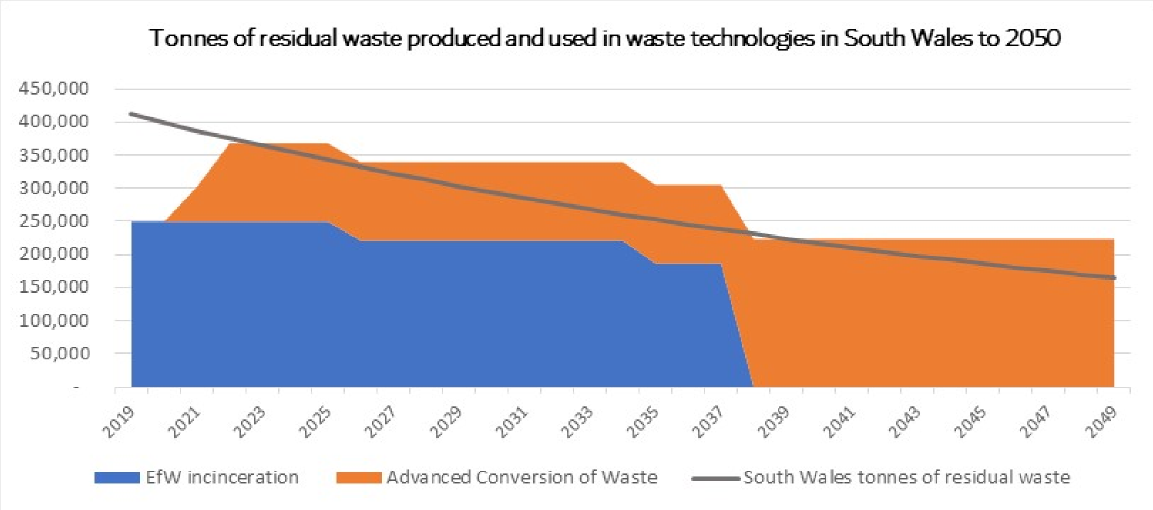

Figure 7-4 Estimated residual waste production and use in ACT and incineration in South Wales to 2050 – all scenarios

The key growth area projected for South Wales is in anaerobic digestion (AD) of food and particularly agricultural wastes. In the Core Hydrogen and High Electrification scenarios, there is anticipated to be more demand for biomethane and as a result the scenarios have additional AD capacity is built after 2035 to provide biomethane into discrete gas networks. This capacity is projected to be in areas with the highest agricultural land grades and therefore with potential to source sufficient AD feedstock. AD capacity is lower in High Hydrogen where high availability of hydrogen reduces demand for biomethane.

In all scenarios the annual energy production from indigenous resources (mainly from anaerobic digestion and Advanced Conversion Technology) is projected to rise to 958 GWh by 2035, and to increase further to 1485 GWh in 2050 under the Core and High Electrification scenarios. This projection is based on an assessment of available resource and the local market potential for biomethane production mainly from food waste, animal waste manure and conversion technologies. In addition, there is potential 1.1 TWh from biomass and energy from residual waste (incineration)[47] used for electricity generation in 2035.

In the Core Hydrogen scenario, which has a higher bioenergy consumption for heat, the modelling has allowed for a significant amount of biomethane imports to provide additional energy for those consumers on local biomethane networks. The logistics of how biomethane networks would operate in parallel with hydrogen networks, including the ability for inter-regional transmission of both gases, will need to be developed.

For more information see technology summary sheets:

- **Anaerobic Digestion**
- **Energy from Waste (incineration)**
- **ACT**
- **Landfill**
- **Biomass**
- **Sewage**

[47] Residual waste incineration is not a bioenergy source but is included here for completeness. Incineration is expected to decline by 2050.

Net Zero South Wales - Supply of bio energy and energy from waste

High Electrification				
Supply source	**Bioenergy supply 2035 (GWh)**	**2035 Total supply**	**Bioenergy supply 2050 (GWh)**	**2050 Energy Supply**
Green Gas Supply				
Anaerobic digestion	292		688	
Sewage	123	**Indigenous supply: 958 GWh**	131	**Indigenous supply: 1485 GWh**
Advanced Conversion Technologies	296		558	
Landfill	248		108	
Imported green gas	*0*	**Imports: 0 GWh**	*0*	**Imports: 0 GWh**
Biomass for electricity generation	819		819	
Energy from waste (Incineration)	304		0	
GRAND TOTAL	**2081**	**GWh**	**2304**	**GWh**

Core Hydrogen				
Supply source	**Bioenergy supply 2035 (GWh)**	**2035 Total supply**	**Bioenergy supply 2050 (GWh)**	
Green Gas Supply				
Anaerobic digestion	292		688	
Sewage	123	**Indigenous supply: 958 GWh**	131	**Indigenous supply: 1485 GWh**
Advanced Conversion Technologies	296		558	
Landfill	248		108	
Imported green gas	*137*	**Imports: 137 GWh**	*932*	**Imports: 932 GWh**
Biomass for electricity generation	819		819	
Energy from waste (Incineration)	304		0	
GRAND TOTAL	**2217**	**GWh**	**3236**	**GWh**

High Hydrogen				
Supply source	**Bioenergy supply 2035 (GWh)**	**2035 Total supply**	**Bioenergy supply 2050 (GWh)**	**2050 Energy Supply**
Green Gas Supply				
Anaerobic digestion	292		448	
Sewage	123	**Indigenous supply: 958 GWh**	131	**Indigenous supply: 1245 GWh**
Advanced Conversion Technologies	296		558	
Landfill	248		108	
Imported green gas	*0*	**Imports: 0 GWh**	*175*	**Imports: 175 GWh**
Biomass for electricity generation	819		819	
Energy from waste (Incineration)	304		0	
GRAND TOTAL	**2081**	**GWh**	**2239**	**GWh**

Figure 7-5: Green gas, biomass for power generation and EfW supply by technology in 2035 and 2050

7.2.2. Net zero biomethane and bioenergy energy consumption

The multi vector properties of biomethane and biomass, and wide variety of uses to which bioenergy can be put make this an extremely valuable energy source to achieve net zero carbon[48]. The scenarios developed for the Net Zero Wales project could only illustrate a few of the possible combinations of bioenergy usage and are not intended to be prescriptive. The key elements of the scenario assumptions for biomethane and bioenergy consumption are outlined in Table 7-2.

Table 7-2 Scenario assumptions for biomethane and bioenergy consumption

Scenario	Consumption of biomethane and bioenergy
High Electrification	• Higher usage for industrial processes and electricity generation • By 2050 electricity generation should be accompanied by carbon capture and store offering the potential to create negative bioenergy carbon emissions (BECCUS) • Heat recovery and usage from electricity generation and industrial processes
Core Hydrogen	• Biomethane becomes a key heating fuel for areas outside the Core Hydrogen network • Increased level of biomethane imports required • Heat recovery and usage from electricity generation and industrial processes
High Hydrogen	• Less biomethane used for transport and heating as hydrogen use is widespread • Some biomethane used for off-gas grid heating and bio LPG • Used for electricity generation in conjunction with CCUS but less that in the High Electrification Scenario • Heat recovery and usage from electricity generation and industrial processes
All Scenarios	**Not modelled** • Potential for even greater levels of biomethane usage and imports to South Wales to be used in for electricity generation in conjunction with CCUS (probably at larger CCGT power plants)

In both the Core and High Hydrogen scenarios bioenergy will play an important role for those areas that are not served by a hydrogen network. This will include rural and industrial areas that are currently off the gas grid.

In order to meet the net zero carbon challenge, it will be important to generate negative carbon emissions to offset those parts of the economy that are unable to fully decarbonise. Bioenergy could therefore have an important function if used in conjunction with carbon capture and storage. This aspect has been partially modelled in the net zero scenarios but not a more extreme scenario where a very large proportion of biomethane and biomass is directed towards electricity generation and industrial usage with CCUS, which could preclude biomethane usage for domestic and commercial heating.

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[48] See for example ADBE Report

Net Zero South Wales - Consumption of bio energy and energy from waste

High Electrification			
Consumption Source	**Bioenergy consumption 2035 (GWh)**	**Bioenergy consumption 2050 (GWh)**	Notes on usage
Green gas energy consumption			
On-site electricity generation	553	682	By 2050 with BECCUS capability and heat recovery
Fossil gas network injection	335	413	Blended to feedstock electricity generation with CCUS
Biomethane network supply	0	0	
Direct heat (LPG) and heat networks	50	65	
Industrial processes	0	183	
Transport	20	99	
Exports	*0*	*43*	
Biomass for electricity generation	819	819	BY 2050 with BECCUS Capability
Energy from waste (Incineration)	304	0	
GRAND TOTAL	**2081**	**2304**	
Electricity Generation	**2011**	**1914**	

Core Hydrogen			
Consumption Source	**Bioenergy consumption 2035 (GWh)**	**Bioenergy consumption 2050 (GWh)**	Notes on usage
Green gas energy consumption			
On-site electricity generation	553	682	By 2050 with BECCUS capability and heat recovery
Fossil gas network injection	332	518	Blended to feedstock electricity generation with CCUS
Biomethane network supply		644	Supplying local green gas networks
Direct heat (LPG) and heat networks	186	248	For outside core hydrogen areas
Industrial processes	0	207	For outside core hydrogen areas
Transport	24	118	
Exports	*0*	*0*	
Biomass for electricity generation	819	819	BY 2050 with BECCUS Capability
Energy from waste (Incineration)	304	0	
GRAND TOTAL	**2217**	**3236**	
Electricity Generation	**2007**	**2019**	

High Hydrogen			
Consumption Source	**Bioenergy consumption 2035 (GWh)**	**Bioenergy consumption 2050 (GWh)**	Notes on usage
Green gas energy consumption			
On-site electricity generation	553	682	By 2050 with BECCUS capability and heat recovery
Fossil gas network injection	134	300	Blended to feedstock electricity generation with CCUS
Biomethane network supply	0	0	
Direct heat (LPG) and heat networks	248	320	
Industrial processes	0	0	
Transport	24	118	
Exports	*0*	*0*	
Biomass for electricity generation	819	819	BY 2050 with BECCUS Capability
Energy from waste (Incineration)	304	0	
GRAND TOTAL	**2081**	**2239**	
Electricity Generation	**1809**	**1801**	

Figure 7-6 Green gas, biomass and EFW consumption by sector

7.3. Domestic and commercial heat

The modelling approach for domestic and commercial heat built on the scenario built for WWU which was refined to include more information on electrical loads. The model is driven by the replacement rate and replacement choice of existing heating technologies.

For existing on gas areas there were three different approaches.

- **High Electrification**, all domestic and commercial heat outside of industrial cluster areas are either electrified or use green heat networks such as shared heat pumps. Where waste resources are available, there are also a small number of discrete biomethane networks with biomethane provided by AD plants.
- In **Core Hydrogen** a hydrogen network replaces the fossil gas network in c. 57% of connections related to the densest areas of domestic and commercial demand in urban areas. Most customers use hydrogen boilers for heat and hot water. The remaining customers are mainly electrified during 2030s. As with High Electrification, there are also a small number of discrete domestic biomethane networks.
- In **High Hydrogen**, the majority of the gas network is converted to hydrogen gas and consumers mainly use a hydrogen boiler leading to the highest use of hydrogen in this scenario. A **hybrid sensitivity** was also developed for this scenario to identify the impact of using hybrid heating systems on electricity and hydrogen usage.

In all scenarios, the areas of South Wales not currently connected to the gas network are decarbonised early, starting in the 2020s, primarily by electrification. Those properties already with electric heating are expected to retain it across all scenarios.

High levels of energy efficiency investment have been assumed to reduce overall power and heat demand in domestic, commercial and industrial premises. Energy efficiency reductions are slightly higher in the **High Electrification** scenario reflecting the importance of this related to the higher assumed efficiency of heat pumps (up to 300%). Energy efficiency is also modelled to be critical in Core and High Hydrogen given the expected higher cost of hydrogen fuel.

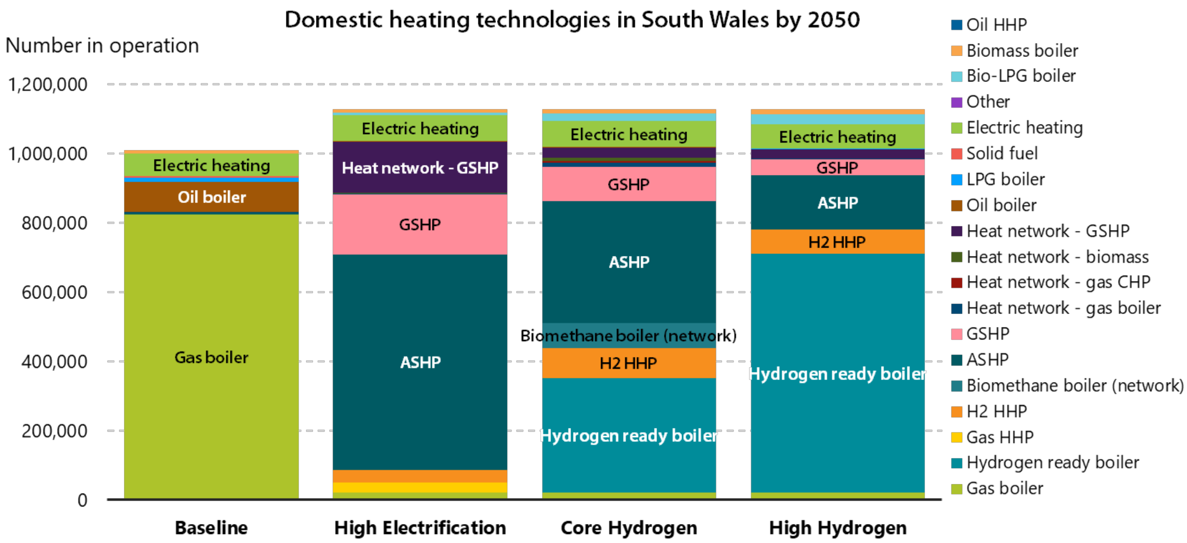

Figure 7-7 Domestic heating technologies by scenario

For more information see model technology summary sheets in appendix:

- **Non-domestic heat**
- **Domestic heat**

7.4. Currently-on-gas industrial processes

The industrial demand sector is a key sector for South Wales and for a cross-vector analysis. The majority of demand load is currently fossil gas and as a result scenario analysis had been done for WWU scenario but not for WPD which did not previously analyse underlying demand. Key additional elements to the cross-vector modelling included new electricity demand loads as a result of industrial process electrification.

For this analysis it has been modelled that currently-on-gas industrial output remains constant during the scenario period, reductions in demand from the baseline are therefore due to fuel switching, new processes and efficiency rather than continued de-industrialisation or through new clean growth.

In all three scenarios the South Wales industrial cluster areas are decarbonised using hydrogen (or equivalent low carbon gas). However, the scenarios vary as to the power and heat source vary for commercial and industrial users who are outside cluster areas.

In both **Core Hydrogen** and **High Hydrogen**, these consumers join a hydrogen network and in **High Electrification** these users are electrified.

Hydrogen electrolysis was also featured within this analysis. FES 2019 sensitivity information was used to estimate the potential capacity for hydrogen electrolysis demand and supply. Electrolysis plants were assumed to be located in the industrial cluster areas next to demand from both heavy transport and processes.

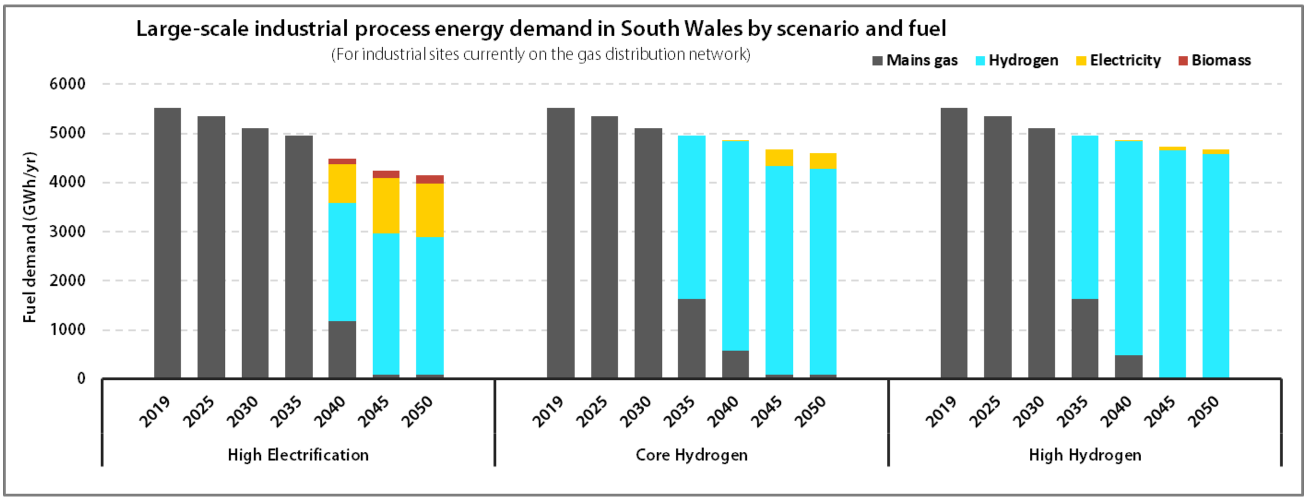

Figure 7-8 Large-scale industrial energy demand by scenario, for sites that are currently on the gas distribution network

For more information see model sector summary sheets:

- **Large-scale industrial processes**
- **Small-scale industrial processes**

7.5. Transport

Across various net zero scenarios, such as those produced by the Committee on Climate Change Further Ambition scenario and National Grid FES 2019 Net Zero Sensitivity, as well as Regen analysis for the Welsh regional energy strategies, road transport is near-fully decarbonised by 2050. Elements of transport had been projected in previous scenarios for both WWU and WPD. For this analysis Regen's transport model was used and extended to cover the full sector and the full switching of petrol and diesel demand to low carbon sources by 2050.

As a result, these scenarios assume that current restraints such as in the supply chain are resolved and road transport is fully fuelled by either electricity, hydrogen or biomethane by 2050.

The analysis also projects the number of electric vehicle charger capacity required to support the electric vehicles including domestic chargers (on or off-street) and larger chargers at commercial locations including petrol stations, vehicle depots and car parks.

The key uncertainty explored in this analysis was the approach to heavier transportation. There is higher electrification of heavy transport in **High Electrification** than in **Core Hydrogen** or **High Hydrogen.** However, HGVs are primarily hydrogen in both scenario pathways.

Table 7-3 The number of electric vehicles to 2050 by scenario

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	EV cars	Number	4,775	139,321	571,967	1,053,227	1,178,128	1,173,657	1,167,383
Core and High Hydrogen	EV cars	Number	4,775	139,321	571,967	1,053,227	1,178,128	1,173,657	1,167,383
High Electrification	EV LGVs	Number	227	3,049	14,438	33,029	78,781	140,072	157,229
Core and High Hydrogen	EV LGVs	Number	227	1,772	7,727	25,185	70,937	132,228	149,385
High Electrification	EV HGVs	Number	3	315	912	1,618	2,390	3,453	4,193
Core and High Hydrogen	EV HGVs	Number	3	277	631	975	1,197	1,489	1,692
High Electrification	EV buses	Number	1	50	207	651	1,764	4,018	6,434
Core and High Hydrogen	EV buses	Number	1	45	184	573	1,534	3,481	5,567

For more information see model technology summary sheets:

- **Electric vehicles**
- **Electric vehicle chargers**
- **Hydrogen vehicles**
- **Gas vehicles**

7.6. Renewable electricity generation – wind, solar and hydro

Different pathways for non-fuel renewable generation such wind, solar and hydro plants are a core part of the WPD scenarios, however in a cross-vector net zero study, this element became less critical as it directly impacted only one network. As a result, the scenarios projected only one trajectory for renewable generation in the region. This is because in a net zero approach renewable generation will need to be optimised at all levels and in all pathways.

There was a significant increase in renewable generation projected in the scenarios. By 2050 South Wales had more than quadrupled existing capacity, with growth predominately from a substantial increase in distribution connected onshore wind as well as from large scale ground mounted solar PV.

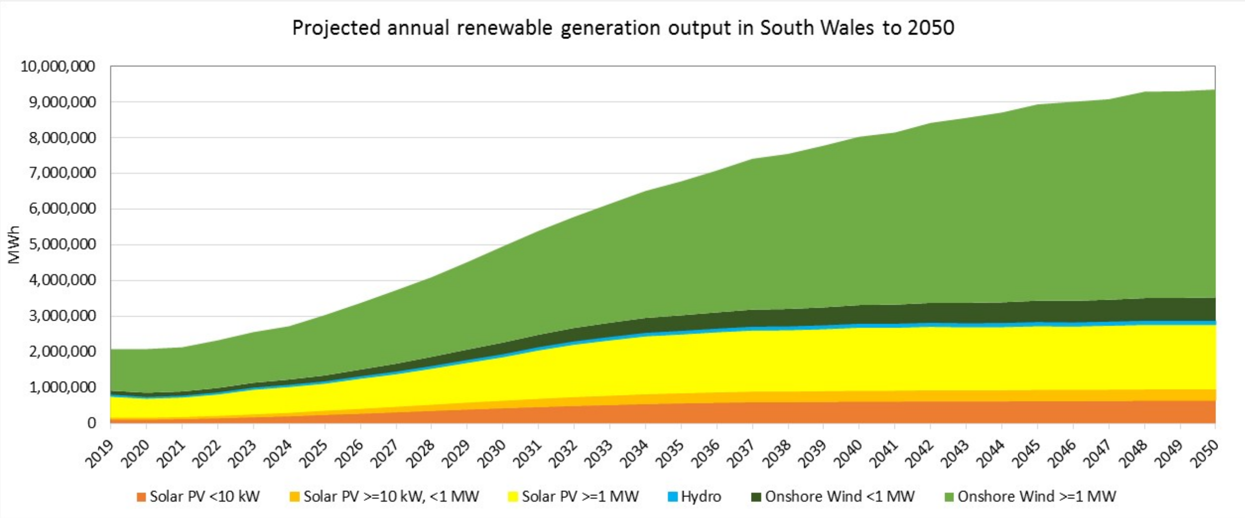

Figure 7-9 Increase in annual renewable generation output in all scenarios

In the medium and long term, the capacity increase in generation is consistent with Welsh Government strategy and reaches a level that optimises local and decentralised resource to estimate maximum energy output. The modelling has in general been aligned to FES 2019 Community Renewables.

For more information see model technology summary sheets:

- **Solar PV (<1 MW)**
- **Solar PV (>1 MW)**
- **Onshore wind (both < 1 MW and > 1 MW)**
- **Other Renewables**

7.7. Fossil fuel and peaking generation

Fossil gas peaking plant is a key cross-vector technology and, although some capacity of fossil fuel generation could potentially remain in an 80% carbon reduction scenario, it is expected to decline much more significantly as a result of net zero targets.

The **High Electrification** scenario is assumed to require more peaking services, especially during the winter months to support the electrification of heat. However, with no unabated fossil generation past 2050, peaking capacity is assumed to be replaced by a combination of batteries, demand side response, waste and bioenergy, as well as with transmission connected generation using fossil gas with CCUS.

The capacity of fossil gas peaking declines earlier in both the **Core Hydrogen** and **High Hydrogen** scenarios than High Electrification. This is due to the availability of hydrogen in some areas from c. 2040, some fossil gas peaking plant is replaced by hydrogen peaking plant towards 2050.

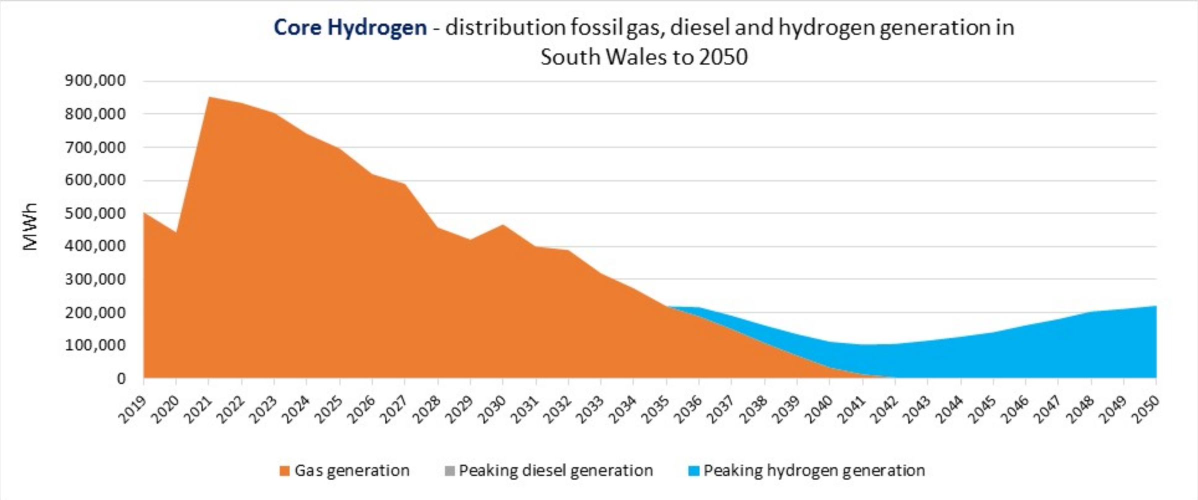

Figure 7-10 Peaking fossil gas, diesel and hydrogen generation projections in Core Hydrogen

This modelling considers a potentially strong uptake under an as-yet-unknown business model of hydrogen peaking generation under the two hydrogen scenarios. Whereas in reality, depending on the price of hydrogen gas, the potential for hydrogen fuelled flexible generation could be feasibly a lot lower.

For all scenarios gas power stations, which are connected to WWU's gas distribution network and the electricity transmission network, are assumed to continue operating out to 2050, with the addition of CCUS technology. It is likely that power stations would retain a dedicated fossil gas supply 'spur' connected to the gas transmission network.

Across all scenarios commercially operated diesel generation is expected to decommission by 2025, except that which provides mains back-up services.

For more information see technology summary sheets:

- **Diesel generation**
- **Gas generation (including hydrogen)**

7.8. Electricity storage

The battery storage analysis is a key flexible technology that had only previously been modelled in WPD scenarios. The existing WPD model was used and extended to 2050 for this analysis.

The scenario projections for electricity storage focuses on power capacity (MW), whilst considering that the storage duration (hours) and thus the energy storage (MWh) is an equally important characteristic for the size and operation of storage projects now and in the future. A high level summary of future MW:MWh ratios for storage projects is included in Table 7-4.

The technology scope of the electricity storage modelling focusses on battery projects only in this project, as other electricity storage technologies are assumed to either connect to the transmission network or are not viable to be sited in South Wales.

Four business models, or classes of storage asset, developed by Regen have been used within the modelling to categorise electricity storage projects:

- **Standalone grid services**: larger potentially multi-MW scale projects operated as standalone assets providing response and reserve services to the network. The projections for this business model have been driven more top-down than the other three out to 2050, based on baseline and pipeline sites in the near term and a percentage increase in the installed capacity (MW) that aligns with the South Wales regional FES 2019 battery storage projections.
- **Generation co-location:** storage projects that are physically co-located (and potentially co-operated) with electricity generation projects (mostly renewables) to provide network services and/or provide time-shifting or price optimisation services to the generation project. The projections have been driven by modelling a proportion of the onshore wind and ground mount solar capacity projections produced in this project, as having co-located battery storage, based on a ratio of generation to storage capacity, which varies by scenario.
- **High energy user:** smaller (potentially up to 1MW) projects that are installed at commercial and industrial sites behind-the-meter to avoid high cost periods and support energy management activities on site. The projections are driven by modelling a proportion of suitable commercial and industrial property types in the South Wales area as having co-located battery units, based on a typical storage kW/MW capacity that increases over time.
- **Domestic storage:** very small (<10kW) home batteries that may be installed to enable households to self-consume more of their rooftop PV generation and/or potentially participate in domestic DSR services in the future. The projections are driven by modelling a proportion of the domestic rooftop PV capacity projections produced in this project, as having co-located home batteries, based on a kW capacity that increases slightly over time.

There is an increase in connected electricity storage power capacity across all business models under all scenarios, from the late 2020s, as the restriction on new dispatchable generation is lifted between 2027 and 2028[49]. Capacity growth is based on the projections collated from the four individual storage business model analyses.

The **High Electrification** scenario begins to break away from the **Core Hydrogen** and **High Hydrogen** scenarios in the 2030s, reflecting:

- A higher requirement for flexibility to support the development of renewables
- The market for time-shifting variable renewable generation output is stronger in a highly electrified scenario

[49] See WPD Statement of Works update Mar 2017: https://www.westernpower.co.uk/downloads/3907

- More C&I sites are assumed to have behind-the-meter storage in a highly electrified scenario, as businesses look to benefit from price arbitrage from time-of-use charging and volatile electricity prices, as well as participation in national and local flexibility markets
- Co-located home batteries are adopted by many households, time-shifting a more significant deployment of rooftop PV, but also potentially leveraging time of use tariffs, accessing domestic flexibility markets or flexible energy behaviour in the home

This divergence continues out to 2050, with 604 MW of storage capacity connected by 2050 in the **High Electrification** scenario in 2050 and 315 MW connected by 2050 in the **Core Hydrogen** and **High Hydrogen** scenarios. See Figure 7-11.

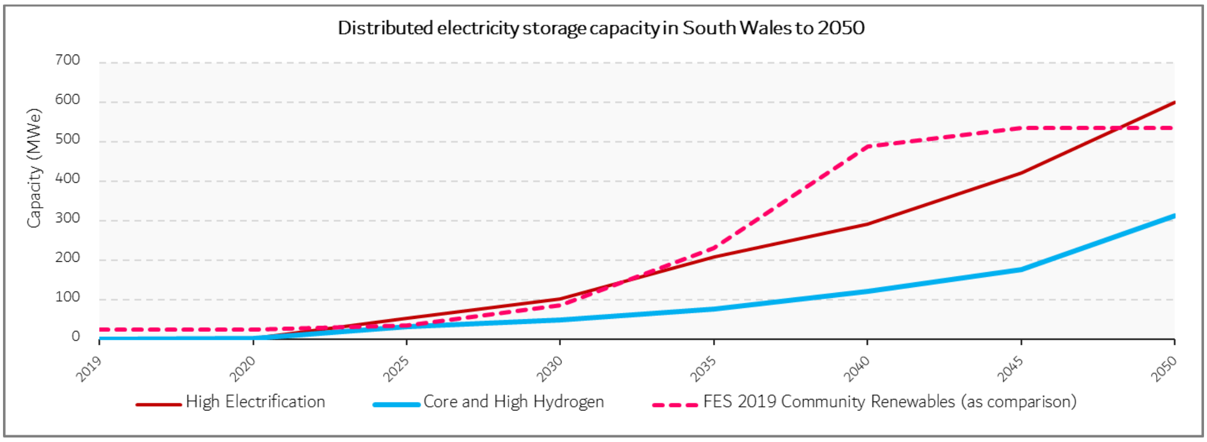

Figure 7-11 Electricity storage capacity by scenario to 2050

As discussed above the energy storage capacity of a storage asset is a key characteristic that determines the cost, size and ability to store/discharge energy for longer periods of time. The energy storage capacity (MWh) of a storage asset is a combination of the power capacity (MW, e.g. inverter size) and the number of hours that it can sustain that power output (hours, e.g. the number of battery cells that available to be charged/discharged sequentially).

It is projected that battery projects will have considerably higher energy storage capacity by 2050 in response both to the expected continued fall in the cost of battery cells[50] and higher demand for flexibility services that are likely to reward those electricity assets that can provide services for multiple hours. Table 7-4 shows the potential increase in the energy storage capacity (shown in hours duration) that we might see under the three net zero scenarios, reflecting battery project sizes increasing across the board by 2050[51].

Table 7-4 Ratio of electricity storage energy capacity (MWh) relative to electricity storage energy capacity (MWh), e.g. hours of electricity storage duration

Model	Units	2019	2025	2030	2035	2040	2045	2050
Standalone	Hours of storage	1	2	3	3	4	4	4
High Energy User	Hours of storage	2	3	4	4	5	6	6
Co-location (solar)	Hours of storage	2	3	4	5	6	6	8
Co-location (wind)	Hours of storage	2	3	4	4	4	4	6
Domestic	Hours of storage	1.5	2	2	2	3	3	4

For more information see summary sheets: **Electricity storage**

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50 See NREL *Cost Projections for Utility-Scale Battery Storage* (June 2019): https://www.nrel.gov/docs/fy19osti/73222.pdf

51 Battery storage capacity has already increased from 30min in 2016/17 to 2-3hours in 2020

8. Seasonal day results overview

Seasonal day analysis was completed to provide some illustration of simulated daily energy demand and generation on key milestone years. The results also helped to highlight additional learning points about the cross-vector impacts of a net zero scenario on the gas and electricity distribution networks.

Many of the results illustrate the potential for increasing variance between demand and supply for energy at a local level and the fundamental need for greater levels of local flexibility, supported by a GB transmission system that will enable regions to balance regional deficits and surpluses in distributed energy supply.

It should be noted, however that this seasonal day analysis is based on generic diversified profiles and design demand factors currently used by WPD and WWU. The analysis shows simulated summer and winter days and therefore is not replicating typical or extreme seasonal days. The profiles used also do not reflect a more dynamic, flexible and smarter future energy system that is expected to be developed by 2035 or 2050. Therefore areas such as dynamic (e.g. time of use) tariffs, smarter EV charging, sophisticated heating control systems, demand side response, extensive use of energy storage and future flexible generation operation are not reflected in the profiles used in this seasonal day analysis.

8.1. Simulated baseline seasonal days

Baseline Summer Day

With an assumed strong solar output and moderate wind output in the summer, there could be just over 1 GW of generation in the middle of the day and c.16.5 GWh of energy delivered into the network. There is also a c.1.2 GWh electricity generation over-supply across the day.

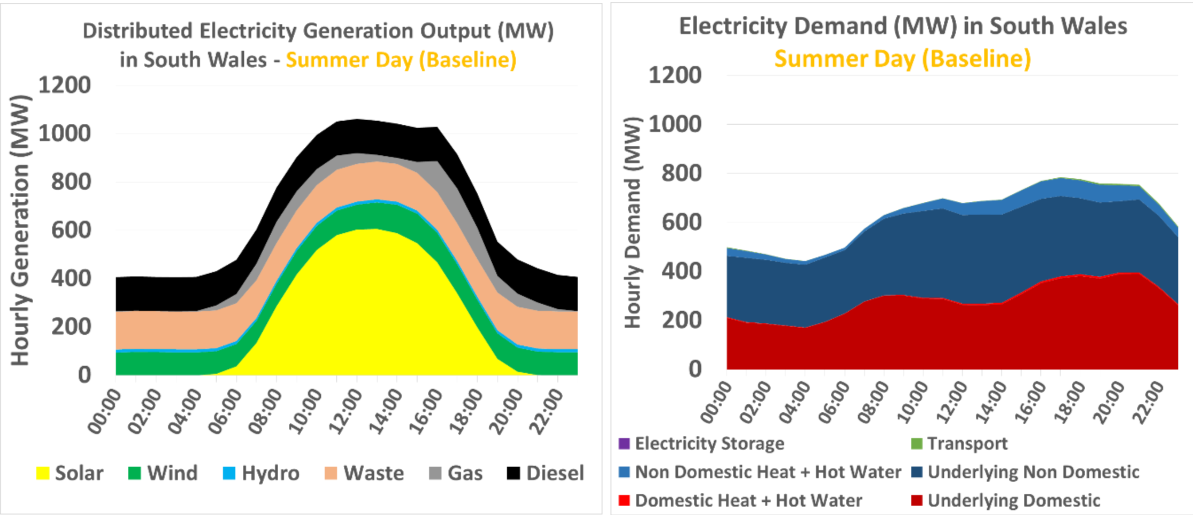
Baseline Winter Day

With next to no solar output, strong wind output and thermal technologies generating across the day in the winter, over a simulated winter day distributed electricity generation maximum is c.0.9 GW and c.19 GWh is delivered into the network.

With more domestic electricity use and existing electric heating demand in homes and businesses, winter day maximum demand reaches c.2.4 GW[52] and usage across the day is significantly higher at c.44 GWh. This highlights a distributed generation vs demand variance of c.1.5 GW (which could be nearer to 2 GW if wind output was low). There is also a c.25 GWh energy volume variance across the day.

Figure 8-1 shows a comparison of distributed electricity generation output and electricity demand on a simulated summer day in 2019. Figure 8-2 shows an equivalent comparison for a winter day.

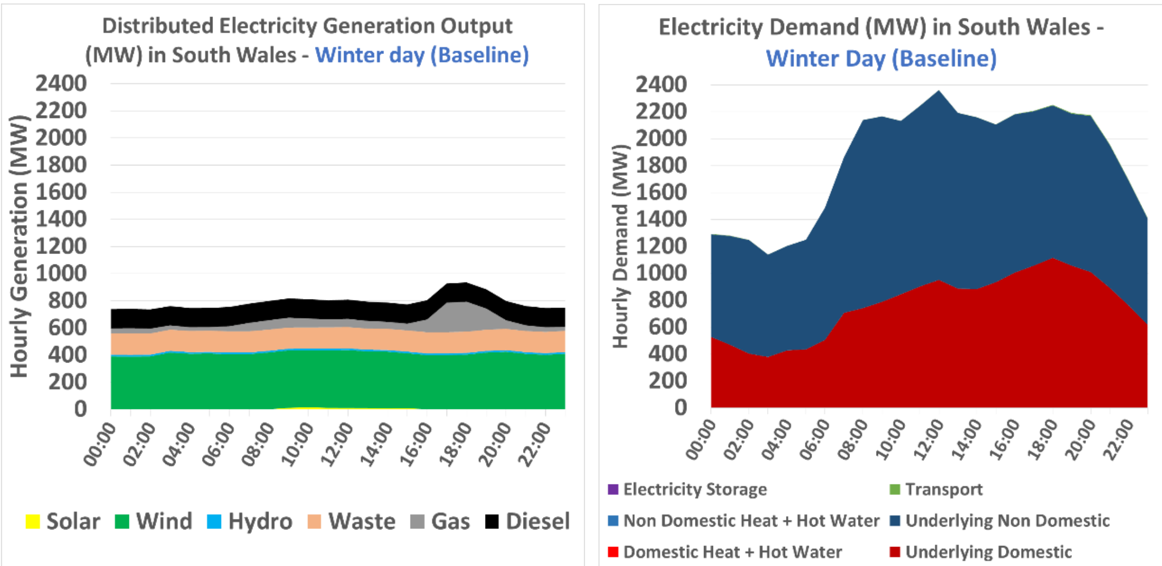
[52] To note that underlying non-domestic electricity demand profiles include some direct transmission demand sites that are connected/fed via WPD's distribution network. The maximum hourly baseline demand is above the WPD observed distribution maximum demand in 2019.



Summer Day Electricity Generation	
Max generation period	**12:00**
Max generation (MW)	**1,062**
Min generation (MW)	**406**
Daily energy (MWh)	**16,454**

Summer Day Electricity Demand	
Max demand period	**18:00**
Max demand (MW)	**785**
Min demand (MW)	**443**
Daily energy (MWh)	**15,223**

Figure 8-1 Simulated baseline summer day electricity generation and demand profiles in South Wales



Winter Day Electricity Generation	
Max generation period	**18:00**
Max generation (MW)	**936**
Min generation (MW)	**737**
Daily energy (MWh)	**19,016**

Winter Day Electricity Demand	
Max demand period	**12:00**
Max demand (MW)	**2,362**
Min demand (MW)	**1,140**
Daily energy (MWh)	**44,342**

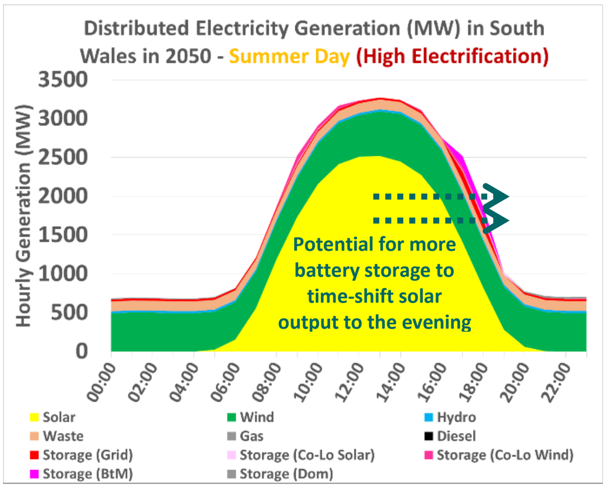
Figure 8-2 Simulated baseline winter day electricity generation and demand profiles in South Wales[53]

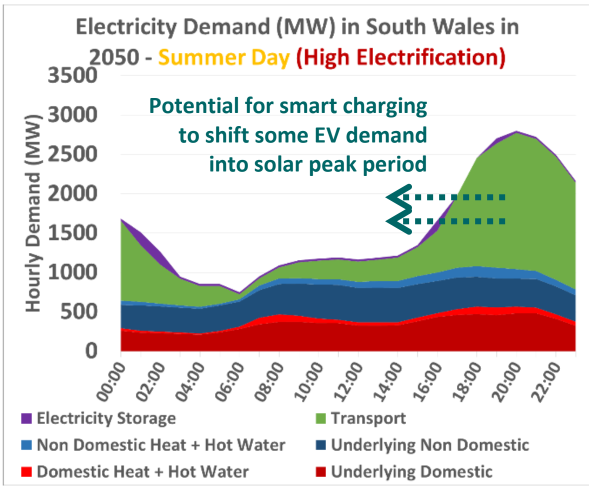
[53] It should be noted that the underlying electricity demand in the baseline daily profiles shown above are assumed to already include electricity demand for properties with existing electric heating and hot water

8.2. High Electrification in 2050

Seasonal days under the High Electrification scenario demonstrate how the scale and seasonal variance in supply and demand could increase by 2050 under a net zero environment, largely using existing profiles. The amount of projected distributed electricity generation (maximum output and daily volume) significantly increases across both summer and winter days.

In a High Electrification scenario distributed electricity generation has a maximum of c.3.3 GW on a simulated summer day at 1pm. Due to an increase in electrified transport the electricity demand on a summer day could be significantly higher in 2050, simulated to have a maximum of c.2.8 GW in this modelling. With a c.3 GWh distributed energy over-supply across the summer day, through the use of EV smart charging, the profile of demand could be partially shifted to enable more distributed generation to be matched to local demand. Or, equivalently the deployment and use of co-located battery storage could potentially time-shift a proportion of solar output to meet evening demand. See Figure 8-3.





Summer Day Electricity Generation	
Max generation period	13:00
Max generation (MW)	3,273
Min generation (MW)	684
Daily energy (MWh)	40,578

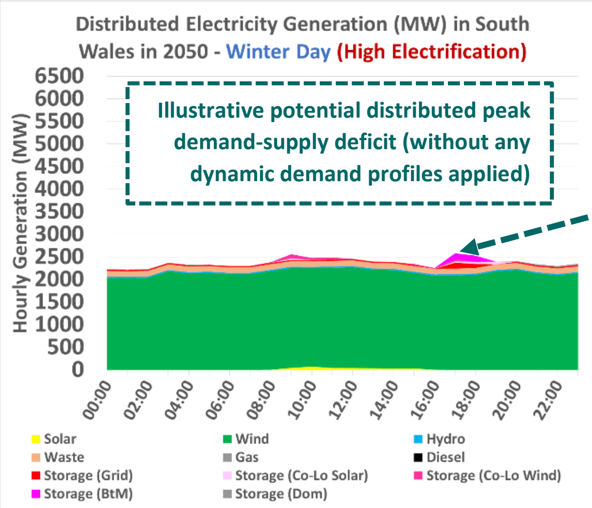
Summer Day Electricity Demand	
Max demand period	20:00
Max demand (MW)	2,800
Min demand (MW)	750
Daily energy (MWh)	37,331

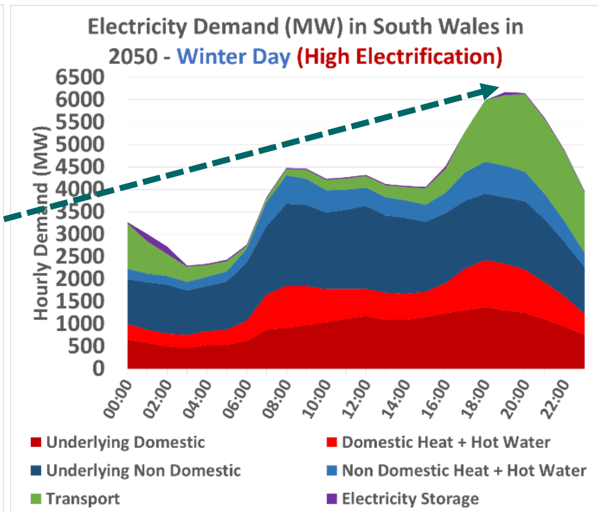
Figure 8-3 Simulated summer day distributed electricity generation and demand profiles in South Wales in 2050 under the High Electrification scenario

Under this High Electrification scenario, some 860,000 heat pumps are modelled to be operating in homes and businesses by 2050. Using fairly generic heat demand profiles, this causes evening maximum electricity demand to potentially increase to c.6.2 GW and overall daily demand totals c.99 GWh.

Assuming a high wind output, electricity generation remains fairly flat at around 2.2-2.6GW across a winter day, generating c. 57 GWh. Should wind output be low to medium however, maximum output could drop to c.0.5 to 1.3 GW and overall energy delivered could fall to between 6 and 24 GWh over a winter day. See Figure 8-4.

Widespread adoption of smart EV charging and more dynamic heat control systems could re-profile this simulated winter day, flattening the maximum and reducing the distributed supply-demand deficit. However, there will likely remain a variance between distributed generation and demand on a winter day in a highly electrified scenario, reinforcing the value of wider UK electricity transmission system and efforts to match demand and supply locally through balancing actions and flexibility.





Winter Day Electricity Generation	
Max generation period	17:00
Max generation (MW)	2,582
Min generation (MW)	2,223
Daily energy (MWh)	56,979

Winter Day Electricity Demand	
Max demand period	19:00
Max demand (MW)	6,176
Min demand (MW)	2,305
Daily energy (MWh)	99,365

Figure 8-4 Simulated winter day distributed electricity generation and demand profiles in South Wales in 2050 under the High Electrification scenario

8.3. Heat demand in High Hydrogen 2050

Winter demand (heavily driven by heat) is a significant factor for both networks. Supplying energy to meet winter evening demand out to 2050 in all scenarios is a significant network issue for both gas and electricity. With over 80% of properties being heated by gas boilers currently, seasonal demand variation on the gas network is at its most significant. Even in the High Hydrogen scenario, which sees the highest number of properties still fuelling their heating via the gas network, the seasonal variance in energy demand lessens by 2035 and again by 2050.

For the High Hydrogen scenario, this highlights the following:

- Summer day demand for gas slightly increases due to some gas vehicle fuelling demand
- Winter day demand for gas moderately reduces, due to some properties still switching to electrified heat, as well as a further deployment energy efficiency measures and improvements in fuel conversion efficiency in all heat supply technologies. To note however that the actual volume of hydrogen delivered would be significantly higher than volume of methane currently delivered as hydrogen gas is around three times less energy dense.

Overall, however, a seasonal demand variation between summer and winter remains out to 2050, though to a slightly lesser extent. See Table 8-1, Figure 8-5, Figure 8-6 and Figure 8-7.

Table 8-1 Simulated winter to summer daily gas demand variation in South Wales 2019, 2035 and 2050 (High Hydrogen scenario)

Snapshot Year	Winter to Summer Seasonal Max Demand Variance (MW)	Winter to Summer Seasonal Daily Consumption Variance (MWh)
Baseline	5,852 MW (+82%)	81,313 MWh (+554%)
2035 (High Hydrogen)	5,301 MW (+82%)	72,002 MWh (+541%)

2050 (High Hydrogen)	4,733 MW (+80%)	63,721 MWh (+498%)

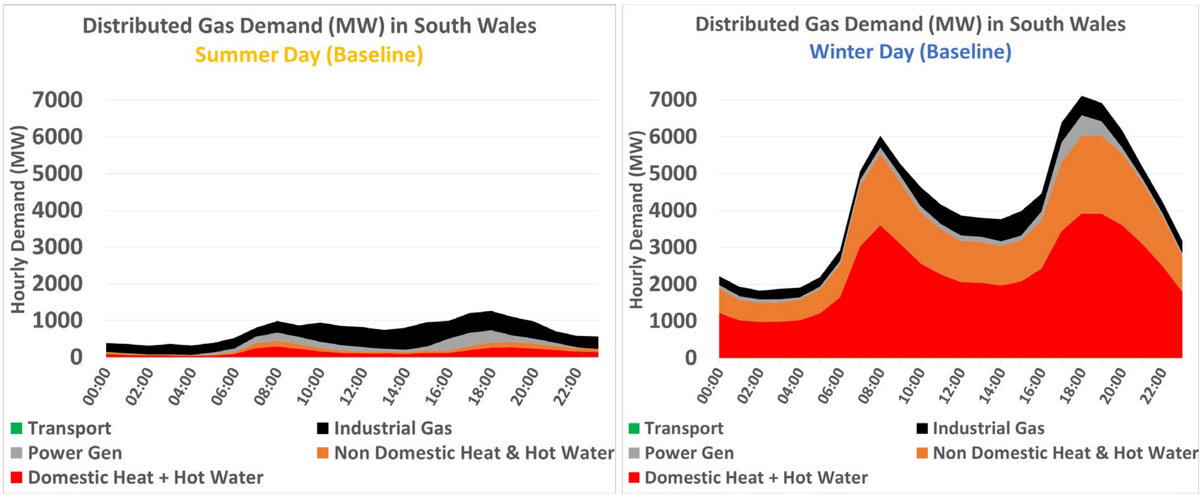


Figure 8-5 Simulated baseline summer and winter day gas demand profiles in South Wales

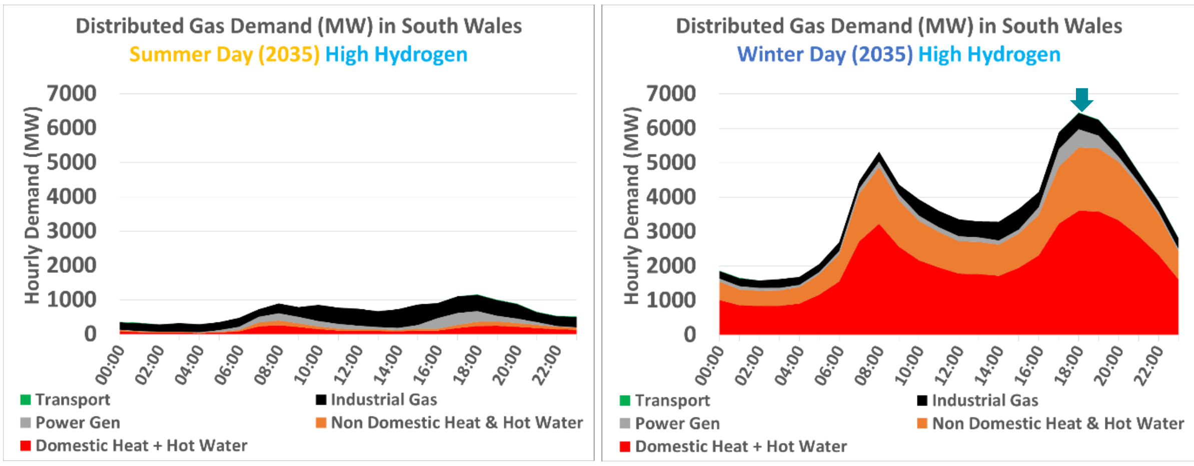


Figure 8-6 Simulated summer and winter day gas demand profiles in South Wales in 2035 in the High Hydrogen scenario

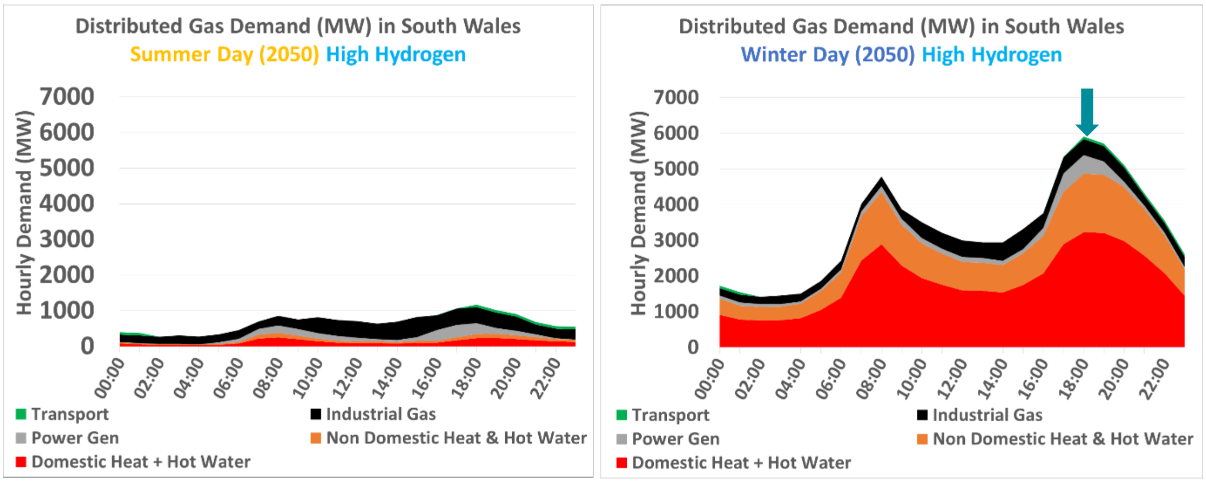


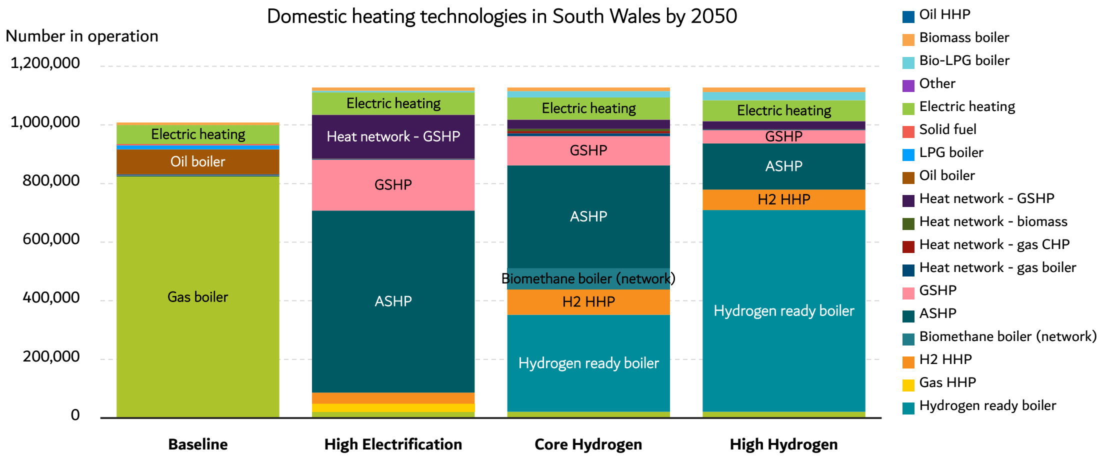
Figure 8-7 Simulated summer and winter day gas demand profiles in South Wales in 2050 in the High Hydrogen scenario

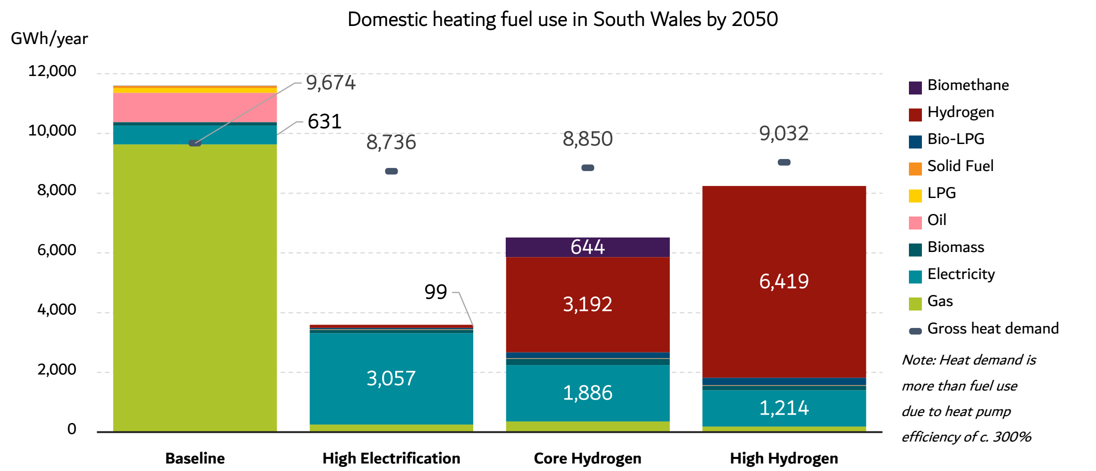
South Wales Net Zero
Technology appendix

1 Domestic heating
2 Non-domestic heating
3 Large-scale industrial processes
4 Small-scale industrial processes
5 Electric vehicles
6 Electric vehicle chargers
7 Hydrogen commercial vehicles
8 Gas (methane and biomethane) heavy vehicles
9 Solar PV (<1 MW)
10 Solar PV (>1 MW)
11 Onshore wind (both < 1 MW and > 1 MW)
12 Other Renewables
13 Hydrogen electrolysis
14 Anaerobic digestion
15 Energy from waste (incineration)
16 Advanced conversion technologies (ACT)
17 Landfill gas
18 Sewage gas
19 Large biomass electricity generation
20 Diesel generation
21 Distributed gas generation
22 Electricity storage

South Wales Net Zero
Sector: Domestic heat
Modelling assumptions and results summary

Domestic heat covers the demand for space heating and hot water provision in households. The modelling includes changing heat demand due to building fabric efficiency improvements as well as shifts in heat delivery technologies.





South Wales key statistics 2019	
Typical household energy demand for heat and hot water	9,577 (kWh/year)
Households served by gas network	827,245 (82%)
Households served by electrified or low carbon heat	77,087 (8%)

Approach to net zero

To achieve net zero, carbon emissions from heat in buildings need to be close to zero. This will be achieved by a combination of energy efficiency measures and an end to unabated combustion of fossil fuels to provide heat. To achieve a net zero outcome, these scenarios make deeper and earlier changes than the 2019 FES.

New buildings are built to increasingly high standards and served by low carbon heat sources. Existing households see a general trend of efficiency improvements, with some significant whole house retrofit in up to 40% of stock. The shift away from fossil fuel appliances is modelled by the proportion of usual annual replacements that instead take up low carbon alternatives.

The level of hydrogen consumption for domestic heating is similar in both the hydrogen scenarios, and is less than the current use of natural gas. In the Core hydrogen scenario, hydrogen use is concentrated in dense urban areas with dedicated hydrogen heating systems which are linked to hydrogen production and distribution clusters. In the High hydrogen scenario, hydrogen use is much more widespread.

Net zero factors	High Electrification	Core Hydrogen	High Hydrogen
On-gas network properties	All properties encouraged to switch to electrified heating and/or heat networks. Greater focus on delivering heat network infrastructure than in hydrogen led scenarios.	Core urban areas (~57% of the 2019 gas connections in the geography) to take up hydrogen-ready boilers from mid-2020s outside core areas incentives to switch to electrified heat.	All properties on gas network encouraged to take up hydrogen ready boilers in late 2020s and 30s.
Off-gas network properties	Off-gas properties are the focus of policy in 2020s incentivising the switch to low-carbon heat.		
Energy efficiency measures	A combination of low energy new buildings, fabric retrofit and whole-house deep retrofit combine to reduce average heat demand by 16% - 19%. The increase in housing means that gross heat demand is reduced by 7% - 10%.		

South Wales Net Zero

Sector: Domestic heat

Modelling assumptions and results summary

Baseline - 2019

Low carbon + electrified heat	
Technology	Households
ASHP	2,815 (.3%)
GSHP	1,384 (.1%)
Electric heating	64,610 (6.4%)
Biomass boiler	8,278 (.8%)

As is typical of the UK, South Wales has relatively inefficient housing stock that is largely heated by natural gas. There are a small number of households heated by low carbon technologies and over 6% on electrified heat

Short term - 2020 to 2025

Low carbon + electrified heat 2025	
	Households
All scenarios	128,856 (12.4%)

In the short-term there is limited difference across the scenarios with significant progress made only in new build developments and off-gas heating. Energy efficiency of new and existing homes continues to improve at a relatively modest rate.

There is a reduction in fossil fuel installations in new build, however significant change is not seen until the 2025 ban on new fossil fuel installations comes into force.

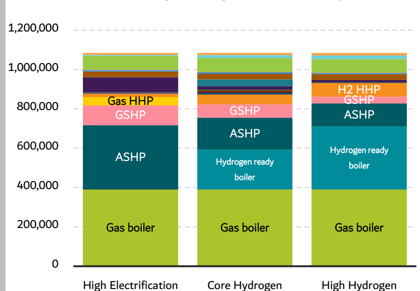
There is an increase in the shift from gas boilers to low carbon sources, however the policy focus is on existing off-gas fossil heating systems, such that by 2025 any appliance replaced must be low carbon. Low carbon solutions are predominantly heat pumps, with some bioenergy such as solid biomass and biogas. Use of bioenergy is higher in the hydrogen scenarios where there is more focus on use of combustible fuels and less on energy efficiency and electrification.

Medium term - 2025 to 2035

Low carbon + electrified heat 2035	
Scenarios	Households
High Electrification	651,177 (60%)
Core Hydrogen	436,446 (40%)*
High Hydrogen	331,979 (31%)*

*Although hydrogen ready appliances are installed, they are not included here as 'low carbon' as hydrogen is not yet flowing within the network

Domestic heating technologies in South Wales by 2035



Typical household demand for heat and water 2035 (kWh/year)		
Scenarios	Existing dwelling	New dwelling
High Electrification	8,112	3,926
Core Hydrogen	8,203	3,926
High Hydrogen	8,719	3,926

Technology

From 2025 new households are served almost exclusively by electrified heat, a mixture of ASHP, GSHP and low temperature heat networks utilising GSHPs.

By 2030 low carbon heat sources are more attractive than fossil fuel appliances for existing households – low carbon solutions are installed when fossil fuel appliances are replaced.

High Electrification - On-gas users that switch mostly choose an ASHP, the remainder are evenly divided between GSHP, a low carbon heat network and hybrid heat pumps. Connection to heat networks or hydrogen distribution is highly location dependent - heat networks are developed in areas close to sources of waste heat, hydrogen is only available where close to an industrial hydrogen cluster.

Core Hydrogen - There is some early deployment of gas hybrid heat pumps, however from 2030 over half of on-gas users that switch move to a hydrogen ready appliance, mostly hydrogen boilers but some hydrogen hybrids. In some areas where hydrogen will not be available but there is good biomethane resource small areas of the network convert to 100% biomethane. In remaining areas households switch to heat pumps.

High hydrogen - There is some early deployment of gas hybrid heat pumps, however from 2030 the vast majority of on-gas users that switch move to a hydrogen ready appliance, predominantly hydrogen ready boilers.

Efficiency

By 2030 all new buildings are highly efficient, with high levels of efficiency achieved earlier in **High Electrification**.

High Electrification - All stock is retrofitted to improved levels of energy efficiency by 2035, driven by the need to achieve acceptable heat pump efficiencies. An increase in deep retrofit sees 18% of stock with significant whole house efficiency measures installed by 2035.

Core Hydrogen - Similarly, all stock is retrofitted by 2035, although fewer efficiency measures deployed in hydrogen connected households results in a slightly higher typical heat demand than in high electrification. Fewer efficiency measures are deployed in these households (despite potential cost benefits) as combustion appliances are still able to deliver acceptable comfort in the face of lower efficiency where a heat pump may not. Deep retrofit is delivered in 14% of stock, to optimise heat pump efficiency in existing housing.

High hydrogen - Most stock is retrofitted to a higher level of efficiency by 2035, the reduction in demand is less than in other scenarios as the widespread availability of gas backup reduces impetus to optimise heat pump performance. For similar reasons, only 7% of stock has undergone deep retrofit.

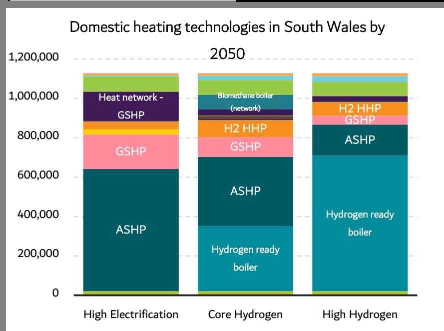
South Wales Net Zero

Sector: Domestic heat

Modelling assumptions and results summary

Long term - 2035 - 2050

Low carbon + electrified heat 2050	
Scenarios	**Households**
High Electrification	1,102,979 (98%)
Core Hydrogen	1,088,707 (97%)
High Hydrogen	1,102,574 (98%)



Typical household demand for heat and water 2050 (kWh/year)		
Scenarios	**Existing dwelling**	**New dwelling**
High Electrification	8,112	3,926
Core Hydrogen	8,203	3,926
High Hydrogen	8,385	3,926

Technology

In this period low carbon alternatives are sufficiently more attractive for existing households such that fossil fuel appliances are being retired early, with 300% the 'typical' replacement rate occurring. For off-gas areas this begins in 2035 in all scenarios, with some variance across the scenarios for on-gas areas. Early retirement of appliances could represent fuel pricing, a carbon levy, a scrappage scheme or uptake of hydrogen ready appliances in anticipation of a network switchover in particular areas.

High Electrification - Some uncertainty about the potential availability of hydrogen delays early retirement of fossil appliances in until 2045. On-gas users continue to switch primarily to an ASHP, the remainder are evenly divided between GSHP or a low carbon heat network. From 2035 aging gas hybrid heat pumps are replaced with ASHPs. Similarly, aging gas-fired heat networks are converted to low carbon sources of heat, such as waste energy.

Core Hydrogen - The potential for some gas network areas beginning to switch to hydrogen from 2035 leads to increased early replacement of natural gas appliances from 2035. By 2040 virtually all remaining gas connections are to a hydrogen network, with a small number of households in discrete network areas fuelled by biomethane.

High hydrogen - From 2035 all on-gas users that switch move to a hydrogen ready appliance, predominantly hydrogen ready boilers. From 2035 aging gas hybrid heat pumps are replaced with hydrogen ready boilers. The potential for some gas network areas begin to switch to hydrogen from 2040 leads to increased early replacement of natural gas appliances from 2040. By 2045 virtually all gas connections are to a hydrogen network.

Efficiency

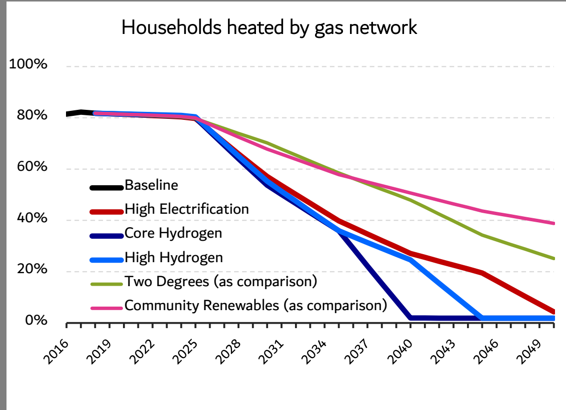
High Electrification - Whilst all stock has been retrofitted to some improved levels of energy efficiency by 2035, deep retrofit continues until 40% of stock has been treated with significant whole house efficiency measures installed by 2050.

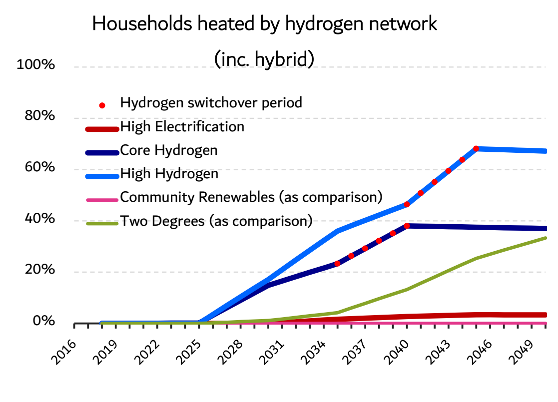
Core Hydrogen - Deep retrofit also continues, although slightly less widespread due to the presence of hydrogen areas, 30% of stock has been treated with significant whole house efficiency measures installed by 2050.

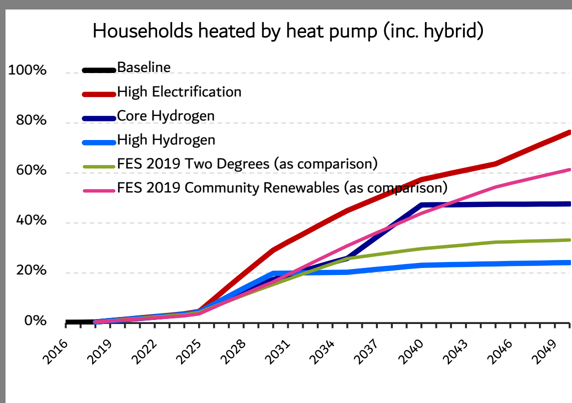
High hydrogen - The remaining untreated stock is retrofitted to a higher level of efficiency by 2040. Deep retrofit is completed in 20% of stock by 2050, less than in other scenarios as the widespread availability of gas reduces impetus to optimise heat pump performance.

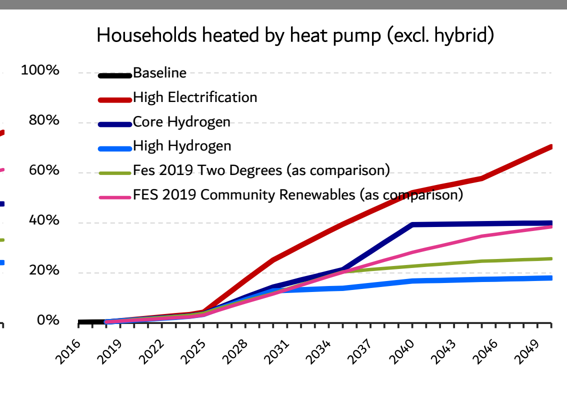
South Wales Net Zero
Sector: Domestic heat
Modelling assumptions and results summary

South Wales domestic properties heated by key technologies









South Wales Net Zero
Sector: Domestic heat
Modelling assumptions and results summary

Distribution approach

There are three aspects to the current and future distribution of domestic heat demand: number of dwellings, the heat demand required for space and hot water heating in these dwellings, and the heating technology used to supply this heat.

Number of dwellings
The number of dwellings in the baseline year is calculated by Output Area (OA) using ONS population estimates, correlated against typical persons per household values from the 2011 Census. New domestic developments are obtained from analysis of Local Authority planning documents and assigned to OAs. In the long term, beyond the timescale of most Local Authority planning, further new dwellings are projected using ONS long-term population projections, and distributed across all OAs, with a bias towards edge-of-urban areas where current planning is focussed.

Heat demand per dwelling
The heat demand per dwelling is calculated at a regional and Local Authority level through disaggregation of sub-national gas consumption data from BEIS, under the assumption that the 82% of households in South Wales served by gas provide a reasonably accurate sample of all housing in South Wales. To calculate heat demand to OA level for distribution, the Local Authority-level heat demand per square meter is applied to the average dwelling floorspace per OA, derived from analysis of EPC certificates. Average heat demand per new build dwelling is assumed to be universal across South Wales.

Projections of heat demand improvements are distributed across all dwellings in accordance with their current EPC rating, reflecting government policy such as the Minimum Energy Efficiency Standard and the Welsh government Arbed programme, which aim to focus energy efficiency improvements on the least efficiency housing and households in fuel poverty. In the near term, efficiency improvements are weighted more heavily to dwellings with an EPC of D or below, with this weighting relaxing over time to distribute efficiency improvements to all but the most well insulated dwellings by 2050. A small weighting is also added OAs with social housing, reflecting targeting of efficacy measures and deep retrofit programmes towards council-managed dwellings.

Heating technologies
The baseline distribution of heating technologies is calculated from analysis of EPC certificates, cross-checked against Census 2011 data to mitigate potential under-representation of certain technologies such as oil and solid fuel. The various on-gas, hydrogen or electrified heating technologies are distributed to OA in accordance with the following parameters:

Gas boilers and gas hybrid heat pumps: The baseline distribution is maintained, as this represents areas where gas connection is available. In the long term, gas heating technologies are mainly replaced by hydrogen heating where available, and electrified heating outside of hydrogen areas. Any methane heating remaining in 2050 is fuelled by biomethane, located in areas modelled to have local biomethane networks.

Hydrogen-ready boilers and hydrogen hybrid heat pumps: Hydrogen-ready heating technologies are distributed to hydrogen areas, pre-empting conversion in the 2030s and 2040s. Under Core Hydrogen this is in the major conurbations of Cardiff and Swansea, which includes nearby urban areas such as Newport and Port Talbot. Under Hybrid Hydrogen this covers most of the existing gas network.

Electric heat pumps: Non-hybrid heat pumps are distributed to off-gas areas in the near term, replacing higher carbon technologies such as oil and LPG, with weightings towards higher affluence and social housing. In the medium term and long term, heat pumps are distributed to all areas of South Wales, particularly under High Electrification, however still weighted towards off-gas areas in scenarios where hydrogen is available. In all cases, air-source heat pumps are weighted towards smaller housing like terraces and flats, whereas ground-source heat pumps are weighted towards larger house, ,where the higher demand for heat warrants higher capital cost to yield improved system efficiency.

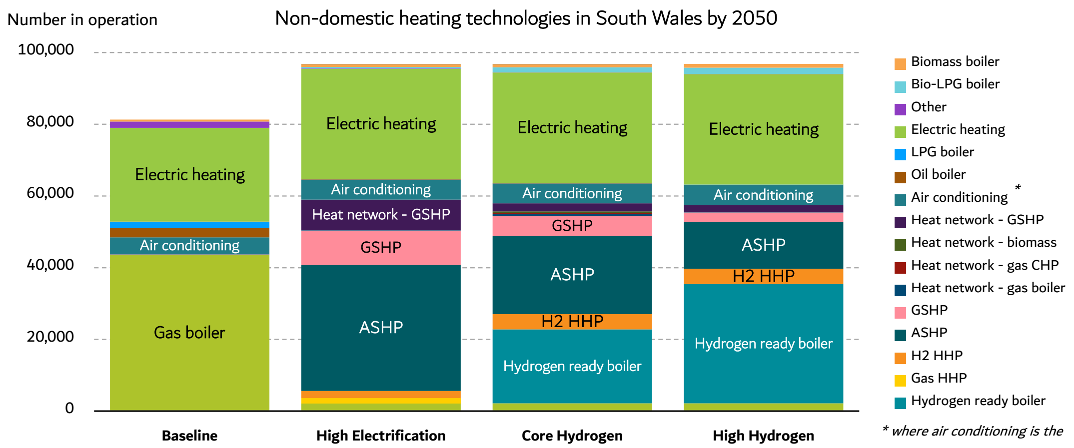
Resistive electric heating: Resistive electric heating is distributed mainly in accordance with its baseline distribution. Where additional resistive electric heating is projected, this is weighted towards flats, where a heat pump installation may not be viable.

Gas boiler and gas CHP heat networks: Gas-fuelled heat networks are distributed in accordance with the baseline and analysis of the HNDU pipeline for near-term distribution. There is no additional gas-fuelled heat network development after 2025.

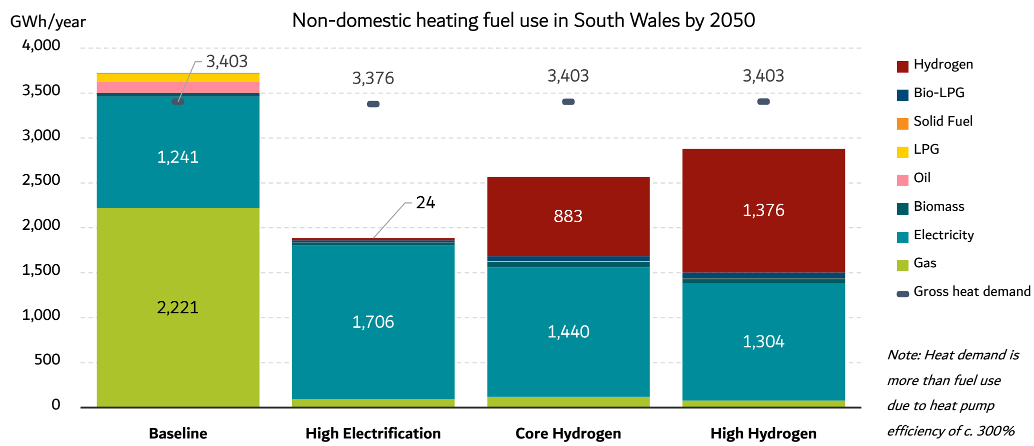
GSHP heat networks: These can represent either a traditional 'centralised' district heat network with a large heat source serving a network, or a series of smaller decentralised heat pumps served by a common low temperature network. In the near term, ground- or water-source heat networks are distributed to denser OAs in areas not on the gas network as well as flats in high-rise buildings in on gas areas. In the medium and long term, GSHP heat networks are modelled to replace existing gas-fuelled heat networks, and new heat networks replacing incumbent heating technologies in denser on- and off-gas areas. Additional weighting is given to industrial areas, where waste heat may be available to be upgraded and delivered by a heat network.

South Wales Net Zero
Sector: Non-domestic heat
Modelling assumptions and results summary

Non-domestic heat covers the demand for space heating and hot water provision in non-domestic buildings. This does not include industrial premises and processes which are covered separately. The modelling includes changing heat demand due to building fabric efficiency improvements as well as shifts in heat delivery technologies.



** where air conditioning is the main source of heat in a*



Note: Heat demand is more than fuel use due to heat pump efficiency of c. 300%

South Wales key statistics 2019	
Typical commercial energy demand for heat and hot water	41,216 (kWh/year)
Properties served by gas network	43,804 (54%)
Properties served by electrified or low carbon heat	26,751 (33%)

Approach to net zero

In all scenarios net zero is achieved by a combination of energy efficiency measures and customers switching away from fossil fuel use. New buildings are built to high efficiency standards and served by low carbon heat sources, the majority being heat pumps. To achieve a net zero outcome, these scenarios make deeper and earlier changes than the 2019 FES.

Existing properties see efficiency improvements, with more radical 'deep retrofit' in up to 10% of stock. The shift in heating technology is modelled by the proportion of usual annual replacements that instead take up low carbon alternatives. The technology varies by scenario.

The level of hydrogen consumption for non-domestic heating is similar in both the hydrogen scenarios, and is less than the current use of natural gas. In the Core hydrogen scenario hydrogen use is concentrated in core areas with dedicated hydrogen heating systems which are linked to hydrogen production and distribution clusters. In the Highhydrogen scenario, hydrogen use is more widespread.

Net zero factors	High Electrification	Core Hydrogen	High Hydrogen
On-gas network properties	All properties encouraged to switch to electrified heating and/or heat networks	Core urban areas (~57% of the 2019 gas connections in the geography) to take up hydrogen-ready boilers from mid-2020s, outside core areas incentives to switch to electrified heat.	All properties on gas network encouraged to take up hybrid and hydrogen ready boilers in late 2020s and 30s.
Off-gas network properties	Off-gas properties are the focus of policy in 2020s incentivising the switch to low-carbon heat.		
Energy efficiency measures	A combination of low energy new buildings, fabric retrofit and deep retrofit combine to reduce average heat demand by 14% - 15%. The increase in property numbers means that gross heat demand increases by 0%		

South Wales Net Zero
Sector: Non-domestic heat
Modelling assumptions and results summary

Baseline - 2019

Low carbon + electrified heat	
Technology	Non-domestic properties
ASHP	17 (.02%)
GSHP	45 (.1%)
Electric heating	26,130 (32.1%)
Biomass boiler	559 (.7%)

As is typical of the UK, South Wales has relatively inefficient building stock that is largely heated by natural gas.

There are a small number of non-domestic properties heated by low carbon sources and a relatively large amount that have electrified heat (32%)

Short term - 2020 to 2025

Low carbon + electrified heat 2025	
Non-domestic properties	
All scenarios	31,310 (36%)

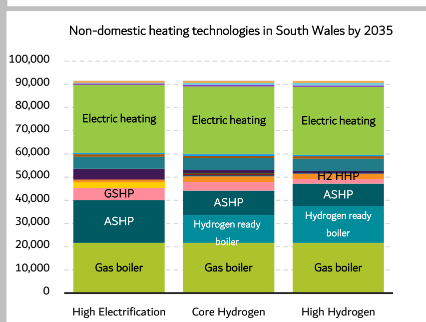
There is limited reduction in fossil fuel installations in new build until the 2025 ban on new fossil fuel installations comes into force.

Early policy tackles existing off-gas fossil heating systems, such that by 2025 any appliance replaced must be low carbon. Low carbon solutions are predominantly heat pumps, with some bioenergy such as solid biomass and biogas. Use of bioenergy is higher in the hydrogen scenarios where there is more focus on use of combustible fuels and less on energy efficiency and electrification.

Medium term - 2025 to 2035

Low carbon + electrified heat 2035	
Scenario	Non-domestic properties
High Electrification	61,876 (68%)
Core Hydrogen	49,253 (54%)*
High Hydrogen	46,222 (51%)*

*Although hydrogen ready appliances are installed, they are not included here as 'low carbon' as hydrogen is not yet flowing within the network



Typical property demand for heat and water 2035 (kWh/year)		
Scenario	Existing property	New property
High Electrification	38,000	22,500
Core Hydrogen	38,180	24,099
High Hydrogen	38,876	24,099

Technology

From 2025 new properties are served almost exclusively by electrified heat, a mixture of ASHP, GSHP and low temperature heat networks utilising GSHPs. By 2030, low carbon heat sources are more attractive than fossil fuel appliances for existing households – low carbon solutions are installed when fossil fuel appliances are replaced.

High Electrification - On-gas users that switch mostly choose an ASHP, the remainder are evenly divided between GSHP, a low carbon heat network and hybrid heat pumps. Connection to heat networks or hydrogen distribution is highly location dependent - heat networks are developed in areas close to sources of waste heat, hydrogen is only available where close to an industrial hydrogen cluster.

Core Hydrogen - There is some early deployment of gas hybrid heat pumps, however from 2030 over half of on-gas users that switch move to a hydrogen ready appliance, mostly hydrogen boilers but some hydrogen hybrids. The remainder, in areas where hydrogen will not be available, switch to heat pumps.

High hydrogen - There is some early deployment of gas hybrid heat pumps, however from 2030 the vast majority of on-gas users that switch move to a hydrogen ready appliance, predominantly hydrogen ready boilers.

Efficiency

By 2030 all new buildings are highly efficient, with high levels of efficiency achieved earlier in **High Electrification**.

High electrification - All stock retrofitted to improved levels of energy efficiency by 2035, driven by the need to achieve acceptable heat pump efficiencies. An increase in deep retrofit sees 5% of stock with significant efficiency measures installed by 2035.

Core Hydrogen - Similarly, all stock retrofitted by 2035, although fewer efficiency measures deployed in hydrogen connected households results in a slightly higher typical heat demand than in high electrification. Deep retrofit is delivered in 5% of stock, to optimise heat pump efficiency in existing properties.

High hydrogen - Most stock is retrofitted to a higher level of efficiency by 2035, the reduction in demand is less than in other scenarios as the widespread availability of hydrogen reduces impetus to optimise heat pump performance. For similar reasons, only 1% of stock has undergone deep retrofit.

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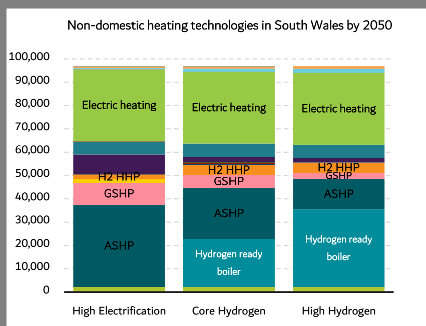
South Wales Net Zero
Sector: Non-domestic heat
Modelling assumptions and results summary

Long term - 2035 - 2050

Low carbon + electrified heat 2050	
Scenarios	Non-domestic properties
High Electrification	88,780 (92%)
Core Hydrogen	88,026 (91%)
High Hydrogen	88,767 (92%)



Typical property demand for heat and water 2050 (kWh/year)		
Scenarios	Existing property	New property
High Electrification	36,750	22,500
Core Hydrogen	37,000	24,099
High Hydrogen	37,000	24,099

Technology

In this period low carbon alternatives are sufficiently more attractive for existing properties such that fossil fuel appliances are being retired early, with 300% the 'typical' replacement rate occurring. For off-gas areas this begins in 2035 in all scenarios, with some variance across the scenarios for on-gas areas. Early retirement of appliances could represent fuel pricing, a carbon levy, a scrappage scheme or uptake of hydrogen ready appliances in anticipation of a network switchover in particular areas.

High Electrification - some uncertainty about the potential availability of hydrogen delays early retirement of fossil appliances in until 2045. On-gas users continue to switch primarily to an ASHP, the remainder are evenly divided between GSHP or a low carbon heat network. From 2035 aging gas hybrid heat pumps are replaced with ASHPs. Similarly, aging gas-fired heat networks are converted to low carbon sources of heat, such as waste energy.

Core Hydrogen - the potential for some gas network areas begin to switch to hydrogen from 2035 leads to increased early replacement of natural gas appliances from 2035. By 2040 virtually all remaining gas connections are to a hydrogen network, with a small number of properties in discrete network areas fuelled by biomethane.

High hydrogen - from 2035 all on-gas users that switch move to a hydrogen ready appliance, predominantly hydrogen ready boilers. From 2035 aging gas hybrid heat pumps are replaced with hydrogen ready boilers. The potential for some gas network areas begin to switch to hydrogen from 2040 leads to increased early replacement of natural gas appliances from 2040. By 2045 virtually all gas connections are to a hydrogen network, with a small number of properties in discrete network areas fuelled by biomethane.

Efficiency

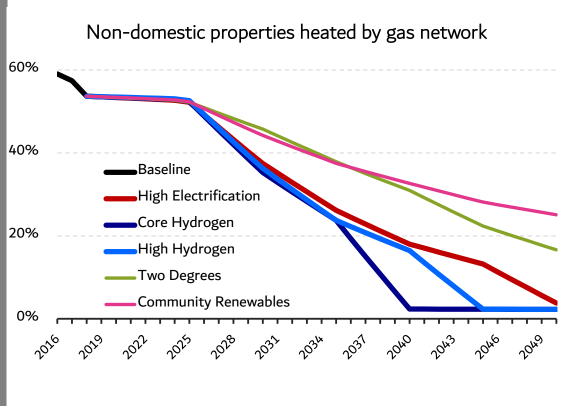
High electrification - Whilst all stock has been retrofitted to some improved levels of energy efficiency by 2035, deep retrofit continues until 10% of stock has been treated with significant efficiency measures installed by 2050.

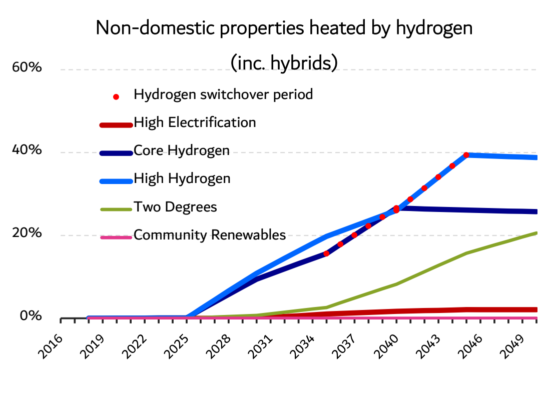
Core Hydrogen - Deep retrofit also continues, although slightly less widespread due to the presence of hydrogen areas, 5% of stock has been treated with significant efficiency measures installed by 2050.

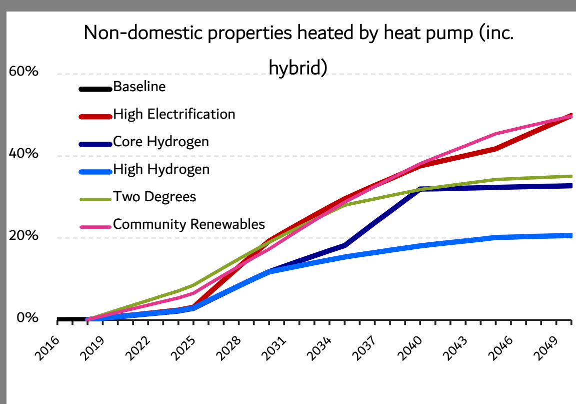
High hydrogen - The remaining untreated stock is retrofitted to a higher level of efficiency by 2040. Deep retrofit is completed in 2% of stock by 2050, less than in other scenarios where use of heat pumps provides more impetus to optimise heating system efficiency.

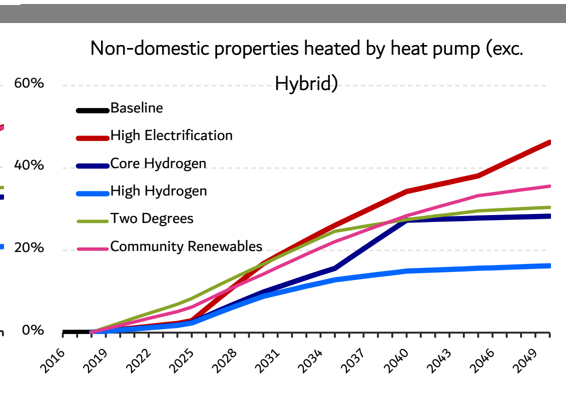
South Wales Net Zero
Sector: Non-domestic heat
Modelling assumptions and results summary

South Wales non-domestic properties heated by key technologies









South Wales Net Zero
Sector: Non-domestic heat
Modelling assumptions and results summary

Distribution approach

There are three aspects to the current and future distribution of commercial and industrial heat demand: number of properties, the heat demand required for space and hot water heating in these properties, and the heating technology used to supply this heat. The commercial and industrial heat distribution methodology follows the domestic methodology, with the exception of domestic-specific factors such as affluence and social housing.

Number of properties
The number of properties in the baseline year is calculated by Output Area (OA) using non-domestic rating data from the Valuation Office Agency, disaggregated into classes using EPC and DEC data. New developments are obtained from analysis of Local Authority planning documents and assigned to OAs.

Heat demand per property
The heat demand per property is calculated at a regional and Local Authority level through disaggregation of sub-national gas consumption data from BEIS. To calculate heat demand to OA level for distribution, the Local Authority-level heat demand per square meter is applied to the average property floorspace per OA, derived from analysis of EPC and DEC certificates. Average heat demand per new property is assumed to be universal across South Wales.

Projections of heat demand improvements are distributed in accordance with their current EPC rating, reflecting government policy such as the Minimum Energy Efficiency Standard, which aims to focus energy efficiency improvements on the least efficient commercial and industrial properties. In the near term, efficiency improvements are weighted more heavily to properties with an EPC/DEC rating of D or below, with this weighting relaxing over time to distribute efficiency improvements to all but the most well insulated properties by 2050.

Heating technologies
The baseline distribution of heating technologies is calculated from analysis of EPC/DEC certificates. The various on-gas, hydrogen or electrified heating technologies are distributed to OA in accordance with the following parameters:

Gas boilers and gas hybrid heat pumps: The baseline distribution is maintained, as this represents areas where a gas connection is available. In the long term, gas heating technologies are mainly replaced by hydrogen heating where available, and electrified heating outside of hydrogen areas. Any methane heating remaining in 2050 is fuelled by biomethane, located in areas modelled to have local biomethane networks.

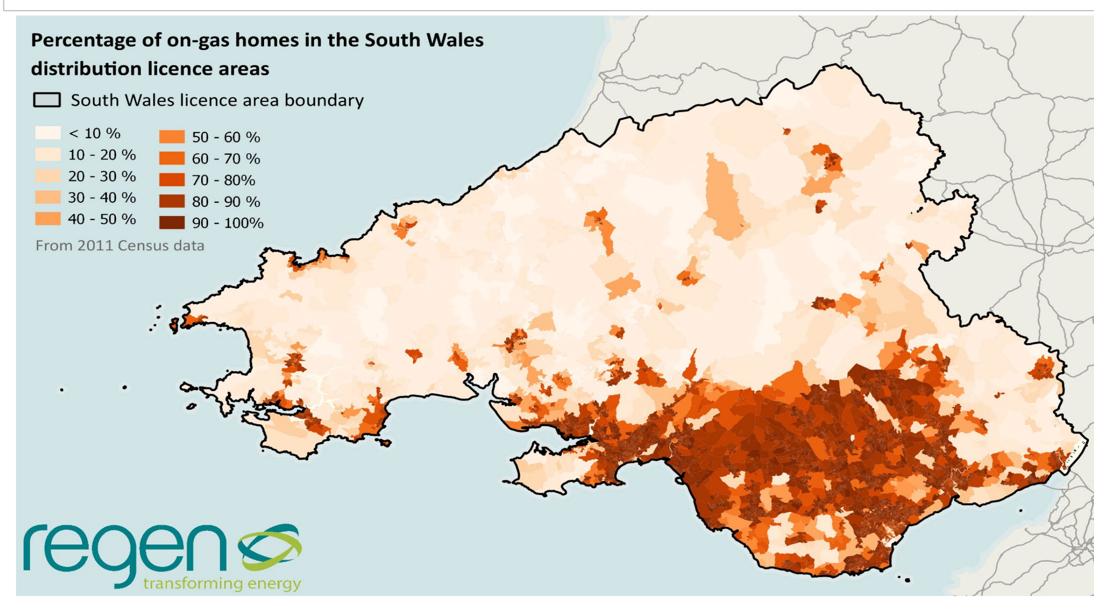
Hydrogen-ready boilers and hydrogen hybrid heat pumps: Hydrogen heating technologies are distributed to hydrogen areas, pre-empting conversion in the 2030s and 2040s. Under Core Hydrogen this is in the major conurbations of Cardiff and Swansea, which includes nearby urban areas such as Newport and Port Talbot. Under Hybrid Hydrogen this covers most of the existing gas network.

Electric heat pumps: Non-hybrid heat pumps are distributed to off-gas areas in the near term, replacing higher carbon technologies such as oil, LPG and resistive electric heating. In the medium term and long term, heat pumps are distributed to all areas of South Wales, particularly under High Electrification, however still weighted towards off-gas areas in scenarios where hydrogen is available. In all cases, air-source heat pumps are weighted towards smaller properties with lower heat demand.

Air conditioning and resistive electric heating: Air conditioning units as the main heating technology, such as in a small retail shop, are distributed in accordance with the baseline distribution. Resistive electric heating is also distributed mainly in accordance with its baseline distribution.

Gas boiler and gas CHP heat networks: Gas-fuelled heat networks are distributed in accordance with the baseline, analysis of the HNDU pipeline for near-term distribution, and stakeholder engagement during previous DFES work. There is no additional gas-fuelled heat network development after 2025.

GSHP heat networks: In the near term, ground- or water-source heat networks are distributed to denser OAs in areas not on the gas network. In the medium and long term, GSHP heat networks are modelled to replace existing gas-fuelled heat networks, and new heat networks replacing incumbent heating technologies in denser on- and off-gas areas. Additional weighting is given to industrial areas, where waste heat may be available to be upgraded and delivered by a heat network.



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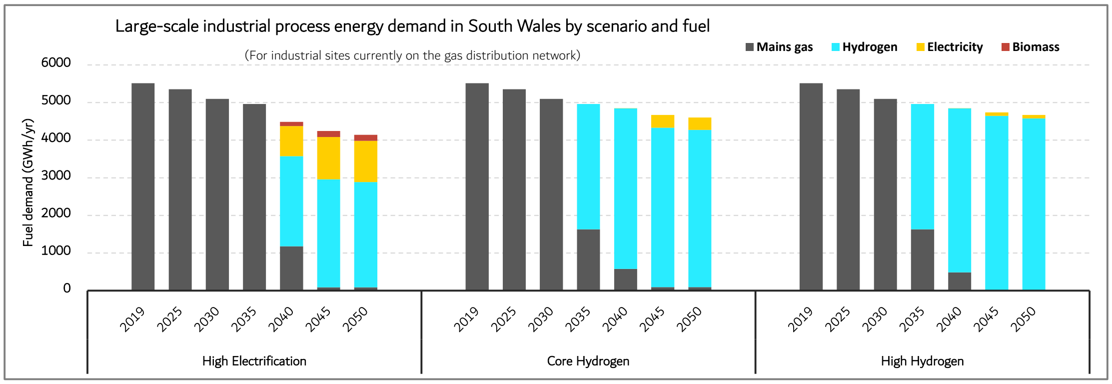
South Wales Net Zero
Sector: Large-scale industrial processes
Modelling assumptions and results summary

The large-scale industrial process sector is defined as sites currently connected to the gas distribution networks as 'Daily Metered' customers, where their energy consumption is large enough to warrant daily logging of mains gas consumption.



Approach to net zero

For large-scale industrial processes currently on the gas distribution network, energy demand is closely tied to economic factors. These net zero scenarios are based on a 'steady state' where levels of production remain at 2019 levels throughout the scenario timeframe. Therefore, decarbonisation is through efficiency improvements and fuel switching to low carbon fuels.

For compliance with net zero carbon, all large-scale industrial energy demand is fuelled by a low carbon source by 2050 under every scenario. This is predominantly low carbon hydrogen, produced through either electrolysis of low carbon electricity and/or auto thermal reformation of natural gas with carbon capture and storage, but also includes grid electricity, biomass and a small remainder of methane in areas that are supplied by biomethane in 2050, which may be delivered through local gas networks rather than a mains gas grid.

Net zero factors to 2050	High Electrification	Core Hydrogen	High Hydrogen
Hydrogen industrial cluster	Industrial hydrogen usage confined to the largest consumers of gas energy in the industrial cluster area, with large anchor loads connecting in the late 2030s.	Industrial hydrogen usage expanded to most consumers of gas energy in the industrial cluster area, with large anchor loads connecting in the early 2030s and smaller loads after.	
Process efficiency improvement	Efficiency improves up to 20% depending on the process, based on BEIS Energy Efficiency Roadmaps and sector-specific studies, due to higher cost of hydrogen and electricity compared to natural gas, ambitious green policy such as carbon levies, and technical feasibility of energy-saving measures such as advanced heat recovery.		
Availability of low carbon fuels	Hydrogen, despite its cost, is still the preferred fuel for most large-scale gas-fired processes, however where processes could reasonably be converted to electricity or biomass, they do so.	Hydrogen is cheap relative to electricity, so processes in the industrial cluster area dominantly switch to hydrogen.	

Scenario	Fuel	Measure	2019	2025	2030	2035	2040	2045	2050
High Electrification	Methane	GWh	5,513,070	5,353,191	5,099,590	4,961,763	1,181,092	88,654	86,491
Core Hydrogen	Methane	GWh	5,513,070	5,353,191	5,099,590	1,629,644	579,245	93,194	91,897
High Hydrogen	Methane	GWh	5,513,070	5,353,191	5,099,590	1,629,644	484,105	-	-
High Electrification	Hydrogen	GWh	-	-	-	-	2,394,884	2,868,148	2,798,194
Core Hydrogen	Hydrogen	GWh	-	-	-	3,332,120	4,265,360	4,239,455	4,180,437
High Hydrogen	Hydrogen	GWh	-	-	-	3,332,120	4,360,501	4,645,695	4,581,021
High Electrification	Electricity	GWh	-	-	-	-	800,911	1,125,198	1,097,754
Core Hydrogen	Electricity	GWh	-	-	-	-	5,862	337,121	332,428
High Hydrogen	Electricity	GWh	-	-	-	-	5,862	90,586	89,325

Baseline - 2019

Daily-metered industrial process demand, 2019	
Business sector	**Demand (GWh)**
Food and drink	368
Low-temperature processes	1547
High-temperature processes	3418
Other	180

Of the 42 baseline sites, high temperature processes, mainly steelworks in South Wales such as Tata Steel in Port Talbot, represent 62% of gas demand for large-scale industrial processes in South Wales. At 3.4 TWh, this accounts for ~13% of all South Wales gas demand in the baseline.

Low temperature processes include paper and packaging production and chemicals works. Food and drink sector demand comes from breweries, bakeries and prepared food factories.

Short term - 2020 to 2025

Large-scale industrial processes are not expected to switch fuels in the short term. Due to the current low cost of mains gas, efficiency improvements are limited due to the long payback periods on the capital investment required. Discussion with large industrial users in South Wales during this project and previous DFES work suggested that, while low carbon options such as hydrogen and electrification are under consideration, these are unlikely to be implemented for a number of years.

Medium term - 2025 to 2035

Fuel switching and efficiency improvements remain limited through the 2020s in all scenarios. In the **Core and High Hydrogen** scenarios, large anchor loads in the South Wales industrial cluster, a 'hot spot' of industrial energy demand[1], are converted to hydrogen in the early 2030s, expanding to smaller industrial loads over time. Under **High Electrification**, the higher cost of hydrogen means that this conversion is not achieved before 2035.

Based on assessment of each large-scale industrial site and their associated fuel uses, electrification of these processes is unlikely before 2035. However, this is a key area of uncertainty and possible change, hinging heavily on the success of hydrogen trials in the near-term, and technological advances and fuel pricing over the longer term.

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727040/CCUS_Cost_Challenge_Taskforce_Report.pdf

Long term - 2035 - 2050

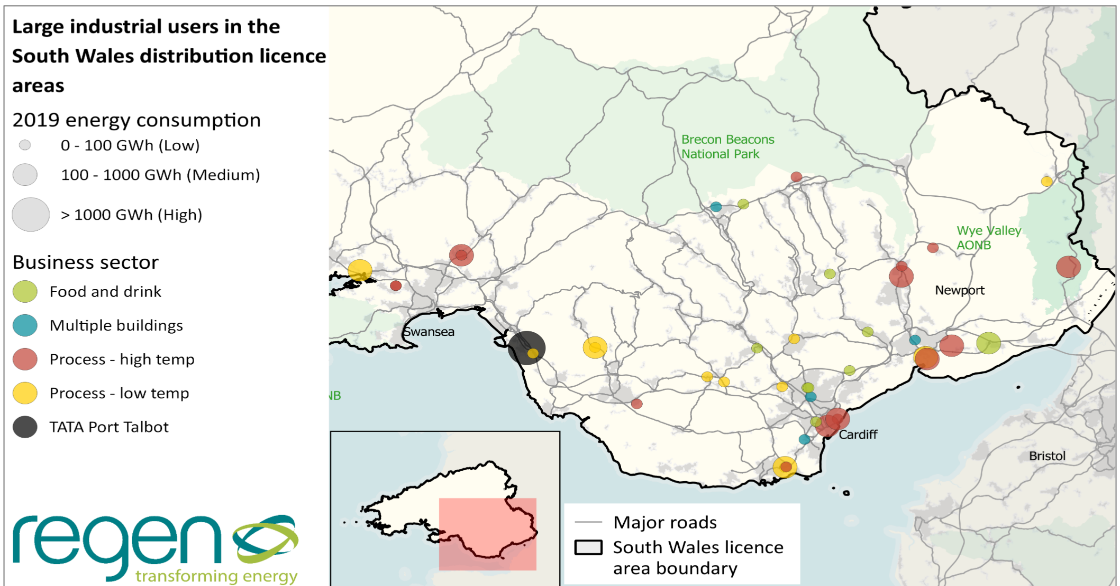
In the **Core and High Hydrogen** scenarios, the hydrogen network continues to develop, allowing smaller industrial loads to convert from mains gas to hydrogen, due to the low cost and ease of conversion of hydrogen relative to electrification in these scenarios. The small number of large-scale industrial that cannot connect to the hydrogen network convert to electricity or biomethane.

Under **High Electrification** the hydrogen industrial cluster develops in the late 2030s and early 2040s, however, some processes suitable for electrification convert to electricity due to the relatively high cost of hydrogen in this scenario. There is a small conversion from mains gas to biomass for industrial process heat, especially for paper and packaging facilities; even today, the majority of European paper industry energy consumption is fuelled by biomass CHP[2]. Therefore, this is a natural fuel switch in a scenario where low carbon gas energy is relatively more expensive.

[2] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC111652/kjna29280enn_jrc111652_online_revised_by_ipo.pdf

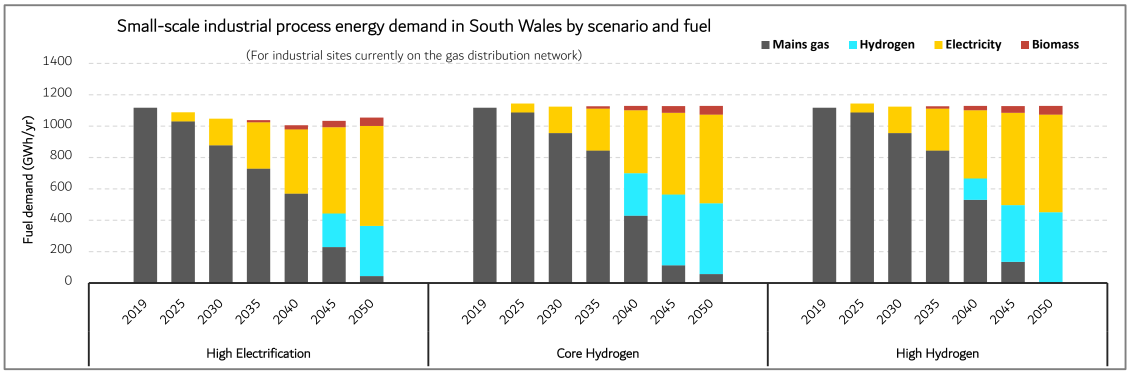
Distribution approach

Each of the 42 baseline sites is assessed separately for fuel usage, potential fuel switching and efficiency improvements. As a result, the distribution of energy demand from each fuel type is directly based on the baseline sites.



South Wales Net Zero
Sector: Small-scale industrial processes
Modelling assumptions and results summary

The 'scale-scale industrial process' sector is defined as sites currently on the gas distribution network, but not large enough to warrant daily metering. The energy consumption of these sites relates to energy for industrial processes only - space heating and hot water are not included in this sector.



Approach to net zero

For small-scale industrial processes currently on the gas distribution network (defined as Non-Daily Metered customers), energy demand is closely tied to economic factors. These net zero scenarios are based on a 'steady state' where levels of production remain at 2019 levels throughout the scenario timeframe. Therefore, decarbonisation is through efficiency improvements and fuel switching to low carbon fuels.

For compliance with net zero carbon, all small-scale industrial energy demand is fuelled by a low carbon source by 2050 under every scenario. This includes electricity and, in the industrial cluster areas, low carbon hydrogen produced through either electrolysis of low carbon electricity and/or auto thermal reformation of natural gas with carbon capture and storage. Additionally, biomass and biomethane supply a small proportion of small-scale industrial demand in 2050.

Net zero factors to 2050	High Electrification	Core Hydrogen	High Hydrogen
Hydrogen industrial cluster	Industrial hydrogen usage confined to the largest consumers of gas energy, with limited expansion of the cluster in the 2040s.	Industrial hydrogen usage expanded to most consumers of gas energy in the industrial cluster area, with large anchor loads connecting in the early 2030s and smaller loads coming online in the late 2030s and early 2040s.	
Process efficiency improvement	Efficiency improves up to 20% depending on the process, based on BEIS Energy Efficiency Roadmaps and sector-specific studies, due to higher cost of hydrogen and electricity compared to natural gas, ambitious green policy such as carbon levies, and technical feasibility of energy-saving measures such as advanced heat recovery.		
Availability of low carbon fuels	Hydrogen and biomethane are expensive relative to electricity, so processes that can easily electrify do so.	Hydrogen is cheap relative to electricity, so processes in the industrial cluster area dominantly switch to hydrogen. Industrial sites outside the clusters typically switch to electrification or electricity-hydrogen hybrid systems.	

Scenario	Fuel	Measure	2019	2025	2030	2035	2040	2045	2050
High Electrification	Methane	GWh	1,117,422	1,030,766	878,573	729,118	569,885	229,071	44,697
Core Hydrogen	Methane	GWh	1,117,422	1,086,763	956,025	844,758	429,064	112,759	56,464
High Hydrogen	Methane	GWh	1,117,422	1,086,763	956,025	844,758	530,684	135,311	-
High Electrification	Hydrogen	GWh	-	-	-	-	-	214,530	318,854
Core Hydrogen	Hydrogen	GWh	-	-	-	-	270,988	451,036	451,709
High Hydrogen	Hydrogen	GWh	-	-	-	-	135,494	360,829	451,709
High Electrification	Electricity	GWh	-	57,198	168,710	295,665	408,983	549,733	637,707
Core Hydrogen	Electricity	GWh	-	57,198	168,710	267,507	400,836	521,510	564,636
High Hydrogen	Electricity	GWh	-	57,198	168,710	267,507	434,709	589,166	621,100

Baseline - 2019

Small-scale industrial process gas demand, 2019	
Business sector	Demand (GWh)
Drying/separation	745
Low-temperature processes	372
High-temperature processes	0
Other	0

There is 2.6 TWh of gas demand for small-scale industrial processes in the baseline year, representing ~10% of total distributed gas demand in South Wales.

48% of small-scale industrial gas consumption in the baseline fuels low temperature processes, such as food and drink production, chemical and pharmaceutical product production, and metalwork such as fabrication and machinery manufacture.

Short term - 2020 to 2025

Small-scale industrial processes are not expected to switch fuels in the short term. Due to the current low cost of mains gas, efficiency improvements are limited due to the long payback periods on the capital investment required. A small amount of electrification is projected, mainly for new industrial sites.

Medium term - 2025 to 2035

In the **Core and High Hydrogen** scenarios, large anchor loads in the South Wales industrial cluster are converted to hydrogen in the early 2030s, however a wider hydrogen network for domestic and smaller-scale non-domestic customers is not developed before 2035. Some drying and low temperature processes are fully or partially electrified or converted to biomass CHP, particularly for new builds and under the **High Electrification** scenario, as industrial-scale heat pumps, including hybrid systems, become increasingly viable, especially when combined with waste heat from industrial processes on site or nearby. The density of industrial energy use in the South Wales industrial cluster provides more opportunities than average to utilise and upgrade waste heat from high-temperature industrial processes for lower-temperature processes, improving the overall efficiency of energy consumption.

Long term - 2035 - 2050

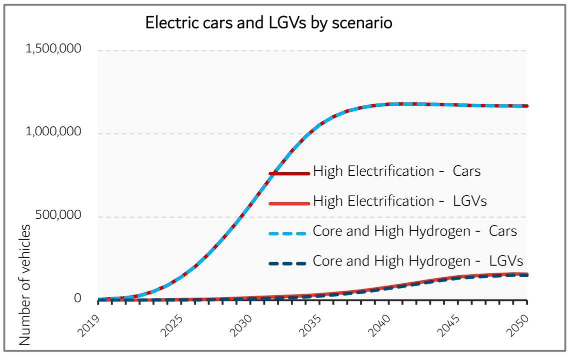
In the **Core and High Hydrogen** scenarios, the hydrogen network continues to develop, allowing smaller industrial loads to convert from mains gas to hydrogen, due to the low cost and ease of conversion of hydrogen relative to electrification in these scenarios, however hybrid heating systems are utilised due to benefits to fuel costs, optionality, providing flexibility and heat recovery. Under **High Electrification** the hydrogen industrial cluster develops in the late 2030s and early 2040s, however, more processes suitable for electrification convert to electricity due to the relatively high cost of hydrogen in this scenario. Outside the hydrogen industrial cluster, net-zero-compliant fuels include electricity, biomass CHP and biomethane or bioSNG, if these are able to be produced nearby or on

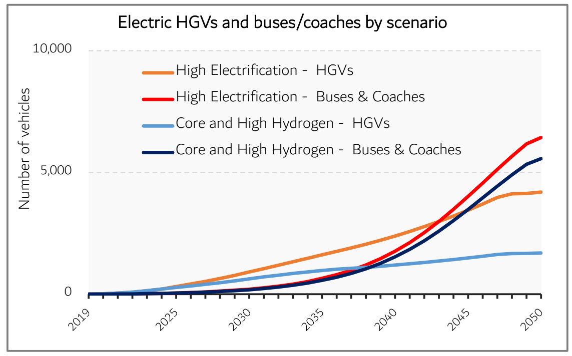
Distribution approach

Current industrial demand is focussed heavily in the South Wales industrial cluster 'hot spot', and this is not projected to change throughout the scenario timeframe. Fuel switching has been modelled based on the availability, or lack of, of low carbon fuels such as hydrogen, and the type of industrial process, which dictates whether a currently gas-powered industrial process is most likely to switch to hydrogen, electrification or biomass CHP. Efficiency improvements are assumed to be consistent across the South Wales licence area.

The location of new industrial sites have been projected through analysis of local authority local plans. The industrial process demand associated with these sites has been assumed to follow the current demand in the area.

South Wales Net Zero
Technology: Electric vehicles
Modelling assumptions and results summary





South Wales key statistics	
Number of road vehicles, 2019	1,365,802
Average cars per household, 2019	1.14
Proportion of vehicles that are EVs, 2019	0.35%

Approach to net zero

Across various net zero scenarios, such as those produced by the Committee on Climate Change and National Grid, road transport is near-fully decarbonised by 2050. These net zero scenarios assume that current restraints such as in the supply chain are resolved and road transport is fully fuelled by either electricity, hydrogen or biomethane by 2050.

The FES 2019 scenarios, Community Renewables and Two Degrees, both achieve elimination of petrol and diesel vehicles by 2050. These trajectories have been used as the basis for the net zero scenarios. However, the uptake of low carbon vehicles is accelerated under the Net Zero scenarios to help meet interim carbon budgets, which is likely to be reflected in the upcoming National Grid FES.

Net zero factors to 2050	
Government policy and support	The ban on the sale of new petrol and diesel cars is brought forward to 2032 at the latest.
Active and public transport	A move to alternative travel reduces car mileage and total number of cars by 10% each, as per CCC Further Ambition.
Availability of EV charging infrastructure	Assumes that EV charging infrastructure is able to meet demand.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	EV cars	Number	4,775	139,321	571,967	1,053,227	1,178,128	1,173,657	1,167,383
Core and High Hydrogen	EV cars	Number	4,775	139,321	571,967	1,053,227	1,178,128	1,173,657	1,167,383
High Electrification	EV LGVs	Number	227	3,049	14,438	33,029	78,781	140,072	157,229
Core and High Hydrogen	EV LGVs	Number	227	1,772	7,727	25,185	70,937	132,228	149,385
High Electrification	EV HGVs	Number	3	315	912	1,618	2,390	3,453	4,193
Core and High Hydrogen	EV HGVs	Number	3	277	631	975	1,197	1,489	1,692
High Electrification	EV buses	Number	1	50	207	651	1,764	4,018	6,434
Core and High Hydrogen	EV buses	Number	1	45	184	573	1,534	3,481	5,567

Baseline - 2019

Electric vehicle registrations			
Year	Electric vehicles	Increase on previous year	% of all vehicles
2016	1,074	79%	0.08%
2017	1,635	52%	0.12%
2018	3,085	89%	0.23%
2019	5,006	62%	0.35%

Electric vehicles currently make up a very small proportion of all vehicles in South Wales, with just over 5,000 EVs in 2019, representing 0.35% of all vehicles. However, in recent years there has been a rapid increase in the number of EVs, with an average year-on-year growth rate of 71% since 2016.

Of the baseline of electric vehicles, 95% are cars and 5% are vans. A single electric bus, operated by Newport Transport, was registered in South Wales as of 2019.

Short term - 2020 to 2025

South Wales is currently well below the average uptake of EVs across GB, hosting 3.6% of all vehicles but only 1.7% of electric vehicles. This is due to several factors, such as public charging infrastructure, access to off-street parking, average journey mileage and levels of affluence. This is not expected to significantly change by 2025, and therefore South Wales uptake of EVs remains below the GB average.

Medium term - 2025 to 2035

The number of EVs rapidly increases as costs reduce, more vehicle models are available, mileage ranges increase, public charging options continue to increase and domestic chargers become more commonplace. The ban on the sale of new petrol and diesel vehicles comes in 2035, which means that the early 2030s are assumed to have the greatest increase in EV cars, as almost every new vehicle is electric.
In High Electrification the trajectory is higher in commercial and heavy vehicles as more choose electrification as a low carbon technology. In Core and High Hydrogen more commercial and heavy vehicles use hydrogen and biomethane. These technologies are explained in separate technology summaries.

South Wales Net Zero
Technology: Electric vehicles
Modelling assumptions and results summary

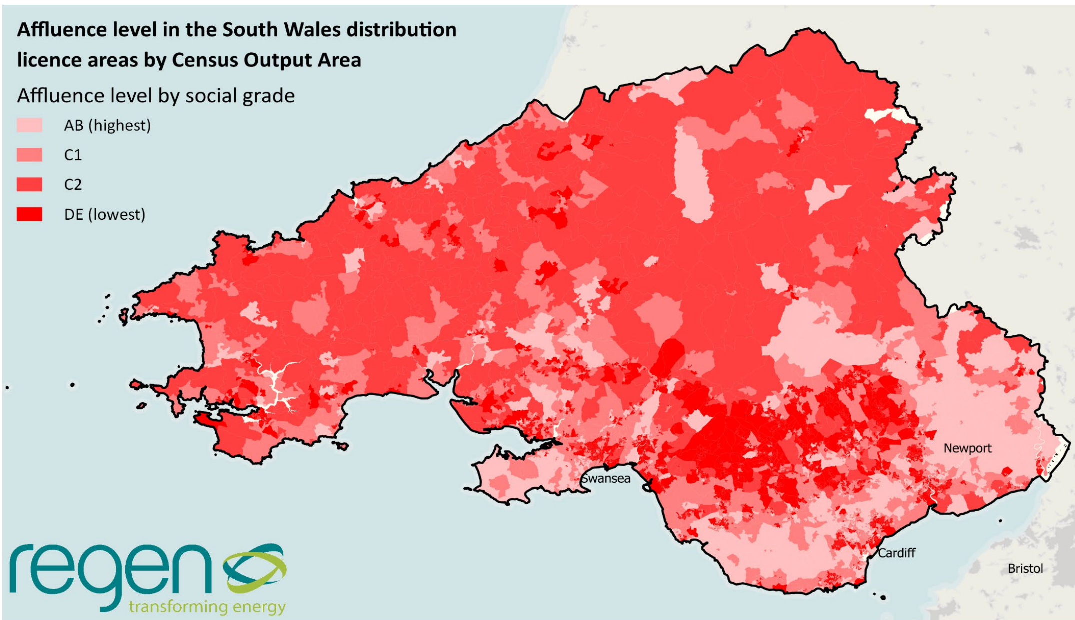
Long term - 2035 - 2050

By 2040, almost all cars are electrified, and after 2040 the total number of cars decreases as people are encouraged to move to public and active transport. Buses, LGVs and HGVs are also electrified, especially for shorter journey, more in **High Electrification** than in **Core and High Hydrogen**. In all scenarios those needing vehicles with a longer mileage range use hydrogen or gas vehicles.

Distribution approach

In the short term, electric cars and LGVs distribution is weighted towards areas with greater levels of affluence (see example distribution map below), off-road parking, households with more than one vehicle and lower annual mileage per car. Throughout the timeframe these weightings are relaxed, as electric personal vehicles become more pervasive due to reducing costs, longer ranges and increasing availability of charging infrastructure.

Electric HGVs and buses are distributed through analysis of Ordnance Survey Addressbase data to identify depots and other sites likely to host a fleet of large vehicles.



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South Wales Net Zero
Technology: Electric vehicle chargers
Modelling assumptions and results summary

Approach to net zero

Regen's **Transport Model** projects EV chargers based on EV numbers - see Electric Vehicles summary.

Increasing efficiency of electric vehicles and chargers, alongside a trend towards active and public transport and away from personal vehicles, results in the required active charger capacity peaking between 2035 and 2040, particularly for domestic chargers.

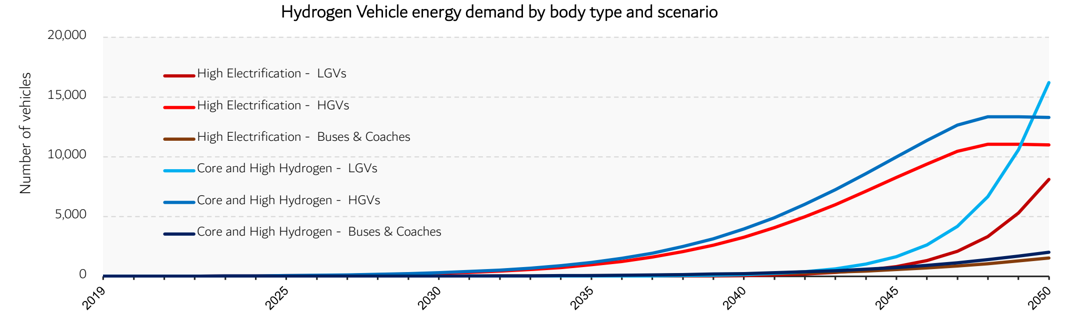
Scenario	Charger type	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Car parks	MW capacity	1	6	25	53	67	74	76
Core and High Hydrogen	Car parks	MW capacity	1	6	25	53	66	71	73
High Electrification	Destination	MW capacity	3	18	38	55	49	40	33
Core and High Hydrogen	Destination	MW capacity	3	18	38	54	49	40	33
High Electrification	Domestic off-street charger	MW capacity	26	646	1,871	2,831	2,671	2,308	1,910
Core and High Hydrogen	Domestic off-street charger	MW capacity	26	643	1,857	2,814	2,655	2,292	1,895
High Electrification	Domestic on-street	MW capacity	1	28	93	174	204	215	213
Core and High Hydrogen	Domestic on-street	MW capacity	1	28	92	173	203	214	211
High Electrification	En-route / local stations	MW capacity	2	25	76	132	146	149	142
Core and High Hydrogen	En-route / local stations	MW capacity	2	24	74	129	143	144	136
High Electrification	En-route national network	MW capacity	1	7	18	33	42	50	53
Core and High Hydrogen	En-route national network	MW capacity	1	7	17	30	38	45	48
High Electrification	Fleet/Depot	MW capacity	0	6	21	45	87	151	188
Core and High Hydrogen	Fleet/Depot	MW capacity	0	5	16	34	68	119	148
High Electrification	Workplace	MW capacity	2	34	97	164	183	192	181
Core and High Hydrogen	Workplace	MW capacity	2	33	93	160	179	187	174

Distribution approach

Each charger type is distributed separately according to the below methodology:
- Car parks - Ordnance Survey Addressbase data classified to car parks
- Destination - Ordnance Survey Addressbase data classified to destinations, such as supermarkets, shopping centres etc.
- Domestic off-street with charger - Census data on off-street parking provision combined with EV projections
- Domestic on-street - Census data on on-street parking provision combined with EV projections
- En-route / local charging stations - Ordnance Survey Addressbase data classified to petrol stations on minor roads
- En-route national network - Ordnance Survey Addressbase data classified to petrol stations on major roads
- Fleet/depot - Ordnance Survey Addressbase data classified to vehicle depots, such as freight, bus, coach and LGV depots.
- Workplace - Ordnance Survey Addressbase data classified to workplaces, such as offices, retail, leisure, factories and warehouses etc.

South Wales Net Zero
Technology: Hydrogen commercial vehicles
Modelling assumptions and results summary

Hydrogen Vehicle energy demand by body type and scenario



Approach to net zero

The current greenest FES 2019 scenarios, Community Renewables and Two Degrees, both achieve elimination of petrol and diesel vehicles by 2050. These have been used as the basis for transport scenarios in this analysis. However, the uptake of low carbon vehicles is accelerated to help meet interim carbon budgets which will now be higher as a result of net zero.

Hydrogen fuel for transport is available from the mid-2020s but expensive, reducing in cost throughout the timeframe. As vehicle-grade hydrogen must be produced by electrolysis rather than methane reformation, the location of hydrogen vehicle fuelling stations is not dictated by the availability of hydrogen for heat or processes.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	H2 LGVs	Number	-	-	1	7	77	818	8,110
Core and High Hydrogen	H2 LGVs	Number	-	-	1	14	154	1,635	16,219
High Electrification	H2 HGVs	Number	-	55	250	967	3,274	8,258	11,010
Core and High Hydrogen	H2 HGVs	Number	-	67	302	1,169	3,958	9,982	13,308
High Electrification	H2 buses	Number	-	4	16	55	180	562	1,526
Core and High Hydrogen	H2 buses	Number	-	5	21	72	237	737	2,003

Baseline - 2019

There are no known registrations of hydrogen vehicles in Wales.

Short term - 2020 to 2025

Due to very few hydrogen vehicles being on the market and lack of fueling infrastructure, hydrogen is projected to remain a very niche fuel for commercial vehicles in the short term, limited to a few hundred vehicles by 2025.

Medium term - 2025 to 2035

Hydrogen vehicle uptake increases in the early 2030s, particularly for HGVs, as increasing numbers of hydrogen models come to market. Mechanisms such as fuel duty and vehicle tax continue to encourage uptake of low carbon alternatives to conventional commercial vehicles fuelled by diesel and petrol.
The projections are higher in **Core and High Hydrogen** as more vehicles are electrified in **High Electrification**. The electric vehicles are summarised in a separate technology sheet.

Long term - 2035 - 2050

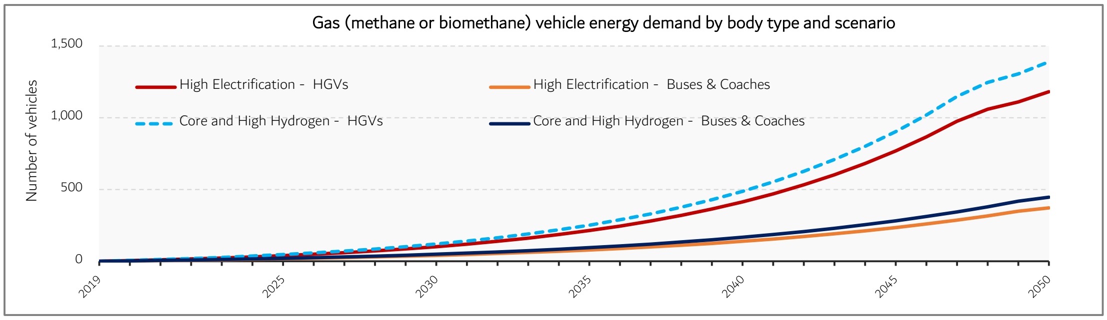
Hydrogen vehicle uptake accelerates, particularly in the late 2040s, as net zero compliance requires no remaining petrol or diesel vehicles by 2050. As costs of hydrogen vehicles and hydrogen fuel continue to fall, lower value, harder-to-electrify transport such as LGVs and coaches move to hydrogen as a low carbon fuel.

Distribution approach

Hydrogen demand is distributed according to the location of vehicle depots for buses and HGV fleets, existing petrol stations on the major road network (initially focussed on the M4 motorway), and weighted towards close proximity to the electricity network, due to electricity demand for electrolysis. Additionally, hydrogen fuelling is weighted towards the industrial cluster area in the longer term, as industrial production of electrolysed hydrogen is used to fuel HGV fleets associated with industrial activity.

South Wales Net Zero

Technology: Gas (methane or biomethane) heavy vehicles
Modelling assumptions and results summary



Approach to net zero

The FES 2019 scenarios, Community Renewables and Two Degrees, both achieve elimination of petrol and diesel vehicles by 2050. These have been used as the basis for the transport scenarios in this analysis. However, the uptake of low carbon vehicles is accelerated ahead of modelling in FES 2019 in order to meet the increased net zero compliant carbon budgets prior to 2050 .

In the short and medium term, gas vehicles are likely to be fuelled by natural gas, in the form of Compressed Natural Gas (CNG) or Liquified Natural Gas (LNG) as well as biomethane, in the form of BioLNG or BioCNG. By 2050, for compliance with net zero carbon, all methane-fuelled vehicles will have to be biomethane vehicles. Biomethane is projected to be an increasingly valuable resource by 2050 with many sectors likely to target its use as a low carbon fuel. This level of demand from other sectors is likely to restrict its use in road transport to high-value, hard-to-electrify vehicles.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Gas HGVs	Number	-	39	102	214	414	769	1,182
Core and High Hydrogen	Gas HGVs	Number	-	46	120	252	487	904	1,390
High Electrification	Gas buses	Number	-	17	41	79	139	235	372
Core and High Hydrogen	Gas buses	Number	-	20	49	95	167	282	446

Baseline - 2019

There are no methane vehicle fuelling stations in South Wales.

Projections - 2020 to 2050

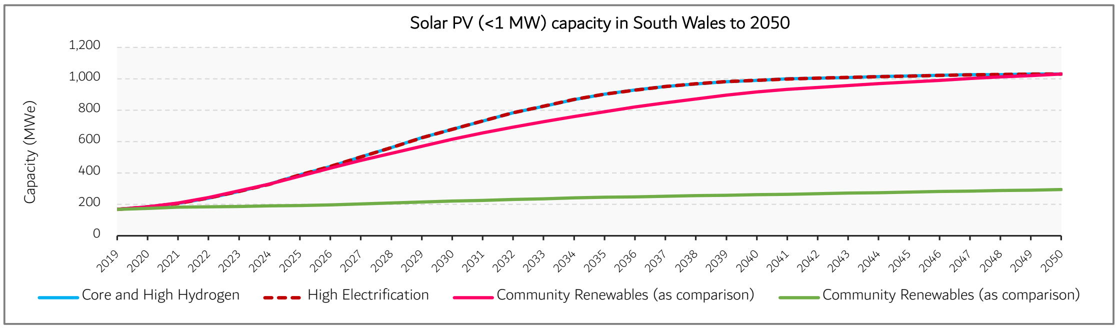
With no methane fuelling stations in the pipeline, gas vehicle numbers in South Wales are expected to remain very low in the near term. Throughout the timeframe, hydrogen is the preferred fuel for HGVs and coaches. By 2050, almost 2,000 methane vehicles are projected in South Wales under the Core and Hybrid Hydrogen scenarios, all of which fuelled by BioLNG or BioCNG.

Distribution approach

The distribution of the demand for methane-based vehicle fuels will depend heavily on the dominant fuel type that emerges, and the level of decentralisation that is optimal for the business model. For example, LNG may be created or imported in large quantities to be tankered to filling stations around South Wales, similar to petrol and diesel today. Alternatively, the gas fuel may be produced on-site in a more decentralised model, with fuelling stations producing gas vehicle fuel from methane obtained through the mains gas grid, or on-site production through anaerobic digestion.

For these scenarios, given the lack of baseline and pipeline indication of gas vehicle fuelling stations in South Wales, gas vehicle demand has been distributed in accordance with the location of vehicle depots for buses and HGV fleets, existing petrol stations on the major road network (initially focussed on the M4 motorway), and proximal to the gas distribution network to allow import and management of mains gas supply. Additionally, gas vehicle fuel demand is weighted away from the hydrogen industrial cluster area in the longer term, and towards areas with high projected levels of biomethane production.

South Wales Net Zero
Technology: Solar PV (<1 MW)
Modelling assumptions and results summary



Approach to net zero

The small scale solar scenario projection does not vary across the scenarios as net zero requires that all low carbon generation is supported to quickly decarbonise grid electricity. This approach is also consistent with the Welsh Government energy strategy.

Small-scale solar PV generation has been projected in line with FES 2019 Community Renewables which assumes strong consumer engagement and green ambition underpinned by policy support government. This results in nearly one in four homes in South Wales hosting rooftop PV by 2050.

This level of installations is close to the maximum potential and as a result net zero does not have a higher trajectory than the previous 80% reduction target. However installations are expected to be installed marginally quicker than under net zero due to the relationship with decarbonised heating and transport.

Net zero factors to 2050	
Government policy and support	Continuation of price support obligations such as the Smart Export Guarentee, and a planning regime favourable towards solar PV.
Consumer buy-in and green ambition	Net zero requires strong engagement from the public, resulting in higher uptake of solutions such as rooftop solar.
Uptake of smart, flexible technologies	Proliferation of smart charging EVs, domestic batteries, smart appliance etc. increase the value and self-consumption of generated solar PV.

Scenario	Sub-category	Measure	2019	2025	2030	2035	2040	2045	2050
High Electrification	<10 kW	Capacity (MW)	117	267	456	606	666	684	692
Core and High Hydrogen	<10 kW	Capacity (MW)	117	267	456	606	666	684	692
High Electrification	≥10 kW, <1 MW	Capacity (MW)	51	121	221	296	324	334	338
Core and High Hydrogen	≥10 kW, <1 MW	Capacity (MW)	51	121	221	296	324	334	338
High Electrification	<10 kW	Generation (GWh)	127	259	443	581	629	645	653
Core and High Hydrogen	<10 kW	Generation (GWh)	127	259	443	581	629	645	653
High Electrification	≥10 kW, <1 MW	Generation (GWh)	55	118	215	284	306	315	319
Core and High Hydrogen	≥10 kW, <1 MW	Generation (GWh)	55	118	215	284	306	315	319

Solar PV (<1 MW) baseline capacity		
Year	Capacity (MW)	Generation (GWh)
2016	157	152
2017	160	156
2018	164	159
2019	168	163

There are over 37,000 solar PV installations of sub-1 MW capacity, totalling 167.6 MW of capacity with an average size of 4.4 kW. The vast majority of this capacity has been commissioned since 2011, with growth slowing significantly since 2015.

76% of baseline installations are domestic, as per Feed-In Tariff data, with an average capacity of 3.5 kW.

Short term - 2020 to 2025

There is limited pipeline data for sub-1 MW projects, especially for kilowatt-scale domestic and small-scale commercial solar PV. Capacity growth is projected to accelerate in the early 2020s as rooftop solar costs continue to decrease, combined with increasing financial viability due to the Smart Export Guarantee, uptake of electric vehicles and installation of domestic batteries. Building-integrated photovoltaics (BIPV), as seen on Swansea University's SPECIFIC Active Classroom, begin to see uptake on non-domestic buildings as a result of high levels of green ambition.

Medium term - 2025 to 2035

The medium term capacity growth has a similar trajectory to the FES Community Renewables scenario, due to policy and incentives to encourage centralised and decentralised forms of low carbon generation in a net zero world. Accelerated uptake of electrified vehicles and heating, in order to meet more ambitious carbon budgets, result in an accelerated uptake of rooftop PV for domestic and non-domestic consumers. Other forms of solar technologies and applications, such as BIPV on public and commercial buildings and east-west solar panels see continued market expansion.

Long term - 2035 - 2050

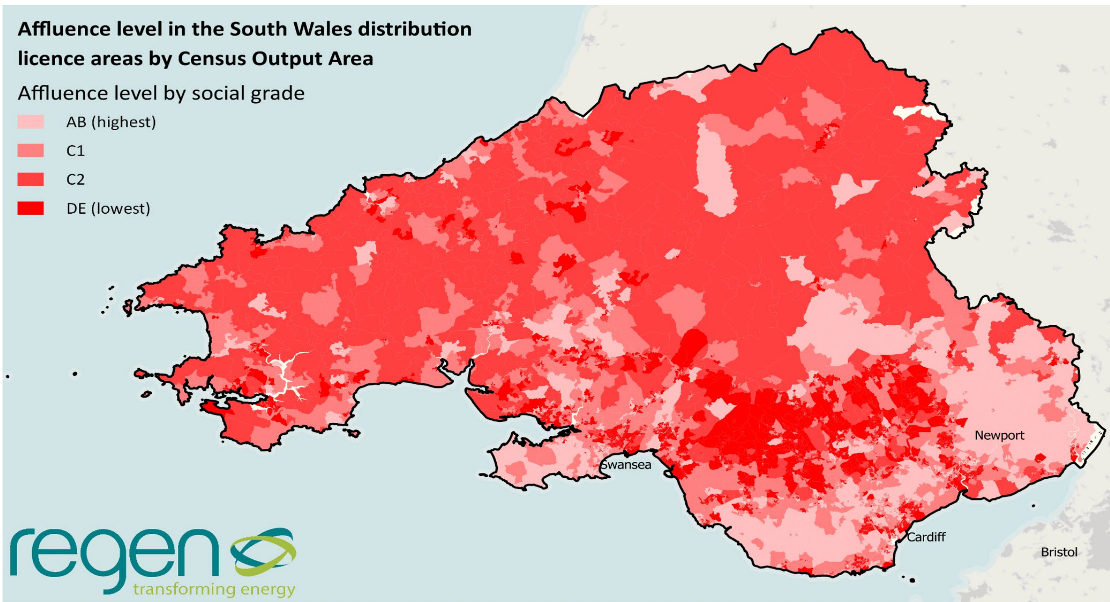
Capacity growth slows as the most-suitable homes and commercial properties are fitted with solar PV in the 2020s and 2030s. By 2040, almost 20% of homes have rooftop solar PV. While electrification of transport and heat continues, self-cannibalisation and widespread uptake of Time-Of-Use-Tariffs reduce the attractiveness of small-scale solar PV.

South Wales Net Zero
Technology: Solar PV (<1 MW)
Modelling assumptions and results summary

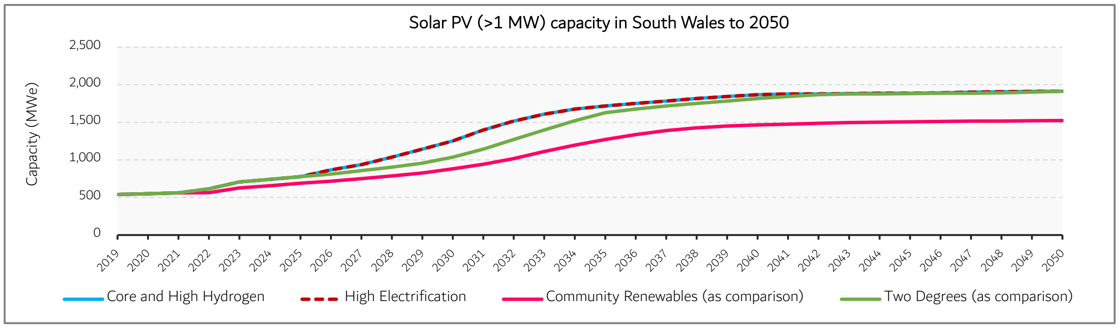
Distribution approach

With over 37,000 projects in the baseline, sub-1 MW solar PV already has a considerable baseline of projects, which informs to distribution of near-term projections.

Beyond this, smaller-scale solar PV is distributed to available space for rooftop arrays, considering domestic and commercial properties, with domestic-scale rooftop PV weighted towards higher levels of affluence in the near term, becoming more spread across all affluence levels in the mid-to-long term.



South Wales Net Zero
Technology: Solar PV (>1 MW)
Modelling assumptions and results summary



Approach to net zero

The small scale solar projection does not vary across the scenarios as net zero requires that all low carbon generation is supported to quickly decarbonise grid electricity. This approach is also consistent with the Welsh Government energy strategy.

The capacity increase of large-scale solar PV generation is projected in line with the FES Two Degrees scenario which assumes solar PV costs significantly decrease, resulting in feasible merchant business models. The near and medium-term projections are informed by Regen's regional energy system visions produced for the Welsh Government, which detail a potential pathway towards net zero carbon for each Welsh region based on bottom-up analysis and stakeholder engagement.

The 2019 FES Two Degrees scenario is already highly ambitious for large-scale solar PV, quadrupling existing capacity to nearly 34 GW in GB by 2050. As a result total capacity has not been projected to be higher in net zero. This is in line with the 2019 FES net zero sensitivity and the CCC Further Ambition scenarios, which contain between 40 and 60 GW of total solar PV capacity, the majority from large-scale ground-mounted solar.

Net zero factors to 2050	
Government policy and support	Continued favourable planning regime for ground-mounted solar PV, particularly in Welsh Government 'Priority Areas'.
Self-cannibalisation of solar PV generation	Self-cannibalisation of solar PV revenue mitigated through high uptake of TOUTs, smart charging, energy storage, electrolysis and interconnectors.
Co-location of renewables with storage	Solar-and-storage business models continue to gain traction, resulting in greater feasibility of merchant solar PV sites.

Scenario	Sub-category	Measure	2019	2025	2030	2035	2040	2045	2050
High Electrification	≥1 MW	Capacity (MW)	540	777	1,252	1,717	1,867	1,887	1,913
Core and High Hydrogen	≥1 MW	Capacity (MW)	540	777	1,252	1,717	1,867	1,887	1,913
High Electrification	≥1 MW	Generation (GWh)	587	756	1,215	1,645	1,763	1,780	1,804
Core and High Hydrogen	≥1 MW	Generation (GWh)	587	756	1,215	1,645	1,763	1,780	1,804

Baseline - 2019

Solar PV (≥1 MW) baseline capacity		
Year	Capacity (MW)	Generation (GWh)
2016	457	445
2017	540	526
2018	540	526
2019	540	526

There are 92 projects in the baseline, ranging from 1 MW to 36 MW in capacity with an average of 5.9 MW. Every site was developed between 2011 and 2017, with no new sites commissioned in the last three years.

Deployment peaked in 2015, with 196 MW of ground-mounted solar connected in that year.

Short term - 2020 to 2025

The is a 536.3 MW pipeline of 27 ground-mounted solar PV projects, with each assessed for planning status and any other development information. Twelve projects, totalling 299.8 MW, were not found to have any indication of development beyond an accepted connection offer, and were therefore not projected to connect before 2025. The remaining 15 projects, totalling 236.6 MW, were projected to connect in the short-term and timescales were based on their planning application progress and developer research, ranging from under construction to early-stage planning applications.

Medium term - 2025 to 2035

There is over 3,000 square kilometres of Welsh Government Priority Areas for Wind in the licence area, showing ample potential and route to market for significant new capacity of ground-mounted solar PV. Combined with the strong pipeline of recent connection applications, ground-mounted solar PV deployment is projected to accelerate throughout the late-2020s and early-2030s, as solar PV costs continue to reduce and encourage merchant business models. In the medium term it is expected that uptake on a national scale will not be high enough to trigger significant concerns around price cannibalisation.

Long term - 2035 - 2050

As the GB electricity grid moves towards full decarbonisation, capacity increase slows as the most-suitable solar farm sites have been taken up in the 2020s and 2030s and price cannibalisation becomes a more critical issue - however, new business models such as colocation with hydrogen electrolysis and east-west solar arrays, and continued colocation with storage mean that new projects and repowering continue throughout the timeframe, albeit at a slower rate than in the medium term.

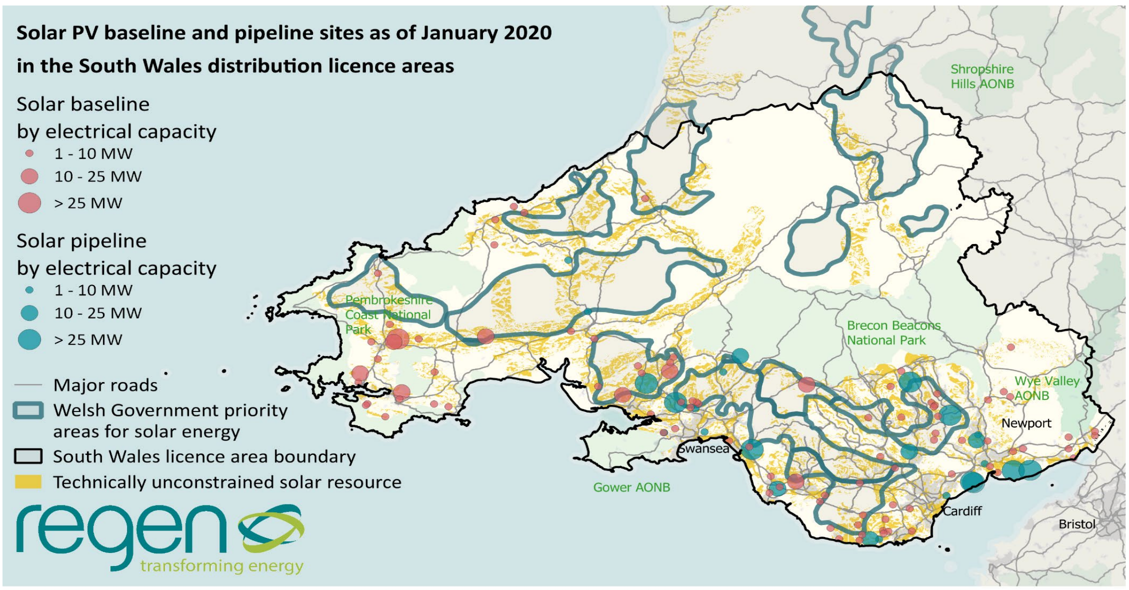
South Wales Net Zero

Technology: Solar PV (>1 MW)

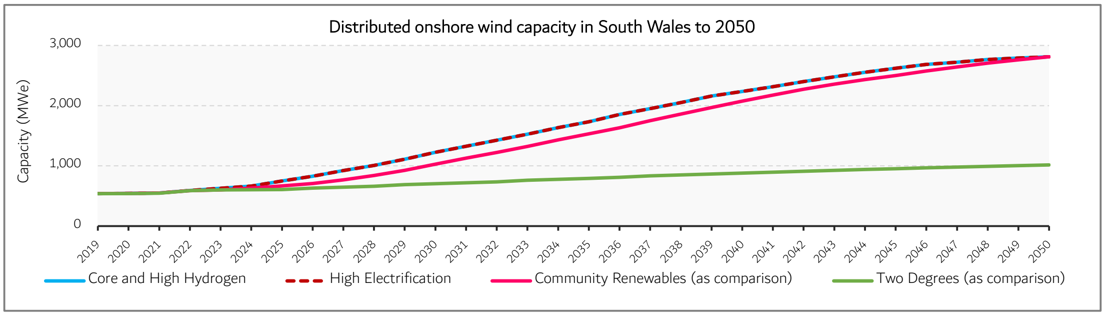
Modelling assumptions and results summary

Distribution approach

Ground-mounted solar PV is distributed according to the location of pipeline sites in the near term. In the medium-to-long term, a resource assessment is undertaken to identify areas of land that are technically unconstrained for large-scale solar development, along with the Welsh Government Priority Areas for solar PV development. This includes avoidance of protected areas and buildings due to planning constraints, proximity to the electricity network based on analysis of baseline and pipeline projects and a weighting towards low grade agricultural land.



South Wales Net Zero
Technology: Onshore wind (both < 1 MW and > 1 MW)
Modelling assumptions and results summary



Approach to net zero

In the net zero scenarios, both large and small-scale low carbon generation is supported in a bid to decarbonise grid electricity. Therefore it is projected that onshore wind capacity would be the same under High Electrification and Core and High Hydrogen.

The 2050 capacity for onshore wind generation is projected in line with the 2019 FES Community Renewables scenario, with strong consumer engagement and green ambition underpinned by policy support from central and regional government. The near and medium-term projections are informed by Regen's regional energy system visions produced for the Welsh Government, which detail a potential pathway towards net zero carbon for each Welsh region based on bottom-up analysis and stakeholder engagement.

The FES Community Renewables scenario is already highly ambitious for onshore wind, alongside other net zero scenarios, such as the CCC Further Ambition scenario, which contains over 100 GW of combined onshore and offshore wind capacity. As a result no additional onshore capacity has been projected to reflect the net zero target. In a High Electrification scenario, further grid decarbonisation is achieved through transmission-level technologies such as nuclear or offshore wind .

Net zero factors to 2050	
Government policy and support	Favourable planning regime for onshore wind, particularly in Welsh Government designated 'Priority Areas'.
Grid constraints	Projections are based on no major grid constraints beyond the near term.
Co-location of renewables with storage	Wind-and-storage business models continue to gain traction, resulting in greater feasibility of merchant sites.

Scenario	Sub-category	Measure	2019	2025	2030	2035	2040	2045	2050
High Electrification	<1 MW	Capacity (MW)	47	68	134	181	224	258	284
Core and High Hydrogen	<1 MW	Capacity (MW)	47	68	134	181	224	258	284
High Electrification	≥1 MW	Capacity (MW)	492	682	1,092	1,552	2,012	2,362	2,528
Core and High Hydrogen	≥1 MW	Capacity (MW)	492	682	1,092	1,552	2,012	2,362	2,528
High Electrification	<1 MW	Generation (MWh)	111,701	167,966	328,942	437,388	525,090	599,391	652,870
Core and High Hydrogen	<1 MW	Generation (MWh)	111,701	167,966	328,942	437,388	525,090	599,391	652,870
High Electrification	≥1 MW	Generation (MWh)	1,158,562	1,687,161	2,690,903	3,746,483	4,708,182	5,491,852	5,819,138
Core and High Hydrogen	≥1 MW	Generation (MWh)	1,158,562	1,687,161	2,690,903	3,746,483	4,708,182	5,491,852	5,819,138

Baseline - 2019

Onshore wind baseline capacity		
Year	Capacity (MW)	Generation (GWh)
2016	363	855
2017	430	1014
2018	537	1266
2019	539	1270

There are 32 baseline sites over 1 MW in capacity, totalling 492 MW, with ten projects over 20 MW. These include the 60.5 MW Brechfa Forest West wind farm, connected in 2018, and the 46.7 MW Pant Y Wal wind farm, connected in 2012.

In addition to the large-scale sites, there are 406 sub-1 MW sites totalling 47.4 MW. This is a mixture of very small, kilowatt-scale domestic and farm turbines, and a number of turbines of several hundred kilowatt capacities.

Short term - 2020 to 2025

There is a 438.2 MW pipeline of 24 onshore wind projects, with each assessed for planning status and any other development information. Twelve projects, totalling 245.7 MW, were not found to have any indication of development beyond an accepted connection offer, and were therefore not projected to connect before 2025. The remaining 12 projects, totalling 192.4 MW, were projected based on their planning application progress and developer research, with the majority of capacity installed from 2023 to 2025.

Medium term - 2025 to 2035

Onshore wind deployment accelerates in the medium-term, with strong policy support from Welsh and UK government to meet climate targets. In the early 2030s, around 100 MW of onshore wind capacity is commissioned each year, from both new sites and repowering of older sites with new, higher-capacity turbines. There is over 2,000 square kilometers of Welsh Government Priority Areas for Wind in the licence area, showing ample potential and route to market for significant new capacity of onshore wind.

Long term - 2035 - 2050

Capacity growth continues in the long term as onshore wind provides low cost renewable generation, with generated energy less susceptible to self-cannibalisation than solar PV. Development slows in the latter years are the most suitable sites have already been developed.

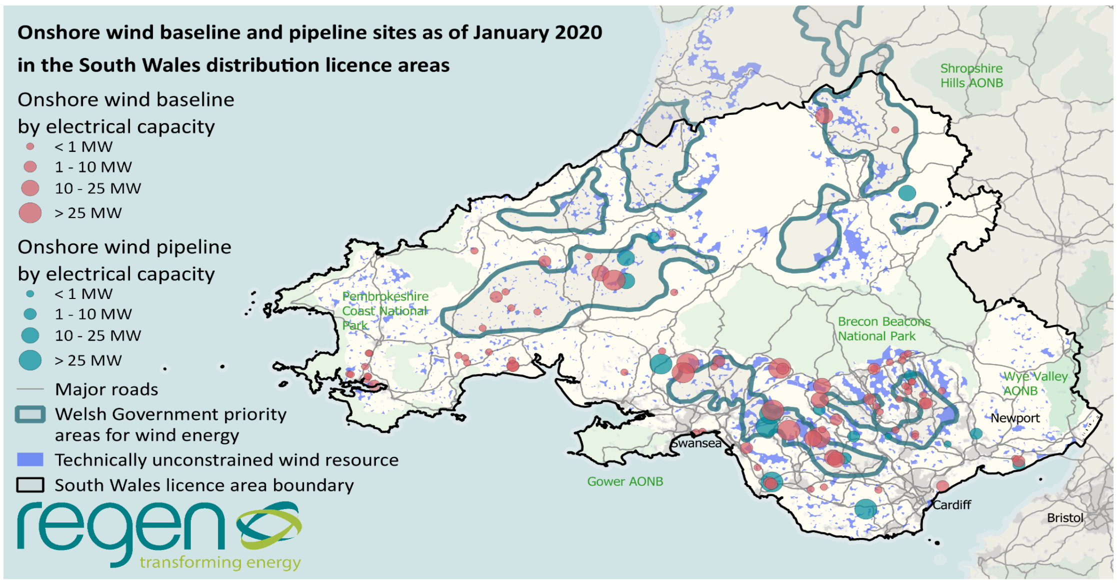
South Wales Net Zero

Technology: Onshore wind (both < 1 MW and > 1 MW)

Modelling assumptions and results summary

Distribution approach

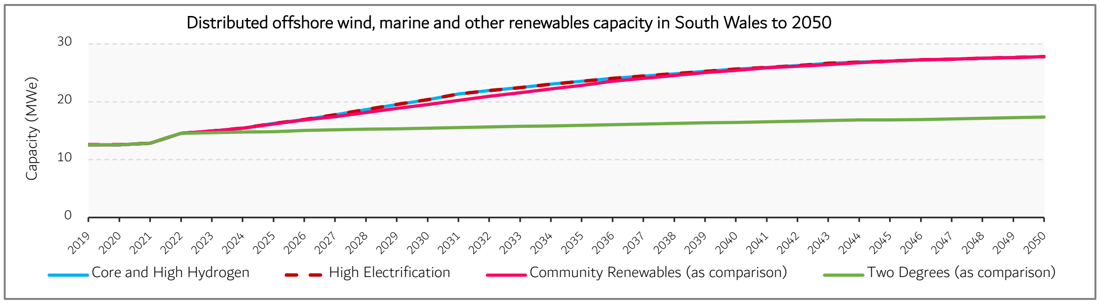
Onshore wind is distributed according to the location of pipeline sites in the near term. In the medium-to-long term, a resource assessment is undertaken to identify areas of land that are technically unconstrained, along with the Welsh Government Priority Areas for onshore wind development in the near and medium term. This includes avoidance of protected areas and a 400m buffer around buildings due to planning constraints, proximity to the electricity network based on analysis of baseline and pipeline projects and a weighting towards areas with a high modelled wind speed at 45 m based on NOABL data.



South Wales Net Zero

Technology: Offshore wind, marine and other renewables

Modelling assumptions and results summary



Approach to net zero

There is a lot of potential for offshore wind, marine and other renewables in South Wales, however, it is assumed that the majority of these technologies will be transmission-connected, such as a Tidal Lagoon and floating offshore wind farms.

'Other Renewables' category includes offshore wind, hydropower, tidal, wave and geothermal electricity. Of these resources, only hydropower is projected to have additional capacity on the distribution network. The capacity is projected to be the same across the scenarios.

The Other Generation trajectories has been projected in line with 2019 FES Community Renewables scenario, assuming continued support for small-scale renewables through mechanisms such as a Smart Export Guarantee and carbon levy on carbon-emitting generation.

Net zero factors to 2050	
South Wales Tidal Lagoon	Any tidal lagoon developed in South Wales is expected to be connected to the transmission network.
Pembrokeshire Demonstration Zone	The Pembrokeshire Demonstration Zone for wave and tidal projects is expected to be transmission-connected.
Geothermal CHP potential	There are no geologically suitable areas for power-generating geothermal projects in South Wales.

Scenario	Category	Capacity	2019	2025	2030	2035	2040	2045	2050
High Electrification	All	MWe	13	16	20	24	26	27	28
Core and High Hydrogen	All	MWe	13	16	20	24	26	27	28
High Electrification	All	MWe	46	51	70	87	98	102	103
Core and High Hydrogen	All	MWe	46	51	70	87	98	102	103

Baseline - 2019

Hydro baseline capacity		
Year	Capacity (MW)	Generation (GWh)
2016	12	33
2017	13	35
2018	13	35
2019	13	35

There are 66 projects in the baseline, all of which are hydropower projects, totalling 12.6 MW capacity. Of these 66 projects, only 6 are larger than 200 kW, most notably the 6 MW Llyn Brianne Reservoir project and the 2.7 MW and 1.05 MW projects at Elan Valley, all of which were commissioned in the late-1990s.

The remaining 60 sites average 43 kW capacity, built between 2006 and 2018 and generating revenue through the Feed-In Tariff.

Short term - 2020 to 2025

There are two projects in the pipeline, both hydropower, totalling 2.0 MW capacity. A 1.71 MW project in north-east Carmarthenshire has been granted full planning permission and has progressed to the detailed design stage. This project is therefore projected to go ahead in 2022 under every scenario. A smaller 0.25 MW project is also expected to progress in every scenario.

Medium term - 2025 to 2035

As shown by the baseline and pipeline, there is limited small-scale hydropower resource in South Wales. In both High Hydrogen and High Electrification, it is projected that hydropower capacity continues in line with baseline trends, with a successor to the Feed-In Tariff providing revenue support for small-scale low carbon generation.
Further renewable generation projects, such as Tidal Lagoons and the Pembrokeshire Demonstration Zone for marine renewables, are expected to connect to the transmission network and as such are not included in these projections.

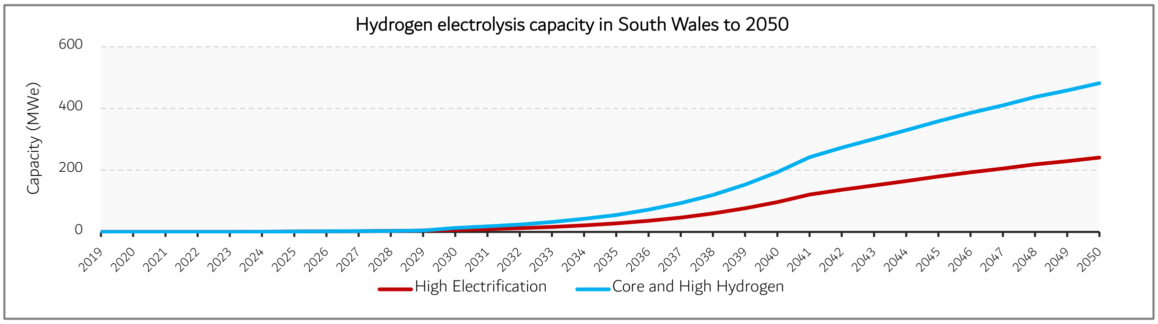
Long term - 2035 - 2050

Small-scale hydropower continues to be supported in the long-term, however, South Wales' already limited resource has mostly been exploited by the 2040s, and capacity growth is limited to small-scale new projects and repowering of existing projects.

Distribution approach

Distribution of projected hydropower capacity beyond the baseline and pipeline sites is based on Regen's hydropower resource assessments previously completed for WPD Distribution Future Energy Scenarios.

South Wales Net Zero
Technology: Hydrogen electrolysis
Modelling assumptions and results summary



Approach to net zero

Under net zero scenarios, hydrogen electrolysis is an increasingly important technology to provide a proportion of the low carbon gas needed by sectors that cannot easily electrolyse, such as heat, heavy transport and industrial processes.

The High Electrification projection uses 16% of excess distribution connected renewable generation to produce approximately 1 TWh of hydrogen by electrolysis by 2050. A higher amount of hydrogen electrolysis has been assumed in both Core and High Hydrogen scenarios in order to supply the higher demand associated with larger heat and industrial hydrogen demand.

In all scenarios the production of hydrogen by electrolysis in South Wales does not meet the demand and it is assumed that further hydrogen is sourced via the transmission network, likely via transmission connected SMR plants, this and associated storage needs have not been modelled in this analysis.

Net zero factors to 2050	High Electrification	Core Hydrogen	High Hydrogen
Location of hydrogen electrolysis plants	In all scenarios, although using excess renewable power it is assumed that plants are co-located with demand in industrial cluster locations.		
Source of power	16% of renewable generation on the distribution network in South Wales	32% of renewable generation on the distribution network in South Wales. Likely using excess from across the UK and Europe.	
Capacity factor (assumed)	A capacity factor of 50% was assumed across the scenarios. Although higher capacities are possible, this capacity factor was chosen to reflect the use of excess renewable generation which is not available at all times.		

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	0	1	7	27	97	179	241
Core and High Hydrogen	Capacity	MWe	0	1	13	55	194	359	482
High Electrification	Hydrogen	m3	0	1,981,774	10,550,701	44,038,266	155,134,323	287,376,975	386,095,123
Core and High Hydrogen	Hydrogen	m3	0	1,981,774	21,101,402	88,076,531	310,268,645	574,753,949	772,190,246

High Electrification	Demand	MWh	0	8,710	45,363	185,131	637,323	1,153,110	1,512,283
Core and High Hydrogen	Demand	MWh	0	8,710	90,726	370,262	1,274,646	2,306,219	3,024,566
High Electrification	Supply	MWh	0	5,416	28,836	120,359	423,991	785,419	1,055,221
Core and High Hydrogen	Supply	MWh	0	5,416	57,671	240,718	847,983	1,570,837	2,110,442

Baseline - 2019

There is no baseline of hydrogen electrolysis in South Wales

Short term - 2020 to 2025

A small demonstrator site for hydrogen electrolysis within the industrial cluster is assumed to be connected by 2025.

Medium term - 2025 to 2035

A small number of hydrogen electrolysis plants are built in the medium term. These produce hydrogen for heavy transport and industrial processes. The electrolysis primarily runs on excess renewable energy capacity and takes advantage of low electricity prices in low demand periods. By 2035 it is assumed that more electrolysis capacity is installed in Core and High Hydrogen scenarios to meet a higher level of fuel demand for the clusters.

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South Wales Net Zero
Technology: Hydrogen electrolysis
Modelling assumptions and results summary

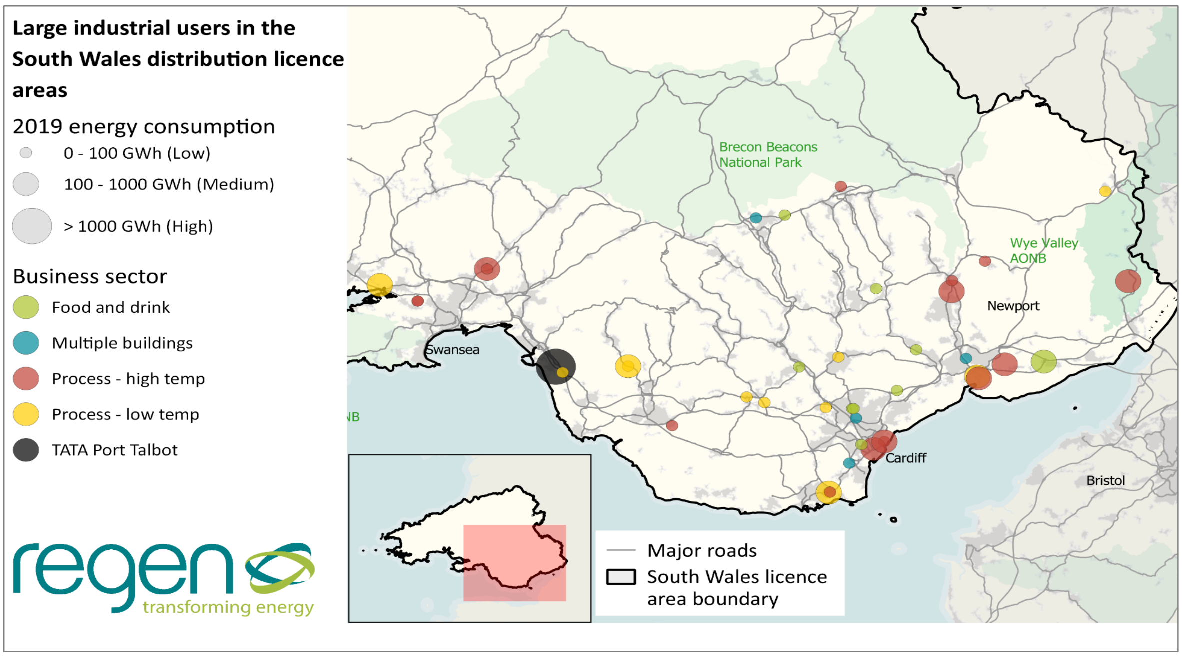
Long term - 2035 - 2050

In the long term, hydrogen electrolysis capacity and output continues to expand in South Wales to support expansion of the industrial cluster. The capacity in **High Electrification** is consistent with the FES 2019 net zero sensitivity and processes predominately excess renewable generation. In **Core and High Hydrogen**, this capacity is doubled as a result of the demand from the South Wales industrial. The capacity provides an estimated 2 TWh of hydrogen by 2050.

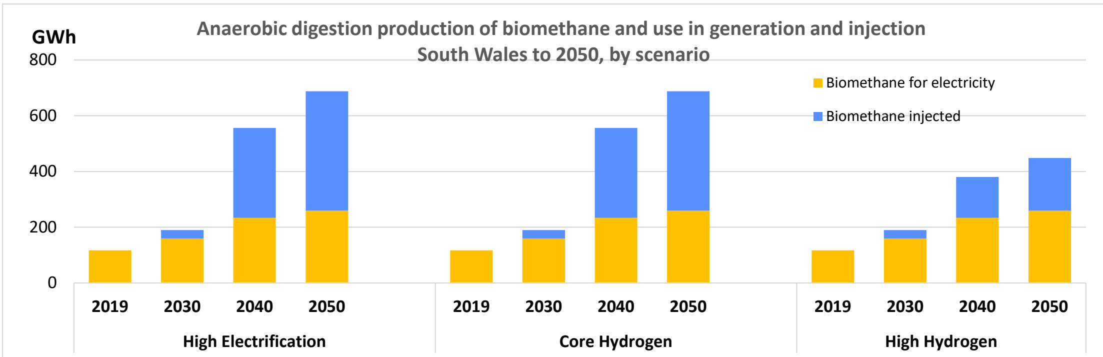
The demand for hydrogen in the industrial clusters significantly exceeds the energy provided by local electrolysis in all scenarios. It is assumed that additional hydrogen is imported via the transmission network, likely to be generated by transmission connected SMR. Transmission supply of hydrogen and associated need for hydrogen storage has not be modelled in this analysis.

Distribution approach

The hydrogen electrolysis plants are distributed in the industrial cluster areas and areas with heavy transport fueling depots, co-locating with their highest demand customers.



South Wales Net Zero
Technology: Anaerobic Digestion
Modelling assumptions and results summary



South Wales key statistics	
Estimated food waste 2019 (Tonnes)	344,432
Estimated food waste 2050 (Tonnes)	196,258
Assumed annual reduction in food waste	2%

Approach to net zero

Anaerobic digestion (AD) capacity and output continues to grow across the scenario period. Feedstock from food and agricultural waste is the key issue for this technology and has limitations in South Wales. Household food waste is already collected across the region and expected to decline over time. In addition the region has proportionally lower than average land grades with c. 1% of the UK arable land. Capacity growth comes predominately from livestock waste [1] with output priortising biomethane production for use in transport and/or heating.

In both Core and High Electrification, additional AD facilities are developed after 2035 to provide biomethane in areas with good agricultural land.

[1] http://www.biogas-info.co.uk/about/feedstocks#yields

Net zero factors	High Electrification	Core Hydrogen	High Hydrogen
Government policy and support	Support provided to incentivise new anaerobic digestion facilities that focus on biomethane injection		
Food waste resource availability	High levels of food waste collection offset by achievement of waste reduction targets		
Amount of agricultural waste	Higher production means under this scenario means maximising of local agricultural waste including some imported waste and energy crops		Facilities use only local agricultural waste

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	9	10	12	15	17	18	19
Core Hydrogen	Capacity	MWe	9	10	12	15	17	18	19
High Hydrogen	Capacity	MWe	9	10	12	15	17	18	19
High Electrification	Biomethane	scm per hour	-	-	519	1,595	5,727	6,086	6,445
Core Hydrogen	Biomethane	scm per hour	-	-	519	1,595	5,727	6,086	6,445
High Hydrogen	Biomethane	scm per hour	-	-	519	1,595	2,527	2,886	3,245
Biomethane used for electrical generation or injection									
High Electrification	Electrical	MWh	116,961	140,994	160,001	199,425	233,592	246,734	259,875
Core Hydrogen	Electrical	MWh	116,961	140,994	160,001	199,425	233,592	246,734	259,875
High Hydrogen	Electrical	MWh	116,961	140,994	160,001	199,425	233,592	246,734	259,875
High Electrification	Injection	MWh	-	-	30,091	92,502	322,478	406,901	427,705
Core Hydrogen	Injection	MWh	-	-	30,091	92,502	322,478	406,901	427,705
High Hydrogen	Injection	MWh	-	-	30,091	92,502	146,592	167,395	188,199

Baseline - 2019

Anaerobic digestion capacity		
Baseline year	MWe	Projects
2016	9	13
2017	9	13
2018	9	13
2019	9	13

South Wales has a total of 13 anaerobic digestion projects totalling an electrical capacity of 9 MW. The largest plant is the 3 MW Stormy Down plant in Brigend which processes commercial and domestic food waste. There has been no increase in capacity since 2016. Currently, none of the projects export biomethane for transport or into the gas network.

Although already collecting and processing food waste in the region, South Wales has only around 1.5% of the baseline UK AD electrical capacity estimated in FES 2019. This low relative number is likely as a result of the nature of Welsh agriculture and small farm sizes. https://seneddresearch.blog/2016/09/26/welsh-farming-

Short term - 2020 to 2025

Project numbers	Total capacity (MWe)
2	2

Two small sites of nearly 1 MWe each have existing accepted connection offer with WPD. These sites are projected to connect in 2021 and will export electricity only. No additional capacity is expected to connect until after 2025.

South Wales Net Zero
Technology: Anaerobic Digestion
Modelling assumptions and results summary

Medium term - 2025 to 2035

After 2025, an increasing number of anaerobic digestion plants are assumed to be built using primarily a feedstock of livestock waste. These are expected to prioritise biomethane production for transport or, where gas network exists, injection into the gas grid. It is assumed in the modelling that for new AD capacity, 75% of the energy output is exported as biomethane with the residual used to generate electricity on site.

The overall potential for further AD capacity is lower in South Wales than in some other areas of the UK. This is due to a number of factors including the nature of

Long term - 2035 - 2050

In **High Hydrogen**, capacity continues to increase through the 2030s but growth slows in 2040s due to the availability of local waste and agricultural resources as feedstock.

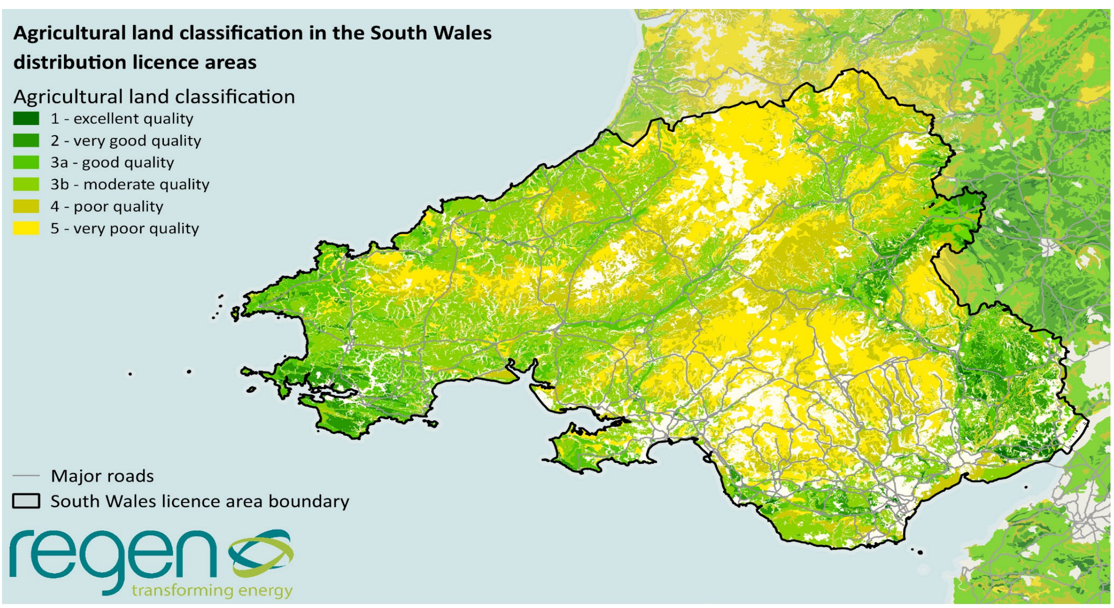
In both **Core Hydrogen** and **High Electrification,** with large parts of the existing gas network no longer receiving fossil gas or hydrogen, some areas with high agricultural land grades and resources develop additional AD capacity to meet the demand for biomethane. These sites use local agricultural waste where available, but may also need to import waste or energy crops.

In all scenarios it would be expected that those sites with electrical connections increasingly operate as peaking generation during periods with high electricity prices, using biomethane to produce electricity.

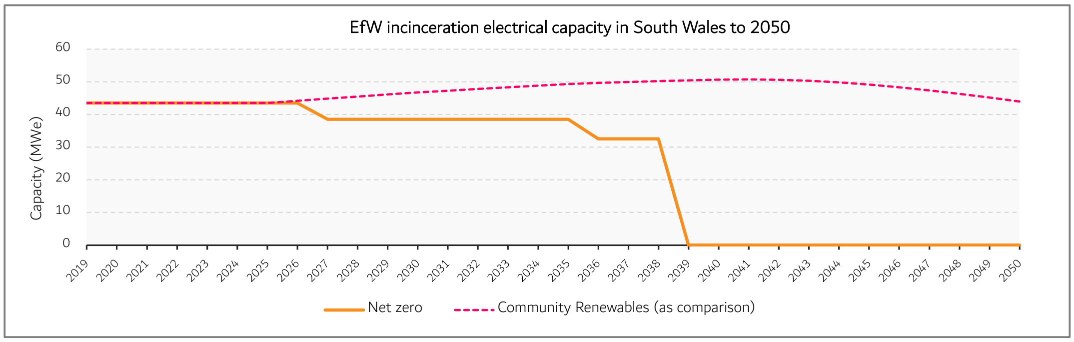
Distribution approach

Additional capacity in AD beyond in the pipeline is distributed towards areas in South Wales with high agricultural output and is focused in areas proximate to the gas network in order to prioritise biomethane injection.

In both Core Hydrogen and High Electrification three areas are assumed to have additional discrete biomethane networks fed by dedicated AD faciltiites, these are located in areas with the highest agricultural land classifications: Pembrokeshire, Powys and Monmouthshire.



South Wales Net Zero
Technology: Energy from Waste (incineration)
Modelling assumptions and results summary



South Wales key statistics

Estimated residential residual waste 2019 (Tonnes)	424,196
Estimated residential residual waste 2050 (Tonnes)	165,002
Annual reduction in residual waste arising	3%

Approach to net zero

The carbon emissions from unabated EfW incineration plants are not consistent with a net zero goal, as a result it is assumed in these scenarios that the energy from waste (EfW) incinceration plant capacity reduces to zero after 2039 as existing capacity is not replaced after 25 year life. This assumption departs from FES 2019 Community Renewables and Two Degrees which still have waste incinceration capacity by 2050.

It is assumed that the remaining residual waste in 2050 is processed through ACT gasification technologies which are expected to have lower associated carbon emissions. The scenario projection for energy from waste does not vary across the scenarios.

Net zero factors for future generation

Government policy and support	Policy support reduces due to high carbon emissions from residual waste incineration. Incineration tax introduced in 2020s.
Resource availability	Resource availability falls as residual waste reduces and competition increases from ACT gasification technologies.
Planning environment	Technology meets increasing local planning hurdles due to emissions and air quality concerns.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	44	44	39	39	-	-	-
Core and High Hydrogen	Capacity	MWe	44	44	39	39	-	-	-
High Electrification	Generation	MWh	137,276	137,276	121,508	121,508	-	-	-
Core and High Hydrogen	Generation	MWh	137,276	137,276	121,508	121,508	-	-	-

Baseline - 2019

EfW (incineration) capacity	
Baseline year	MW
2016	43.5
2017	43.5
2018	43.5
2019	43.5

The majority of the EfW (incineration) baseline in South Wales is from the Trident Park plant in Cardiff which was opened in 2014. This has a capacity of over 30 MW.

There are three smaller sites of between 1 and 6 MW including in Swansea and Usk.

Short term - 2020 to 2025

There is one pipeline site in WPD's connection database. This is 4 MW additional capacity for the Trident Park Cardiff EfW. A proposed 15 MW site, also in Cardiff, is currently looking for planning permission to burn commercial and industrial waste, but due to local opposition and associated carbon emissions from incineration, it is not projected to connect under a net zero scenario.

Medium term - 2025 to 2035

Project numbers	Total capacity (MW)
1	4

The smaller plants close after 25 years of operation, starting to reduce the baseline capacity.

In the medium term, it is projected that a heat network is connected to the Trident Park incinerator, serving commercial customers. This heat nework is modelled to use 56,500 MWth waste heat on average from late 2020s.

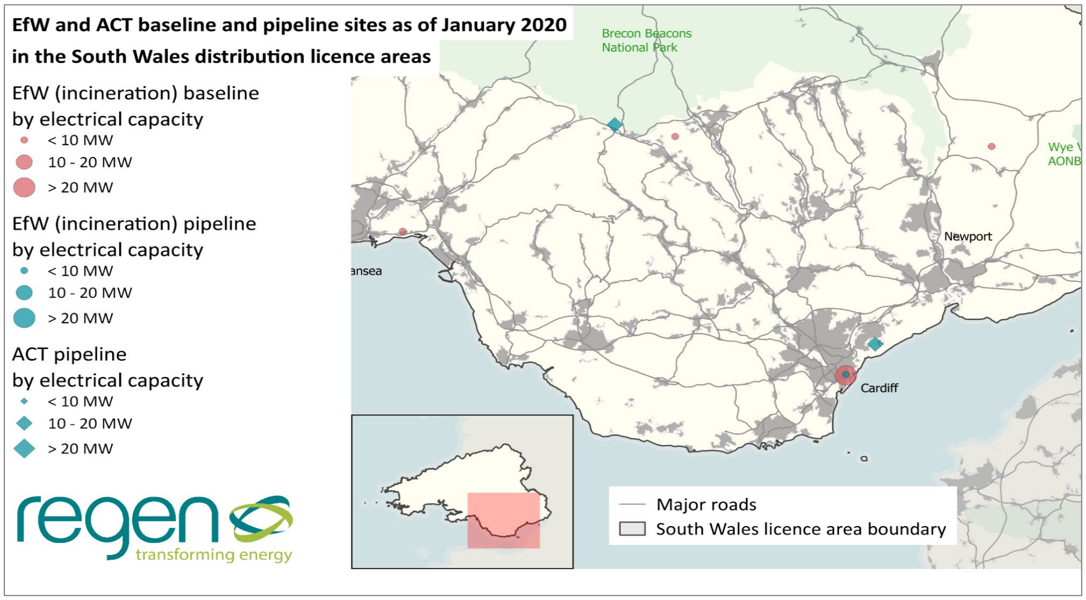
Long term - 2035 - 2050

The models assume that the EfW incineration capacity is replaced by lower carbon ACT gasification technology, leaving electrical capacity from incineration of waste at zero after 2040. The scenarios project that Trident Park EfW and heat network are replaced towards 2040 with a similar capacity ACT gasification plant at the end of its 25 year life. This would ensure the heat network can continue with lower carbon heat.

South Wales Net Zero
Technology: Energy from Waste (incineration)
Modelling assumptions and results summary

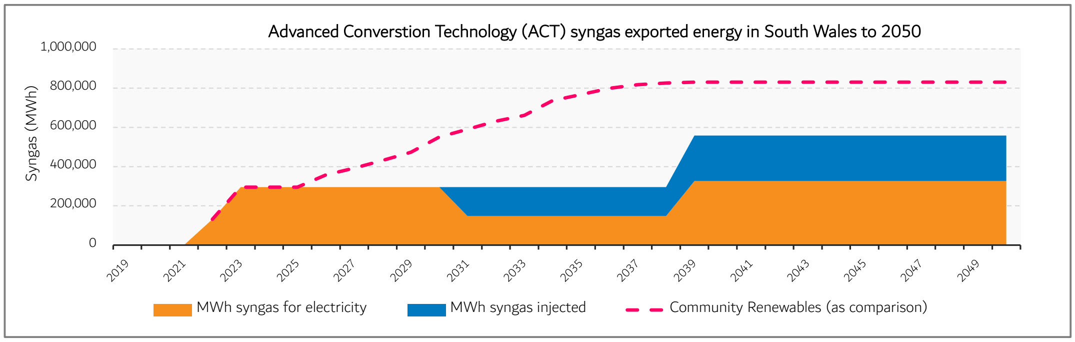
Distribution approach

The distribution only uses locational data from baseline and pipeline sites.



South Wales Net Zero

Technology: Advanced Conversion Technology (ACT)
Modelling assumptions and results summary



South Wales key statistics	
Estimated residual waste 2019 (Tonnes)	424,196
Estimated residual waste 2050 (Tonnes)	165,002
Annual reduction in residual waste	3%

Approach to net zero

There are no ACT plants in the baseline, and capacity growth is seen from two pipeline sites. These switch in 2030 to also exporting synthetic gas (syngas) for use in transport or heating. In the late 2030s, it is modelled in these scenarios that the Trident Park waste incinerator is converted into a 30 MW gasification plant which also powers a heat network with waste heat from generation.

The ACT scenario projection does not vary across the scenarios. Total likely capacity by 2050 is guided by available waste calculations and projections in FES 2019.

Net zero factors for future generation	
Government policy and support	Support continued through Contract for Difference subsidies for new ACT plants.
Waste availability	Waste reduction efforts reduce tonnage residual waste but ACT plants replace incineration.
Technology development	Investment in R&D leads to development of reliable ACT technology.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	-	34	34	17	37	37	37
Core and High Hydrogen	Capacity	MWe	-	34	34	17	37	37	37
High Electrification	Syngas	scm	-	-	-	2,548	4,003	4,003	4,003
Core and High Hydrogen	Syngas	scm	-	-	-	2,548	4,003	4,003	4,003
High Electrification	Electrical	MWh	-	118,260	118,260	59,130	130,512	130,512	130,512
Core and High Hydrogen	Electrical	MWh	-	118,260	118,260	59,130	130,512	130,512	130,512
High Electrification	Syngas	MWh	-	-	-	147,825	232,171	232,171	232,171
Core and High Hydrogen	Syngas	MWh	-	-	-	147,825	232,171	232,171	232,171

Baseline - 2019

There is no baseline of ACT gasification plants in South Wales.

Short term - 2020 to 2025

Project numbers	Total capacity (MW)
2	34

Two medium sized ACT plants are in WPD's pipeline, a 15 MW Cogen site and 18 MW Hirwarn site. The two plants had accepted connections in 2011 and 2016 respectively. The 15 MW Cogen site is awaiting a planning approval and is expected to connect in 2023. The second site has been delayed by technology issues but is still assumed to connect by 2024 under a net zero trajectory.

Medium term - 2025 to 2035

There are no additional ACT plants connected in the medium term. The total of ACT capacity is limited by the amount of residual waste produced in South Wales. There is expected to be continuous reductions in waste volumes in the scenario period, along with competition for resource from incineration plants. In the medium term the models assume that the existing plants start to prioritise syngas production and export as demand for green gas increases. After

Long term - 2035 - 2050

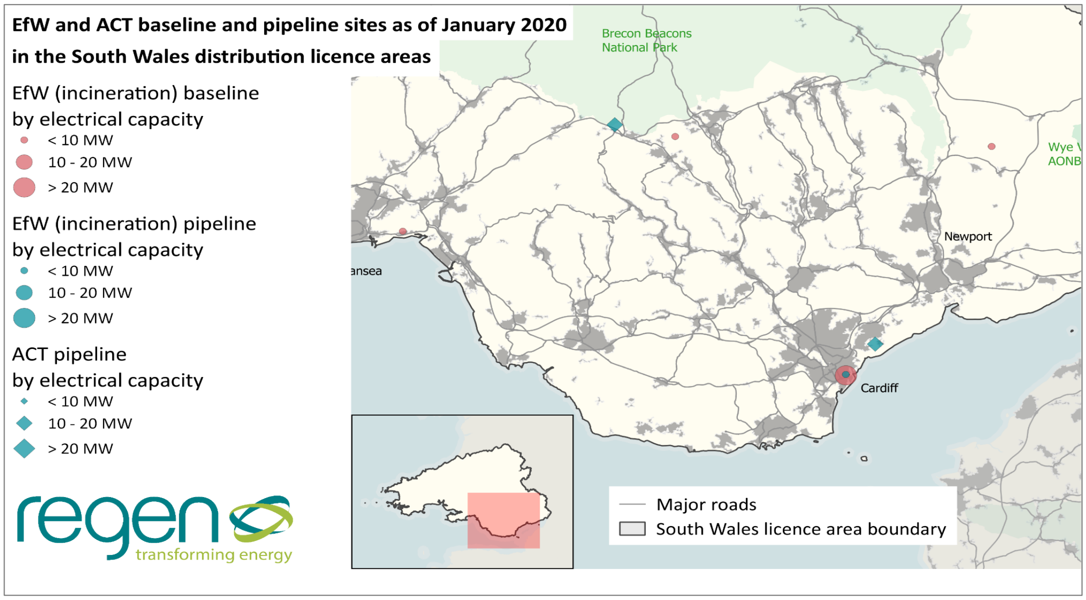
Trident Park incineration is replaced by an ACT gasification plant towards the end of 2030s. The energy from waste plant is expected to power a heat network and this will remain connected to the ACT plant with syngas used onsite to power the heat network. It is modelled that the of the excess, 75% of energy is exported as syngas after 2040 with the residual electrical capacity used to provide peaking services.

South Wales Net Zero

Technology: Advanced Conversion Technology (ACT)
Modelling assumptions and results summary

Distribution approach

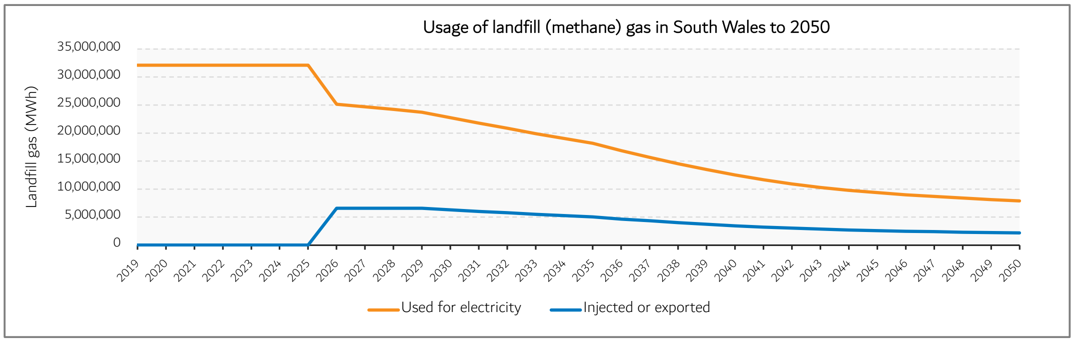
The distribution only uses locational data from baseline and pipeline sites.



South Wales Net Zero

Technology: Landfill gas

Modelling assumptions and results summary



South Wales key statistics	
Estimated residual waste 2019 (Tonnes)	424,196
Estimated residual waste 2050 (Tonnes)	165,002
Annual reduction in residual waste	3%

Approach to net zero

Landfill capacity is expected to decline over time as residual waste is either burnt or gasified as opposed to buried. The reduction in landfill generation in South Wales is aligned to the rate of reduction in capacity projected in FES 2019 Community Renewables. In both scenarios, the most recent and largest landfill site connected (8 MW near Newport) is projected to convert to biomethane export rather than electricity generation. The landfill gas is injected into the network from 2026, though the volume produced also declines over time.

The scenario projection does not vary across the scenarios.

Net zero factors for future generation	
Government policy and support	Landfill tax continues to reduce volumes of waste going to landfill.
Waste availability	Resource availability falls as residual waste reduces and competition increases from ACT gasification technologies.
Technology development	Further landfill sites are not provided with planning permission.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	39	39	35	28	19	15	12
Core and High Hydrogen	Capacity	MWe	39	39	35	28	19	15	12
High Electrification	Landfill gas	scm per hour	-	-	1,794	1,433	986	739	623
Core and High Hydrogen	Landfill gas	scm per hour	-	-	1,794	1,433	986	739	623
High Electrification	Electrical	MWh	137,076	137,076	97,179	77,581	53,405	40,015	33,727
Core and High Hydrogen	Electrical	MWh	137,076	137,076	97,179	77,581	53,405	40,015	33,727
High Electrification	Injected	MWh	-	-	67,154	53,612	36,905	27,652	23,306
Core and High Hydrogen	Injected	MWh	-	-	67,154	53,612	36,905	27,652	23,306

Baseline - 2019

There are 14 landfill gas sites connected to the distribution network in South Wales with a total of 39 MW of generation capacity. One 1.2 MW site was connected prior to 2000 and 12 sites connected in the decade following. The largest site to connect is an 8 MW site in Newport that connected in 2017.

Short term - 2020 to 2025

There is no change projected in the output capacity or connections in the short term to 2025.

Medium term - 2025 to 2035

After 2025, it is assumed that the market for biomethane continues to expand and therefore it is modelled that the largest connected landfill site in Newport switches to export biomethane for transport and no longer exports electricity. Smaller and older sites continue to export electricity but capacity starts to decline as the sites have no additional waste.

Long term - 2035 - 2050

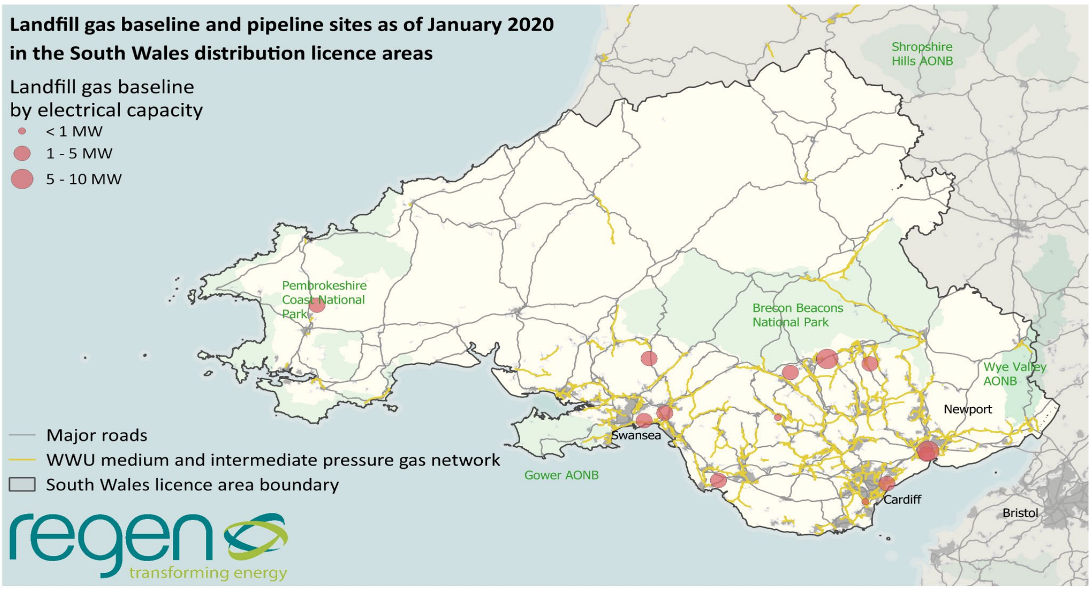
In the long term the export capacity of landfill sites in both electricity and gas declines as per projections from National Grid FES 2019 Community

South Wales Net Zero

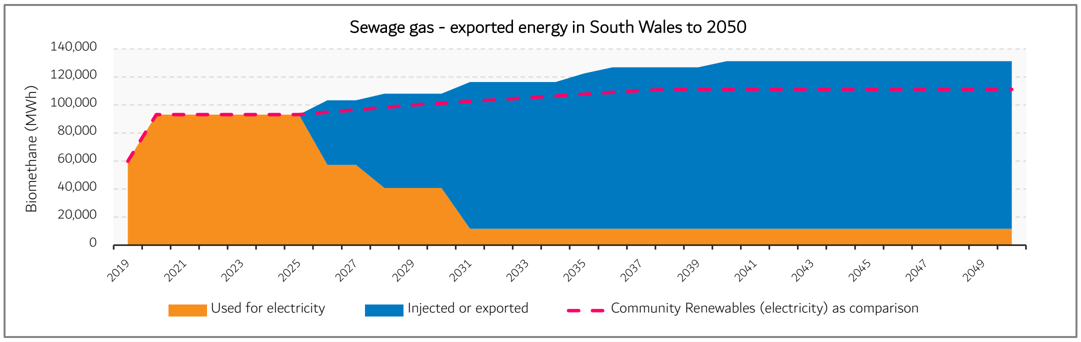
Technology: Landfill gas

Distribution approach

The distribution only uses locational data from baseline and pipeline sites.



South Wales Net Zero
Technology: Sewage gas
Modelling assumptions and results summary



South Wales key statistics	
South Wales population 2019	2,356,643
Estimated biomethane m3 per person per year	c. 7.6 m3
Theoretical maximum biomethane MWh per year	192,920

Approach to net zero

There is currently 9 MW of electrical capacity from sewage plants in South Wales. Technology calculations suggest that the maximum potential resource for electricity generation is c. 15 MW given the total population size.

Modest growth is therefore projected but the key net zero trend modelled in the scenarios and discussed with Welsh Water is for sewage plants to prioritise biomethane generation above electrical export and to reduce the level of self consumption of biomethane as exports become more profitable. The scenario projection for sewage gas does not vary across the scenarios.

Net zero factors to 2050	
Government policy and support	Incentives to produce biomethane over electricity from sewage plants
Waste availability	Waste availability limited by population numbers
Technology development	AD and biomethane units become economic for smaller waste sites.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	6.8	10.6	4.7	1.3	1.3	1.3	1.3
Core and High Hydrogen	Capacity	MWe	6.8	10.6	4.7	1.3	1.3	1.3	1.3
High Electrification	Biomethane	scm	-	-	1,468	2,419	2,610	2,610	2,610
Core and High Hydrogen	Biomethane	scm	-	-	1,468	2,419	2,610	2,610	2,610

High Electrification	Electrical	MWh	59,831	93,119	40,767	11,640	11,640	11,640	11,640
Core and High Hydrogen	Electrical	MWh	59,831	93,119	40,767	11,640	11,640	11,640	11,640
High Electrification	Biomethane	MWh	-	-	67,310	110,891	119,651	119,651	119,651
Core and High Hydrogen	Biomethane	MWh	-	-	67,310	110,891	119,651	119,651	119,651

Baseline - 2019

There are two sewage plants connected to WPD's distribution network with a total of 7 MW. This includes a nearly 5 MW site in Cardiff and a 2 MW site near Port Talbot. Neither site currently export biomethane.

Short term - 2020 to 2025

Project numbers	Total capacity (MW)
1	3.8

There is one Welsh Water site in WPD's connection database. This is a 3.8 MW site to the south of Cardiff and Welsh Water stated that construction commenced in 2019, and is therefore expected to connect in 2020.

Medium term - 2025 to 2035

Discussions with Welsh Water indicate that the existing sewage plant sites are likely to move towards prioritising biomethane production for export after the mid 2020s as the incentives for electricity generation are removed. The biomethane used as a transport fuel and where possible, biomethane to be injected into the gas network.

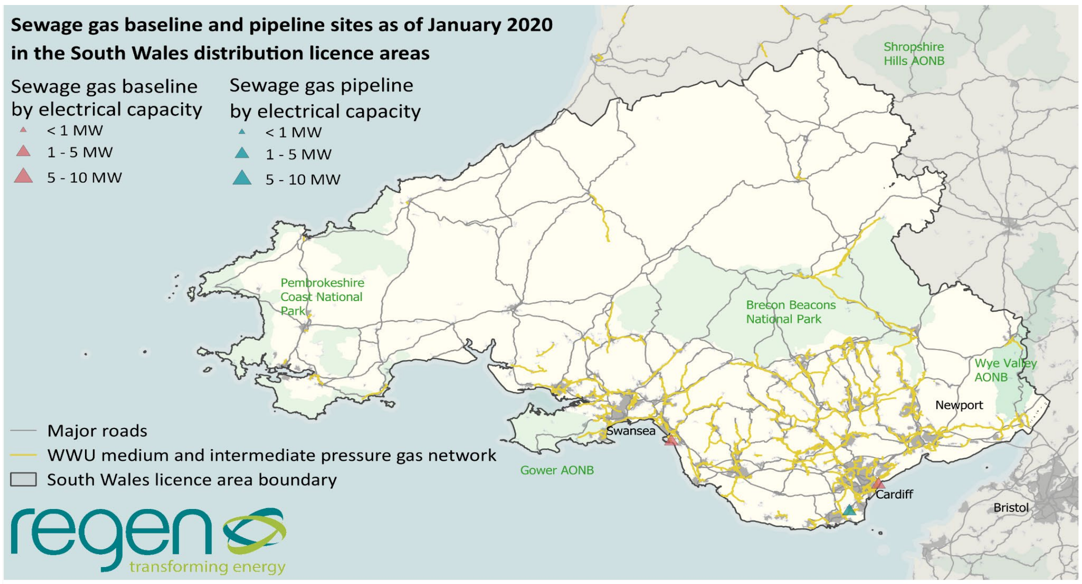
Long term - 2035 - 2050

In the longer term, it is projected that a number of additional smaller waste processing sites to the west of the licence area will be converted to AD units and biomethane production. These are areas not currently covered by sewage anerobic digestion.

South Wales Net Zero
Technology: Sewage gas
Modelling assumptions and results summary

Distribution approach

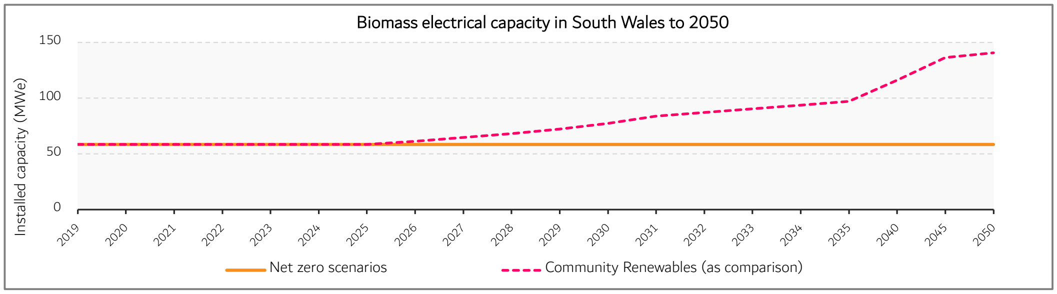
The distribution methodology uses locational data from baseline and pipeline sites in the short and medium term.
Longer term a small number of growth sites have been distributed by areas with higher population and existing sewage treatment sites (currently without sewage AD technology) in the West of the licence area.



South Wales Net Zero

Technology: Large biomass electricity generation

Modelling assumptions and results summary



Approach to net zero

Sustainable biomass is a limited sustainable resource and with over 6% of UK biomass capacity already in the licence area, the scenarios do not project an increase in capacity of biomass for electricity generation above the existing capacity. Both existing generators, which are stated to use waste biomass as a feedstock, are assumed in the scenarios to continue standard thermal generation to 2050.

There is however potential that these sites will be used to provide negative emissions and/or provide synthetic gasified biomass for industrial processes, however this has not been modelled in these scenarios.

Net zero factors to 2050	
Government policy and support	Burning of biomass for electricity only sees a reduction in government support over time. Biomass with carbon capture is prioritised.
Resource availability	There is limited sustainable resource in South Wales for expansion beyond the existing capacity.

Scenario	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	MW	58	58	58	58	58	58	58
Core and High Hydrogen	MW	58	58	58	58	58	58	58
High Electrification	MWhe	327,644	327,644	327,644	327,644	327,644	327,644	327,644
Core and High Hydrogen	MWhe	327,644	327,644	327,644	327,644	327,644	327,644	327,644

Baseline - 2019

Biomass MWe	
Baseline year	Incineration
2016	47
2017	58
2018	58
2019	58

There are six sites currently generating electricity from biomass in South Wales. Four sites are under 2 MW and two projects have significant capacity connected, a 44 MW site, Margam Biomass and an 11 MW in Barry Docks. These were connected in 2013 and 2017 respectively.

The Margam site in Port Talbot was upgraded from an earlier 15 MW site and started generating at higher capacity in 2019. Although connected in 2017, the Barry biomass website announced that it has finished construction and

Short term - 2020 to 2025

There is no change to existing capacity in the short term.

Medium term - 2025 to 2035

There is no change to existing capacity in the medium term.

Long term - 2035 - 2050

There is no change to existing capacity in the long term.

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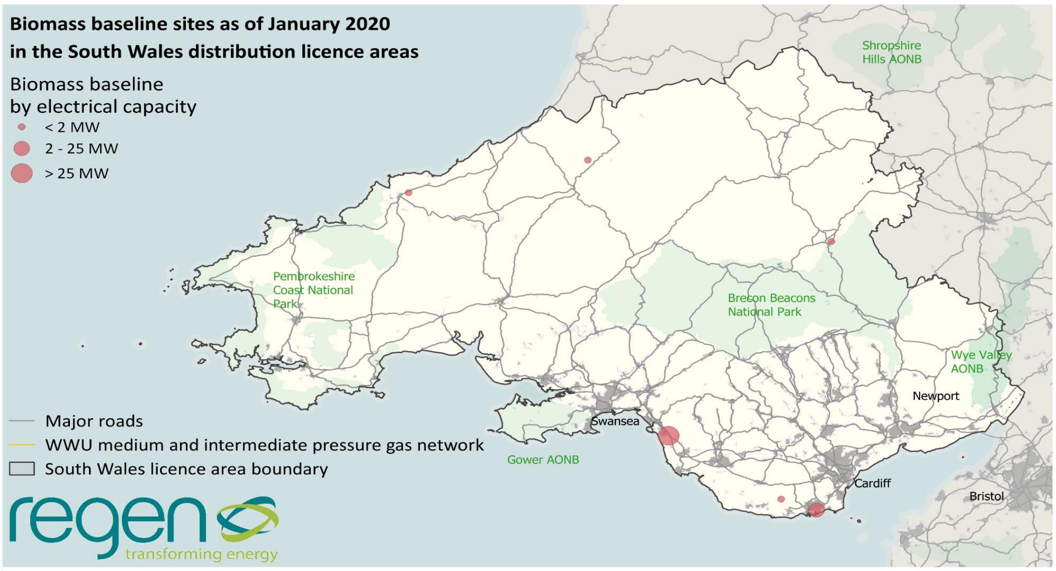
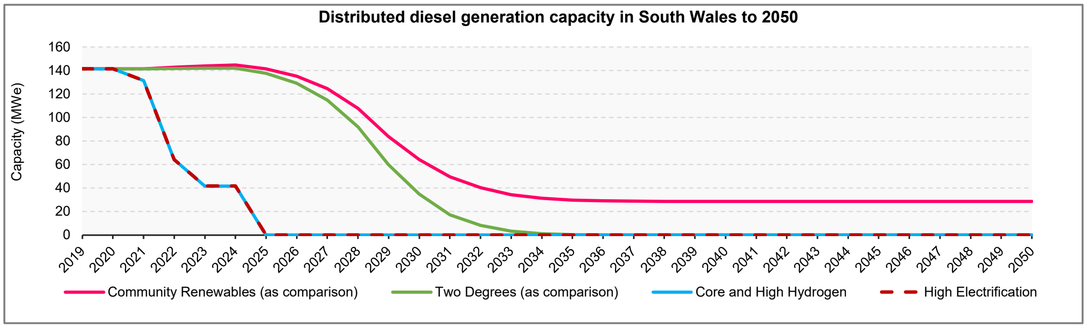
South Wales Net Zero
Technology: Large biomass electricity generation
Modelling assumptions and results summary

Distribution approach

The distribution only uses locational data from baseline and pipeline sites.



South Wales Net Zero
Technology: Diesel generation
Modelling assumptions and results summary



Approach to net zero

Both the transmission network constraint on connecting new thermal generation until the mid/late 2020s and increasingly stringent air quality limits, mean there is no imcrease in diesel generation in South Wales and existing capacity is decommissioned by 2025 in both scenarios. The EU's Medium Combustion Plant Directive (MCPD) adoption into UK Law enforces stringent air quality limits that impact viability of diesel generators in the South Wales (except those used soley for back up). All existing plants will need to be complying with permitted emissions limits by 2025.

The eight sites in the baseline, totalling 141 MW have been modelled to decommission 10 years after their connection year, or by 2025, whichever comes first.

Neither of the two sites in the pipeline, totalling an additional 60 MW, have been modelled to connect in either scenario. This results in there being no distributed diesel generation operating commercially by 2025. Back-up diesel generation has not been modelled.

Net zero factors to 2050	
Government policy	MCPD implementation (Industrial Emissions Directive, Environmental Permitting) in effect now and moving forward.
Network capacity restrictions	NGET Statement of Works and associated thermal generation capacity restrictions, preventing any additional diesel to connect, including pipeline sites.
Net Zero	Both scenario pathways have been treated the same, as there is no clear distinctions between electrification or hydrogen focussed scenarios for diesel

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	141	-	-	-	-	-	-
Core and Hybrid Hydrogen	Capacity	MWe	141	-	-	-	-	-	-
High Electrification	Capacity Factor	%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.59%
Core and Hybrid Hydrogen	Capacity Factor	%	0.04%	0.04%	0.04%	0.04%	0.00%	0.00%	0.00%
High Electrification	Generation	MWh	526,180	-	-	-	-	-	-
Core and Hybrid Hydrogen	Generation	MWh	526,180	-	-	-	-	-	-

Baseline - 2019

Diesel generation capacity		
Baseline year	MWe	Projects
2016	120	6
2017	141	8
2018	141	8
2019	141	8

Most of the baseline are 10-25 MW diesel generating sites that were intended to participate in the Short Term Operating Reserve (STOR) balancing service for National Grid ESO.

With the stringent air quality standards now enforced under the MCPD, these sites will not be able to operate commercially (e.g. in STOR) unabated. Abatement technology at this scale is unlikely to be cost effective.

Short term - 2020 to 2025

Project numbers	Total capacity (MW)
2	60

Due to the National Grid Statement of Works in South Wales preventing any thermal generation from securing generation connection capacity until the late 2020s, there are only two diesel sites in the pipeline, totalling 60 MW. Neither of these had any activity in the capacity market, or planning approval. They both would also fall under the same restrictions of the MCPD, so neither project has been modelled to connect in either scenario.
In addition to this the baseline 8 baseline sites have also been modelled to be decommissioned by 2025 or 10 years after their connection year, whichever comes first.

Medium/long term - 2025 to 2050

No further development of distributed diesel generation has been modelled beyond 2025. It should be noted that non-synchronous diesel generation (e.g. only operating as back-up when mains failure occurs) is not subject to the MCPD, but as this would not impact network generation constraints, it has not been considered to be within the scope of this technology category or the wider project.

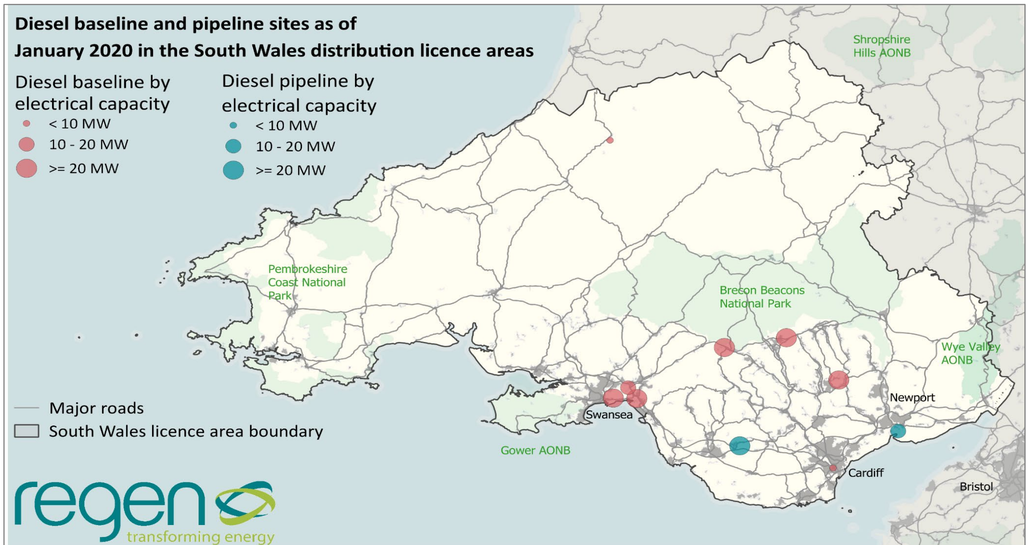
South Wales Net Zero

Technology: Diesel generation

Modelling assumptions and results summary

Distribution approach

The distribution of the capacity is based on the actual locations of the baseline sites. Neither of the two pipeline sites have been modelled to connect in either pathway. Therefore there are no new projections or further growth requiring further distribution beyond the baseline.



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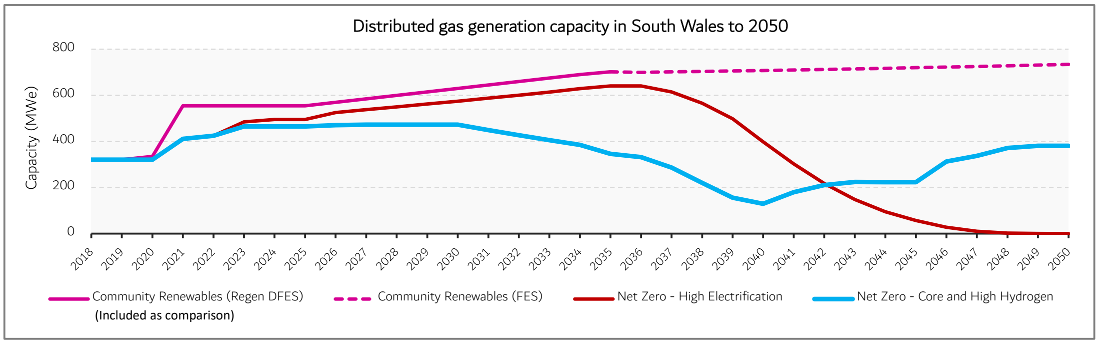
South Wales Net Zero

Technology: Distributed gas fired generation

Modelling assumptions and results summary



Approach to net zero

For the purpose of this project, distributed gas generation has been defined as any power generation asset that is connected to both WPD's electricity network as a synchronous generator and to WWU's gas network as a gas demand user. All scenarios assume there is no unabated fossil gas generation by 2050 and, with a 10-15 year operating life, fossil gas capacity starts to decline from 2035 as older generators are not replaced.

Gas generation is assumed to primarily provide flexibility and this market drives short and medium term growth in capacity. However transmission constraints in South Wales until the late 2020s mean this trajectory in South Wales is lower than the national trend. Up to 2035, the scenario trajectory is based on the WWU analysis Regen completed in 2019. The earlier analysis used FES 2018 Community Renewables projections as a reference scenario.

The **High Electrification** scenario has the highest capacity growth due to flexibility required to balance more electrified heating. However, capacity then reduces to zero by 2050, under a scenario in which CCS or other abatement technologies are assumed to not be viable for small scale distribution connected gas generation.

In the **Core and High Hydrogen** scenarios, a lower requirement for flexibility leads to less growth in capacity. However some low-carbon gas generation (hydrogen or biomethane) capacity has been modelled to connect to both networks again in the 2040s, specifically in green gas supply areas (e.g. hydrogen industrial clusters). Lower pressure hydrogen supply areas in the High Hydrogen scenario has been assumed to be prioritised for heating homes and businesses.

Net zero factors	Core and High Hydrogen	High Electrification
Need for flexible generation	Flexible sources of power are less important than in High Electrification and as heat is primarily provided by low carbon gas. As a result capacity growth is lower in 2030s.	Flexibility requirement is higher in High Electrification to support the development of renewables. Towards 2050 capacity at distribution network level falls as more flexibility is provided by batteries and transmission connected gas with CCUS.
Carbon capture in distributed fossil gas generation	Exhaust stack abatement technologies (or CCS/CCUS) are assumed to be uneconomical for the scale of projects at distribution network level. Net zero requires no unabated fossil fuel generation by 2050 and therefore capacity of unabated natural gas generation drops to zero by the late 2040s.	
Transition to low carbon gas generation	With the development of distributed high pressure hydrogen supply in industrial areas of South Wales in both hydrogen scenarios, a moderate amount of distributed low-carbon gas generation is modelled to connect in the 2040s.	There is minimal low carbon gas (mainly biomethane) in the gas network as a fuel for flexible generation, as it is prioritised for other fuels/uses e.g. vehicle fuel, low carbon heat networks.

Scenario	Measure	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Capacity	MWe	321	495	575	641	398	57	-
Core and High Hydrogen	Capacity	MWe	321	465	473	347	129	223	381
High Electrification	Capacity Factor	%	15.8%	16.4%	8.2%	7.2%	6.6%	7.7%	9.7%
Core and High Hydrogen	Capacity Factor	%	15.8%	15.0%	10.2%	6.9%	6.3%	6.8%	7.4%
High Electrification	Generation	GWh	504	747	515	411	220	37	-
Core and High Hydrogen	Generation	GWh	504	697	468	220	112	141	221

Baseline - 2019

Gas generation capacity		
Baseline year	MWe	Projects
2016	233	14
2017	281	17
2018	321	19
2019	321	19

There are 19 sites totalling 321 MW connected to both WWU and WPD's distribution networks. The projects are all reciprocating engines or CHPs and are between 8-20 MW capacity. Most of them are located in more industrial areas of South Wales.

In addition WWU also had two large gas CCGT sites exporting to the electricity transmission network which have been excluded from the modelling. These are a CCGT of (850 MW) and another power station, which decommissioned in March 2019.

Short term - 2020 to 2025

Scenario	Project numbers	Total capacity (MW)
Total pipeline	14	238
Core and High Hydrogen	8	144
High Electrification	10	174

There are 14 reciprocating engines and CHP sites with electricity and gas connection applications with a capacity between 10-20 MW. Each pipeline project was assessed against information provided by WWU, activity in the UK Capacity Market and local authority planning information. Sites that either secured planning approval or **won** a Capacity Market contract were modelled to go through in the **Core and High Hydrogen** scenario. Sites that either secured planning approval or had **positive activity** in the Capacity Market (e.g. successful prequalification or won a contract) were modelled to go through in the **High Electrification** scenario.
Using this information 10 projects, totalling 174 MW, are modelled to connect in **High Electrification** and eight projects, totalling 144 MW, were modelled to connect in the **Core and High Hydrogen** scenario.

South Wales Net Zero

Technology: Distributed gas fired generation

Medium term - 2025 to 2035

Beyond 2025, the capacity of installed natural gas generation diverges across the two scenario pathways. In **High Electrification** scenario, gas capacity peaks around 2035. The **Core and High Hydrogen** scenarios have lower growth in the mid/late 2020s and due to a lesser need for distributed flexible generation under this scenario, connected projects/capacity begins to decommission earlier as alternatives including low carbon gas generation and peaking are developed.

Long term - 2035 - 2050

Under the **High Electrification** scenario, connected capacity falls from 2035 as older projects are not repowered. With exhaust abatement technologies or CCS unlikely to be economically viable for the scale of distribution network connected projects and the use of biomethane being prioritised in other areas (e.g. for heating), this means that other low carbon flexible generation technologies take on the role of system flexibility, and gas generation shifts back to larger scale electricity transmission network connected sites with CCS/abatement technologies.

Under the **Core and High Hydrogen** scenarios, a similar rate of decommissioning of connected capacity occurs into the 2040s. However, towards the end of the scenario period some low carbon gas generation sites are connected to provide some peaking and flexibility services. These are centred around existing gas generation sites (location and MW capacity) that are in low carbon gas network areas e.g. hydrogen industrial clusters. In a High Hydrogen scenario where there is a wider spread hydrogen supply network, it has been assumed that hydrogen fuelled electricity generation will still be limited to sites in industrial cluster areas, due to lower pressure hydrogen supply being priorised to heating homes and businesses.
The 381 MW of connected capacity by 2050 under the two hydrogen scenarios, consider a potentially strong uptake under an as-yet-unknown business model of hydrogen peaking generation. In reality, the potential for hydrogen fuelled flexible generation could be feasibly a lot lower.

Distribution approach

Both baseline sites and the pipeline sites that are modelled to connect are located at their location addresses. (Note: the CCGT has not been included on the map, due to the scope of this analysis being electricity and gas distribution network connected assets only).

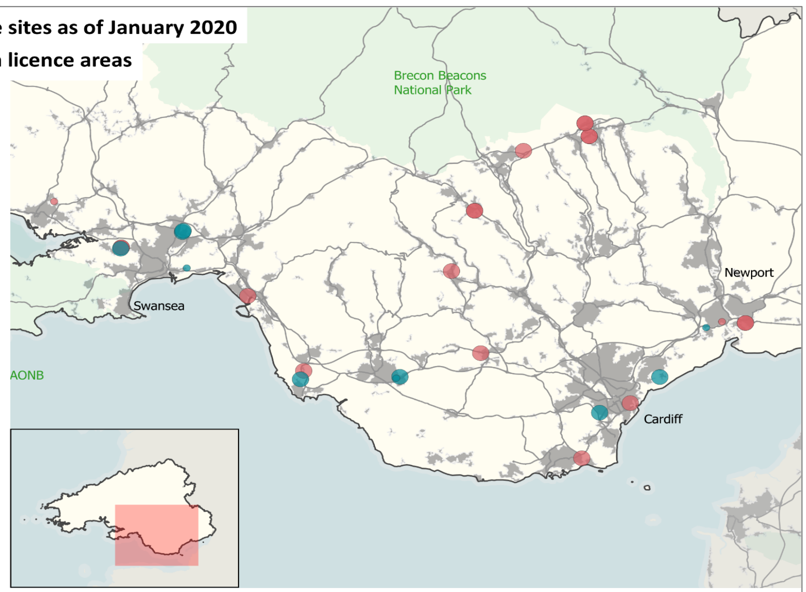
In the medium term additional capacity is distributed to mainly brownfield land proximal to the gas network and 132 kV electricity network.
In the long term, in the **Core and High Hydrogen** scenarios, low carbon gas generation is distributed to sites/areas where hydrogen or biomethane clusters have been modelled to be, sourced from hydrogen industrial cluster modelling within this project.

Fossil gas baseline and pipeline sites as of January 2020 in the South Wales distribution licence areas

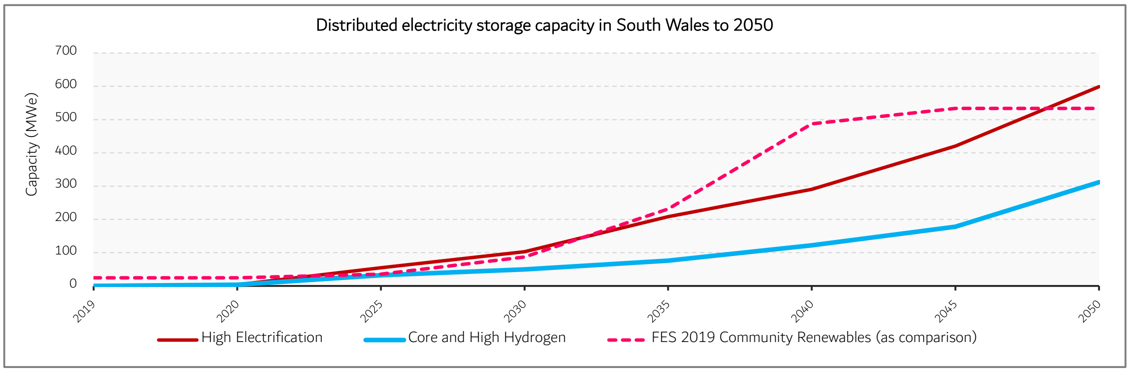
Fossil gas baseline by electrical capacity
- < 10 MW
- 10 - 20 MW
- >= 20 MW

Fossil gas pipeline by electrical capacity
- < 10 MW
- 10 - 20 MW
- >= 20 MW

Major roads
South Wales licence area boundary



South Wales Net Zero
Technology: Electricity storage
Modelling assumptions and results summary



Approach to net zero

The modelling for electricity storage has primarily considered and projected the installed power capacity (MW) of projects connecting in South Wales. However the energy storage capacity (MWh) of projects is a key determining factor of its physical footprint as well as its capability and operability in different markets. Therefore modelling has also projected a separate set of storage duration figures, reflecting ratios of energy storage capacity (MWh) to power capacity (MW), this is summarised in a table below.

The electricity storage has been categorised into four business models or asset classes. **Standalone Network Services, Generation Co-location, High Energy User** and **Domestic.** For each business model, the modelling directly uses other technology scenarios to steer installed storage capacity. As a result, net zero battery storage projections are influenced by assumptions that have been made about renewable generation in particular. Both scenarios assume that battery storage will play a key role in providing flexibility to the electricity network, replacing in-part high carbon peaking gas and diesel generation. More electricity storage power capacity has been projected under the High Electrification scenario than the Core and High Hydrogen scenarios, assuming a higher need for flexibility in the electricity system to support higher electrified heating deployment under this pathway. In the High Hydrogen scenario there is also some low carbon gas generation that replaces some fossil gas generation capacity.
To note the modelling assesses battery storage only, other storage technologies are assumed to connect at transmission or are not viable in South Wales, though we are aware of transmission connected storage assets in Wales, such as the Pen-Y-Cmoedd battery storage project co-located with Vattenfall's wind farm.

Modelling is based on the following business models		Core and High Hydrogen	High Electrification
Standalone - Network Services	Standalone 'in-front of the meter' storage projects, 10-100 MW scale targeting national or local network commercial services and markets.	Flexible sources of power are less important in High Hydrogen and as heat is primarily provided by low carbon gas, growth is lower in 2030s.	Flexibility requirement is higher in the High Electrification scenario to support the development of renewables. Towards 2050 capacity at distribution network level flattens as more flexibility is provided by batteries and transmission connected gas with CCUS.
Generation co-location	Projects that share connection points and/or co-operate with distributed onshore wind and ground mounted solar PV targeting price arbitrage or additional revenues/markets.	A lower number of solar or wind projects have been modelled to have co-located battery storage in the Core and High Hydrogen pathway than the High Electrification pathway. This assumes that the market for time-shifting variable renewable generation output is stronger in a highly electrified scenario, thus driving more deployment of co-located and co-operating storage systems alongside standalone generation sites.	
Commercial & Industrial High Energy User	Behind-the-meter installations co-located with larger demand user sites, typicall under 5 MW or kW scale to avoid price peaks and provide supply resilience.	The modelling assumes that 14% of all non-domestic premises have the potential for connecting battery storage. The average capacity of these C&I battery installations has been modelled to increase from 100kW to 500kW across both pathways, reflecting cost reductions. In the High Electrification pathway more C&I sites are asssumed to have behind-the-meter storage than Core and High Hydrogen, as businesses look to benefit from price arbitrage from time-of-use charging and volatile electricity prices as well as participation in national and local flexibility markets.	
Domestic scale batteries	Battery units for the home co-locating with rooftop PV, electric heating or electric vehicles. Vehicle-to-grid is not modelled as part of domestic battery storage.	Co-located home batteries are adopted by some households, predominantly to shift PV generation to the evening to maximise self-use.	Co-located home batteries are adopted by many households, time-shifting rooftop PV, but also potentially leveraging time of use tariffs, accessing domestic flexibility markets or flexible energy behaviour in the home.

Scenario	Model	Units	2019	2025	2030	2035	2040	2045	2050
High Electrification	Standalone	MWe	0.0	20	20	32	51	82	131
High Electrification	High Energy User	MWe	0.1	18	28	47	58	78	133
High Electrification	Co-location	MWe	0.0	8	18	38	48	89	162
High Electrification	Domestic	MWe	0.0	8	37	91	133	171	173
High Electrification	**Total**	**MWe**	**0.1**	**54**	**103**	**208**	**291**	**420**	**599**
Core and High Hydrogen	Standalone	MWe	0.0	20	20	24	29	35	41
Core and High Hydrogen	High Energy User	MWe	0.1	6	9	16	26	39	80
Core and High Hydrogen	Co-location	MWe	0.0	4	12	21	35	49	122
Core and High Hydrogen	Domestic	MWe	0.0	3	9	15	33	55	69
Core and High Hydrogen	**Total**	**MWe**	**0.1**	**32**	**50**	**76**	**122**	**178**	**312**

Scenario	Model	Units	2019	2025	2030	2035	2040	2045	2050
All scenarios	Standalone	Hours of storage	1.0	2	3	3	4	4	4
All scenarios	High Energy User	Hours of storage	2.0	3	4	4	5	6	6
All scenarios	Co-location (solar)	Hours of storage	2.0	3	4	5	6	6	8
All scenarios	Co-location (wind)	Hours of storage	2.0	3	4	4	4	4	6
All scenarios	Domestic	Hours of storage	1.5	2	2	2	3	3	4

South Wales Net Zero
Technology: Electricity storage
Modelling assumptions and results summary

Baseline - 2019

Gas generation capacity		
Year	MWe	Projects
2016	0	0
2017	0.099	1
2018	0.099	1
2019	0.099	1

To date there is a single 99kW battery in the South Wales connection baseline. This project was classified as a High Energy User behind-the-meter project.

The baseline is low in South Wales, in part due to the transmission constraint which was imposed in 2016 and restricts new connections for new dispatchable generation technologies above 1 MW. This will impact new large scale battery storage until network upgrades are completed in the late 2020s.

Short term - 2020 to 2025

Project numbers	Total capacity (MW)
4	24

There are four battery storage projects in the South Wales pipeline. This includes a 6.9 kW domestic battery, a 100kW battery (likely a High Energy User behind-the-meter project), a 4 MW battery located at a Wepa Papermill industrial site and a 20 MW standalone project that has planning approval and pre-qualified for the 2022 T-4 capacity market auction. The two larger sites had accepted connection offers before the transmission constraint Statement of Works in 2016. Therefore, 24 MW has been projected forward to connection between 2023 and 2025 in all scenarios. The individual business model projections also modelled a further 10 MW of capacity to connect before 2025 in the **High Electrification** pathway.

Medium term - 2025 to 2035

There is an increase in connected electricity storage capacity across all business models under all scenarios, from the late 2020s, as the restriction on new dispatchable generation is lifted between 2027 and 2028. Capacity growth is based on the projections collated from the individual business model analyses.

The **High Electrification** scenario begins to break away from the **Core and High Hydrogen** scenarios in the 2030s, reflecting further storage connections under a more favourable market and policy environment for storage at various scales.

Long term - 2035 - 2050

The variance between High Electrification and the hydrogen scenarios continues out to 2050, with 604 MW of storage capacity connected by 2050 in the **High Electrification** scenario in 2050 and 315 MW connected by 2050 in the **Core and High Hydrogen** scenarios.

South Wales Net Zero
Technology: Electricity storage
Modelling assumptions and results summary

Distribution approach

A method for geographical distribution has been determined for each of the four storage business models, due to being driven by different locational factors. These are summarised in the table below:

Storage business model distribution factors				
Timeframe	**Standalone**	**Generation co-location**	**Behind the meter C&I**	**Domestic**
Short-term	> Baseline and pipeline site locations	> Baseline and pipeline site locations	> Baseline and pipeline > OS Addressbase classification of commercial and industrial	> High affluence areas > Rooftop PV projections > EV projections
Medium-term	> Proximity to electricity network, weighted towards 132 kV > Brownfield land	> 1 MW solar PV and onshore wind projections	> OS Addressbase classification of commercial and industrial	> Medium affluence > Rooftop PV projections > EV projections
Long-term	> Proximity to electrical network, weighted towards 132 kV > Brownfield land > Peaking plant baseline and pipeline sites			> Rooftop PV projections > EV projections