Technical Report

Local Area Energy Plan (LAEP)

Monmouthshire

Sponsors: Delivery partners:

Abbreviations

Acronym	Meaning	Acronym	Meaning
BEIS	Business, Energy and Industrial Strategy.	EGW	Energy Generation in Wales.
CAPEX	Capital Expenditure.	EPC	Energy performance certificate.
CCGT	Combined Cycle Gas Turbine.	ESC	Energy Systems Catapult.
CCR	Cardiff Capital Region.	EV	Electric Vehicle.
CCUS	Carbon Capture, Utilisation and Storage.	FES	Future Energy Scenarios.
CPO	Charge Point Operator.	GDN	Gas Distribution Network.
COP	Coefficient of Performance.	GHG	Greenhouse Gas.
DESNZ	Department for Energy Security and Net Zero.	GIS	Geographic Information System.
DFES	Distribution Future Energy Scenarios.	HGV	Heavy Goods Vehicles.
DfT	Department for Transport.	LAEP	Local area energy planning or Local area energy plan.
DNO	Distribution Network Operator.	LDP	Local Development Plan.
ECOFLEX	Flexible Eligibility Energy Company Obligation.	LGV	Light Goods Vehicles.
ECR	Embedded Capacity Register.	LSOA	Lower super output area, a small area classification in the UK designed to have a comparable population.
EfW	Energy from Waste.	LULUCF	Land Use, Land Use Change and Forestry.

Abbreviations

Acronym	Meaning	Acronym	Meaning
MSOA	Middle super output area, a medium-sized area classification in the UK designed to have a comparable population.	RFI	Request for Information.
NAEI	National Atmospheric Emissions Inventory.	RIIO	Revenue = Incentives + Innovation + Outputs, a regulatory framework used by the UK energy regulator, Ofgem.
NGED	National Grid Electricity Distribution.	RLCEA	Renewable and Low Carbon Energy Assessment.
NZ	Net Zero.	RSP	Regional Skills Partnership.
NWTM	North Wales Transport Model.	RTP	Regional Transport Plan.
NZIW	Net Zero Industry Wales.	SAP	Standard Assessment Procedure.
OPEX	Operational Expenditure.	SEWBCC	Southeast Wales Business Climate Coalition.
OS	Ordnance Survey.	SEWTM	Southeast Wales Transport Model.
PRI	Pressuring Regulating Installation.	SDP	Strategic Development Plan.
RdSAP	Reduced data Standard Assessment Procedure.	SLES	Smart Local Energy System.
REA	Renewable Energy Assessment.	SMR	Steam Methane Reformation.
REPD	Renewable Energy Planning Database.	SPEN	SP Energy Networks.
REPEX	Replacement Expenditure.	SSE	Scottish and Southern Energy plc.

Abbreviations

Acronym	Meaning
SWIC	South Wales Industrial Cluster.
TEC	Transmission Embedded Capacity.
TfW	Transport for Wales.
WIMD	Welsh Index of Multiple Deprivation.
WWU	Wales and West Utilities.

Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners: ARUP, Carbon Trust, Afallen, Prifddinas Ranbarth Caerdydd | Cardiff Capital Region

Contents

This report was prepared by Arup, Carbon Trust and Afallen on behalf of Monmouthshire Council and co-ordinated across the region by the Cardiff Capital Region. Energy Systems Catapult is the Technical Advisor for the LAEP Programme in Wales.
This report's development was funded by the Welsh Government.

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Sponsors: Llywodraeth Cymru Welsh Government

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Monmouthshire LAEP – Technical Report

1. Introduction (Stage 1)

1. Introduction

LAEP development

Monmouthshire's LAEP was prepared by Arup, Carbon Trust and Afallen on behalf of Monmouthshire County Council and the Cardiff Capital Region. Energy Systems Catapult were the Technical Advisors for wider the LAEP Programme in Wales. The LAEP programme and the development of this LAEP's was funded by the Welsh Government.

In this report, the term "we" has been used throughout to refer to the consultants introduced above, that have been commissioned by Welsh Government to support the development of this LAEP. We developed Monmouthshire's LAEP in accordance with ESC's LAEP Guidance[T01], which breaks the LAEP development process down into seven stages (See Figure 1.1.1).

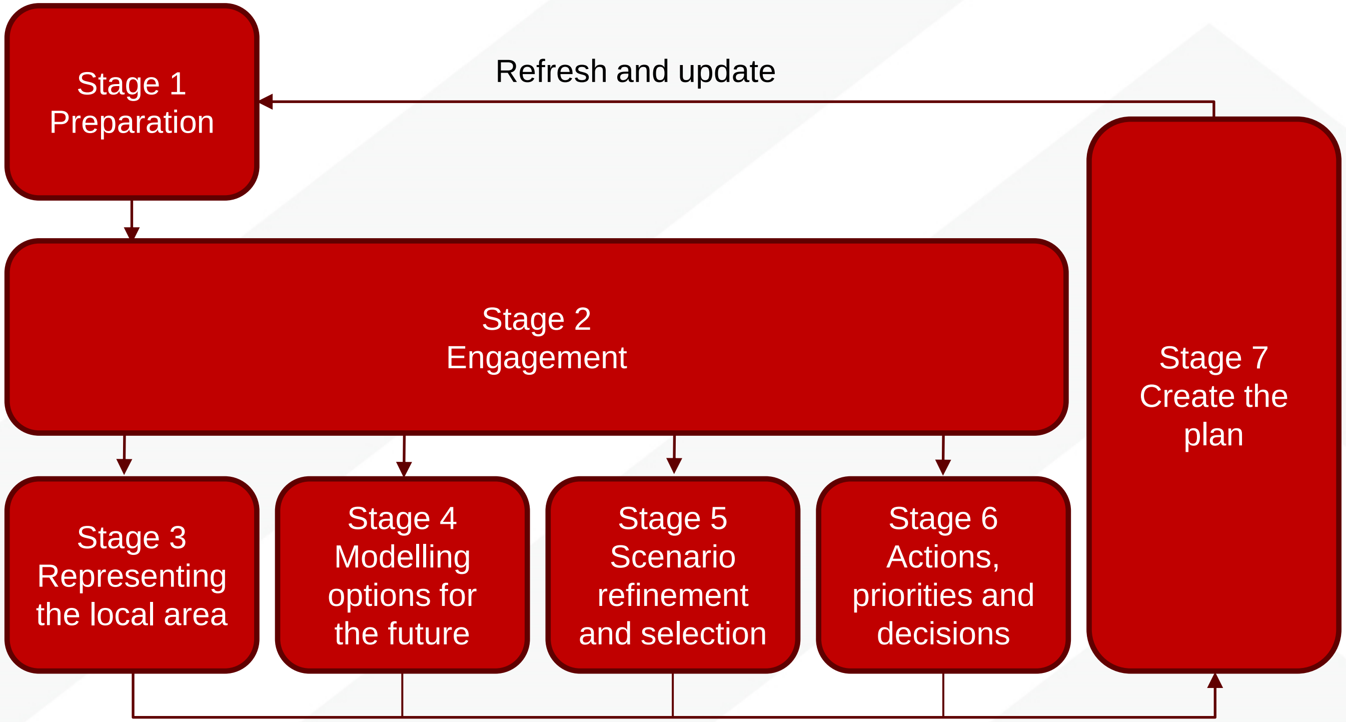

Figure 1.1.1: Seven stages of local area energy planning (LAEP) according to ESC's LAEP Guidance[T01]

1. Introduction

Introduction to Technical Report

Monmouthshire's Local Area Energy Plan (LAEP) provides an evidence-based plan of action that identifies the most effective route to a net zero local energy system for the area. This LAEP has been developed by bringing local organisations and groups together to discuss the evidence created as part of the development process and collectively agree on the best way forward to achieve this objective.

Applying this approach, the LAEP puts local needs and views at the centre of the planning process, and helps creates a co-ordinated, place-based plan that avoids the duplication of efforts, aims to save money, and realises additional social benefits that might otherwise have been over-looked.

The LAEP has been divided into three separate documents to make the content accessible to a variety of audiences and to make it easier for readers to find what they are looking for:

This is the **Technical Report**, which contains the graphs, charts, maps and supporting data for the results published in the LAEP. It also provides more detail about the approach to the modelling and scenario analyses that we completed.

The other two documents are the Local Area Energy Plan and the Renewables Investment Prospectus.

The **Local Area Energy Plan** focuses on Monmouthshire's local energy strategy and action plan.

The **Renewables Investment Prospectus** highlights short-term, regional and local renewable energy opportunities that have the greatest potential for delivery across Monmouthshire.

Figure 1.1.3 (overleaf) shows a summary of the content of this Technical Report, to help navigate this report. For a summary of the content of other reports and how this relates to Energy systems Catapult's (ESC) LAEP Guidance[T01], please see Appendix B9.

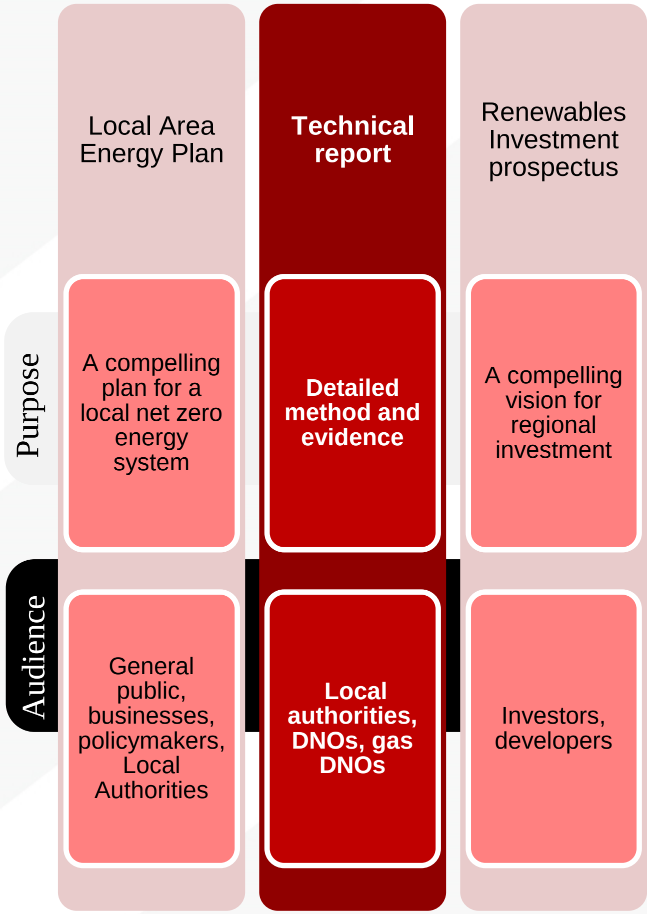

Figure 1.1.2: Summary of LAEP reports' purpose and audience

1. Introduction

Introduction to the Technical Report

Navigating this report

Section	Content
1. Introduction	• Overview of LAEP programme. • Process of preparing a LAEP, identifying resources, appointing lead organisation and agreeing roles. • Definition of the system boundary and scope of the LAEP.
2. Stakeholder engagement	• Approach taken to identify, prioritise and engage stakeholders throughout the development of the LAEP.
3. The current energy system	
Methodology	• Summary of data sources used to inform the energy system baseline. • Summary of assumptions used to define the energy system baseline.
Analysis	• Presentation of local socio-economic context. • Discussion of Monmouthshire's baseline energy use from buildings, industry and transport and energy generation.

Figure 1.1.3: Summary of content in Technical Report

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Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners: ARUP, CARBON TRUST, Prifddinas Ranbarth Caerdydd Cardiff Capital Region

1. Introduction

Introduction to the Technical Report

Navigating this report

4. The future energy system

Scenario analysis

Deployment modelling

5. Action planning

Energy propositions

Creating the plan (Main LAEP Report only)

Figure 1.1.4: Summary of content in Technical Report

Content

- Summary of modelling approach for scenario analysis.
- Summary of modelling parameters used, such as cost, emission factors and network dependencies.
- Comparison of key characteristics of four future energy scenarios modelled: National Net Zero, High Demand, Low Demand and High Hydrogen.
- Summary of results from sensitivity analysis.

- Method for development deployment pathways.
- Estimated impacts of each future energy scenario on air quality and employment.
- Summary of deployment pathways for each scenario, with additional discussion across buildings, industry, transport and renewable generation.

- Summary of the process of developing energy propositions.
- Introduction to Monmouthshire's energy propositions that form the framework for Monmouthshire's LAEP, and the focus for the next 5-6 years.
- Monmouthshire's plan on a page summarising the priority focus zones identified for each system component that contribute to Monmouthshire's energy propositions.
- Presentation of the detailed evidence to support delivery of each energy proposition, including the "focus zones" investment requirements.

1. Introduction

The local energy system

A LAEP considers energy use, supply and generation within the council boundary.

There are three core parts to the local energy system:

Infrastructure – The physical assets associated with the energy system such as electricity substations.

Supply – Generation (renewable and non-renewable), storage and distribution of energy to local consumers for use in homes, businesses, industry and transport.

Demand – The use of energy driven by human activity e.g. petrol/diesel used in vehicles, gas burned for heat in homes. required for the energy system to operate.

Fuel for transport, heat and power in buildings and heat and power for industrial processes and other energy needs are considered together in the planning process to ensure that the interactions and dependencies between the generation and use of different energy sources across different sectors are fully considered. This can also help to identify where different systems can work better together to improve the overall resilience and flexibility of the energy system.

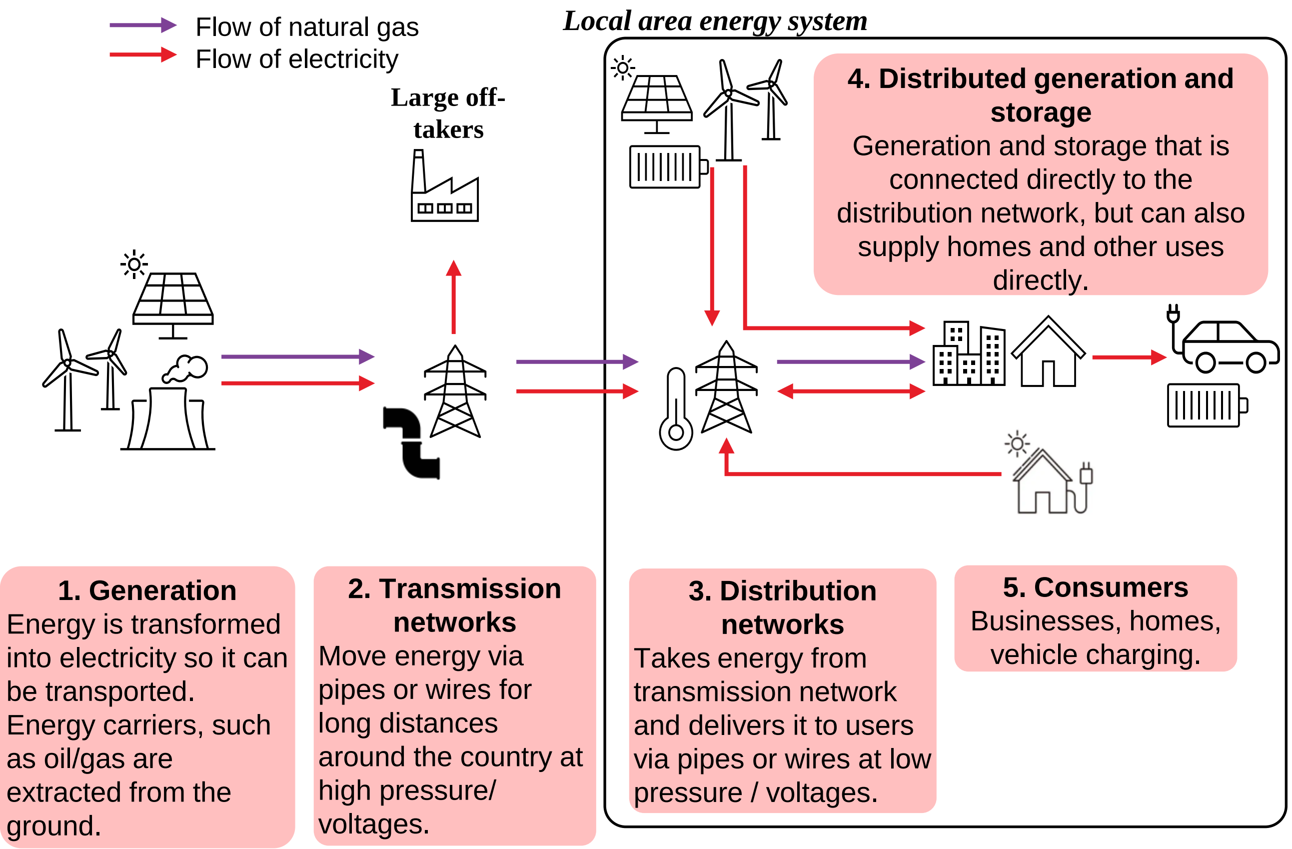

Figure 1.1.5: Schematic of electricity and gas transmission and distribution network and the system boundary for LAEP

1. Introduction

The local energy system

Boundary

The LAEP is a plan to support the transition of the local energy system to net zero, and therefore requires an understanding of the emissions produced by the local energy system as well as energy supply, use and infrastructure. To do this, the geographic boundary was used to set the boundary of the study, which meant that any energy generating assets, energy use and infrastructure in that boundary was considered for inclusion in the LAEP.

Scope

The scope of the LAEP was then determined based on ESC's LAEP Guidance[T01]. The Guidance states that certain energy assets should be considered national rather than local, where the asset serves the wider energy needs of the UK. Considering this, electricity connection at lower voltages (132 kV / 33kV / 11kV) was defined as "local" and included in the modelling for the LAEP. Any assets connected at higher voltages (400 kV / 275 kV) or with capacities > 100 MW were considered "national" and excluded from the modelling unless otherwise specified.

If local government has control over the siting of generation/production and associated infrastructure (e.g. through the planning process) then it is local energy production. When permitting for siting and construction is controlled by national organisations (e.g. for offshore wind) then it is national energy production. Energy generation should be considered local where the key input to energy production is a local resource. Energy generation where the key resource comes from outside the local area (e.g., imported biomass) should be considered part of the national energy system.

Similarly, any demand connected to the transmission network is excluded, as we are looking at the local distribution network.

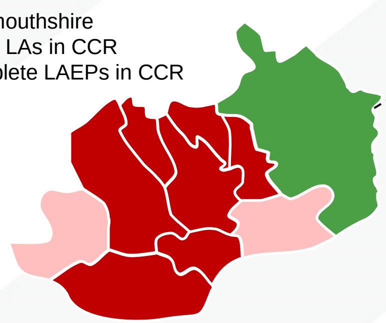

Figure 1.1.6: Location of the Cardiff Capital Region economic region (red) and the LAEP system boundary for Monmouthshire (black)

Figure 1.1.7: Monmouthshire boundary

Monmouthshire LAEP – Technical Report

2. The current local energy system (stage 3)

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Delivery partners:

2. The current local energy system

Overview

This section is structured as follows:

Methodology

This section summarises the data sources and assumptions applied to describe the characteristics of Monmouthshire's local energy system as it looks today.

Analysis

Presents key findings from the baseline analysis, discussing energy use in buildings, transport and industry and how energy is currently generated in the local area.

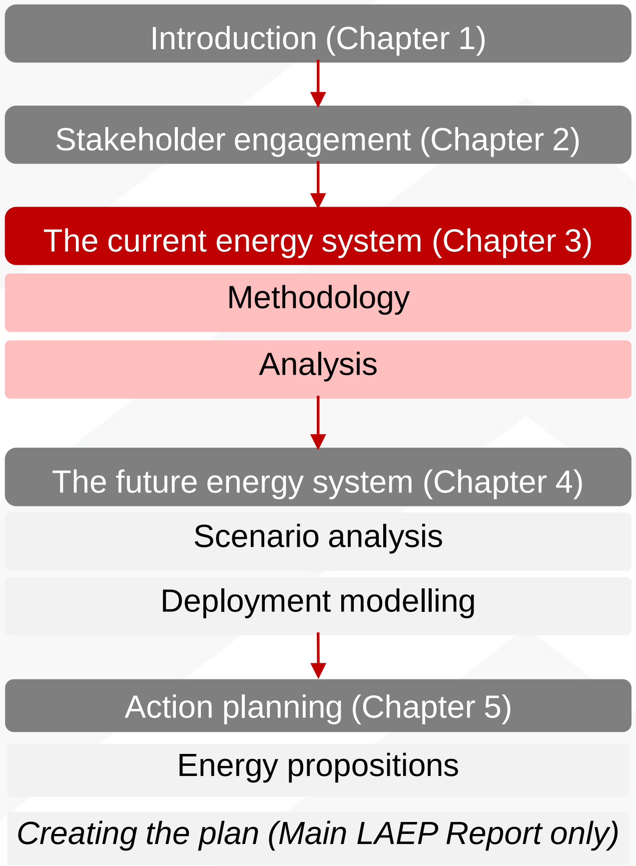


Figure 2.0.1: Flow diagram showing the chapters and sub-chapters in this report (the chapter that follows is highlighted in red)

Monmouthshire LAEP – Technical Report

2. The current local energy system (stage 3)

Method

2. The current local energy system

Methodology overview

This section provides a detailed overview of the local energy system baseline, and describes the methodology and assumptions used to understand current energy infrastructure, what types of energy are used, what technologies are used to convert it from one form to another (e.g. heat) and how much is consumed.

1. Data collection

We compiled energy consumption data and the capacities for existing energy generators in Monmouthshire from local and regional sources, prioritising the highest level of granularity possible. We circulated a Request for Information (RFI) to the Local Authority to gather council-owned datasets and policy documents to inform the broader context for renewable energy in the area. Sectoral datasets were sourced through other organisations such as Transport for Wales (TfW), distribution network operator (DNO) and the gas distribution network operators (GDN) where relevant. Publicly available data sources and existing databases were also used where appropriate. The resulting dataset comprised of six core modules; buildings, transport, industry, renewable energy, heat networks, and energy supply infrastructure. Detailed methodologies for each of these modules are outlined overleaf.

We collected baseline data for 2023 to include the most up to date data for housing stock and renewable generation installations. The exception to 2023 datasets was for transport (2015) and industry data (2019). Transport and industry datasets are the least likely to have changed in terms of electrification over the years 2019 to 2023, and transport is the most likely dataset to have changed due to the COVID-19 pandemic.

2. Data validation

We cross-referenced the calculated results with existing datasets to evaluate their accuracy. This validation process was essential to understand any discrepancies between datasets and ensure the overall precision of our reporting. The Department for Energy Security and Net Zero's (DESNZ) (formerly BEIS) sub-national total final energy consumption dataset[T05] formed the main source of validation, with other datasets also considered for other emission sources.

3. Data analysis

We generated maps to present spatial information related to the current energy system to support analysis alongside data tables to consolidate and compare different datasets to understand trends. These are shown overleaf.

1. **Context:** maps showing socioeconomic and energy efficiency data.
2. **Demand:** maps showing electricity, heat/gas and transport demand data.
3. **Infrastructure:** maps showing primary substation demand headroom, generation headroom and the proportion of properties that are not connected to the gas.
4. **Supply:** maps showing energy generators.

2. The current local energy system

Methodology – electricity and gas network infrastructure

Electricity

Capacity data was combined with the corresponding primary substation service area, assigning primary substation capacity and headroom to each primary substation service area.

Each 11kV cable was mapped to a primary substation, and then to a Local Authority boundary. Where primary substation service areas intersected one or more Local Authority boundaries, they were divided into smaller modelling zones at the boundary. The capacity of the primary substation was then distributed proportionally among its constituent modelling zones based on the modelling zone's area as a fraction of the primary substation service area.

Exclusions

This piece of analysis only considers the distribution network, as the transmission network is considered a national asset and therefore out of scope of the LAEP.

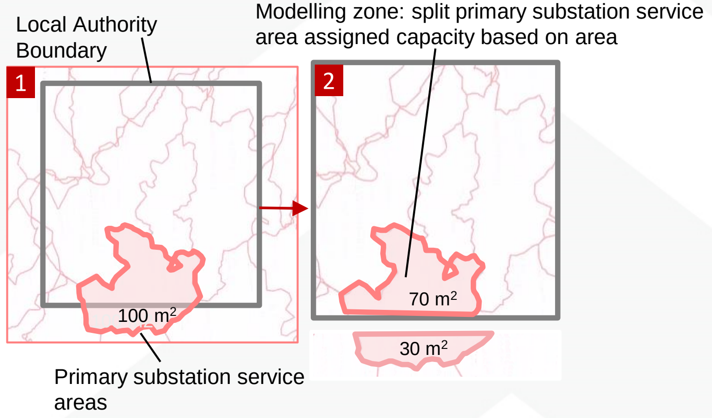
There were some areas where no supply/generation headroom data was available, these were excluded

Gas

We used the percentage of off-gas homes derived EPC data[T07] to understand the extents of the existing natural gas service area. The EPC data contains address-level statistics for around 60% of homes, including information on heating type. The percentage of off-gas homes in the current system is the proportion of domestic EPC records that are not heated by natural gas. To extrapolate the on- or off-gas designation to buildings without an EPC rating, we created building archetypes and extrapolated the statistics using a nearest-neighbour extrapolation method

Data input	Data source	Data type	Data quality
Primary substation service areas and headroom	NGED Open Data Portal[TC06]	Primary	For four substations in CCR, the data did not indicate primary capacity.
Off-gas grid homes	EPC data[T07]	Primary	Heating-type data available for ~60% of homes

Table 2.1.1: Electricity and gas network infrastructure – data sources



*Note: areas shown here are theoretical values.

Figure 2.1.1: Process of mapping primary substation service areas to the local authority boundary

2. The current local energy system

Methodology – electricity and gas network infrastructure

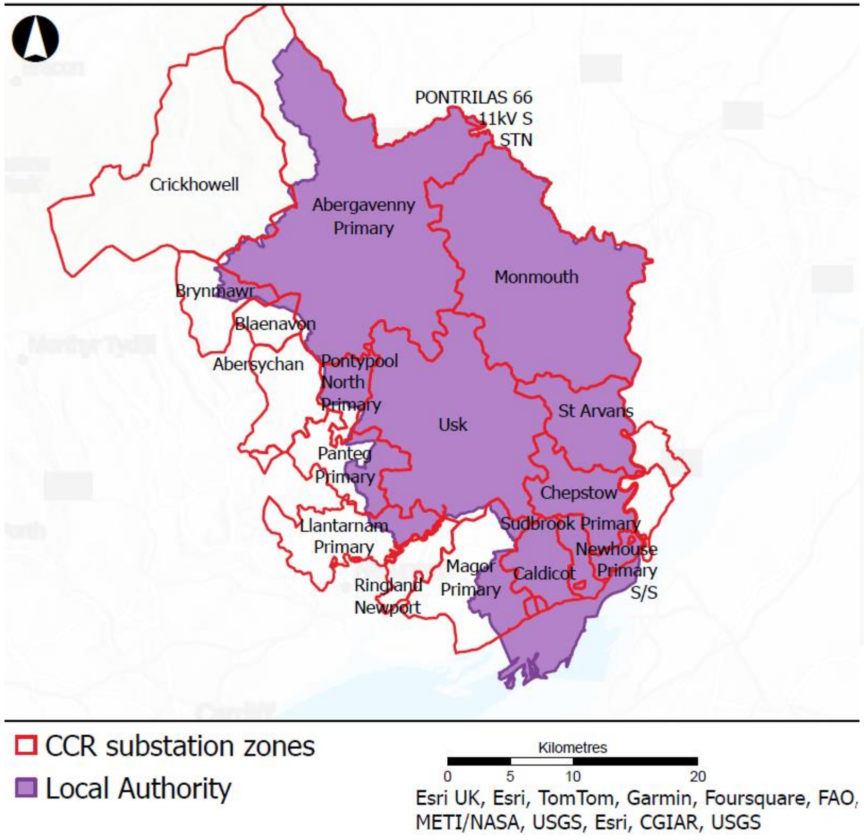


Figure 2.1.2: Map of substation zones in Monmouthshire

2. The current local energy system

Methodology – building energy demand

Carbon Trust has a well-established address-level database that uses a "bottom-up" approach for both domestic and non-domestic properties. The Carbon Trust's address-level model enables a more accurate assessment of building-level energy demand and provides a detailed platform for assessing decarbonisation measures and scenarios.

Address-level database

We created an address-level database for this assessment by combining energy performance certificate (EPC)[T07] (accessed February 2023) and council data with Ordnance Survey (OS) AddressBase Plus[T08].

For properties with no EPC record, we extrapolated insulation statistics at the postcode level.
Where possible, we supplemented this database with council-supplied data to improve the accuracy of energy consumption statistics.

Data input	Data source	Data type	Data quality
Address-level attribute data (property type, insulation, construction age, heating fuel etc.)	Domestic & non-domestic EPC, display energy certificates (DEC)[T07]	Primary	Approximately 60% of building stock covered. Attributes extrapolated to remaining buildings based on closest neighbours. Last updated April 2023.
Outline polygons for buildings (GIS mapping)	OS AddressBase Plus[T08]	Primary	Quality assured by GeoPlace and contains the most extensive and accurate information available. Last updated April 2023.
Gas and electricity consumption data	Council-supplied data	Primary	Council-owned non-domestic stock only.
Domestic heat and electricity demand profiles	Profiling tool commissioned by NGED and developed by Hildebrand[TC06]	Secondary	Uses data from approximately 10,000 smart meters from across the UK categorised by archetype to estimate average electricity and heat demand profiles.
Non-domestic heat, electricity and cooling profiles	CIBSE non-domestic electricity and gas benchmarks[T10] and Arup's normalised profiles	Secondary	Building profiles used have been tested against other buildings of the same type.

Table 2.1.2: Baseline data sources (buildings)

Sponsors: Delivery partners:

2. The current local energy system

Methodology – buildings energy demand

We categorised all domestic and non-domestic properties into a numbered list of archetypes based on the following parameters:

- Property type and built form (e.g. Detached house, top floor flat)
- Construction age (before/after 1930)
- Level of insulation
- Prevalence of building type in Wales

An archetype is assigned the median or most common attributes of all properties in the archetype category. E.g. the median attributes for archetype 1 are cavity wall (filled); insulated loft; uninsulated solid floor; 38kWh/m^2 electricity demand; and 114kWh/m^2 annual heat demand.

Data validation

We generated building profiles at the archetype level and aggregated to local authority area to adjust the annual consumption based on DESNZ's sub-national energy consumption statistics[T05].

Differences are expected when comparing the national dataset to our bottom-up results due to the difference in scope, boundary, technology efficiencies, occupancy and consumer behaviour. The DESNZ's sub-national statistics[T05] are therefore used to sense check our results and scale the fuel consumption where the difference is high.

Consumption taken from DESNZ's sub-national statistics[T05] is 16% lower per address than the bottom-up generated profiles for electricity. The difference signifies that the bottom-up estimate for fuel consumption is close to the DESNZ's sub-national statistics.

Unoccupancy of buildings has not been considered in the bottom-up approach. Also, for non-domestic, one limitation of the archetype approach is that it does not capture the range of ways floor area can be used for unclassified archetypes. Refer to Appendix B3 for a detailed list of energy benchmarks.

Monmouthshire	% diff
Domestic electricity demand difference	-7.0%
Domestic heat demand difference*	-22%
Non-domestic electricity demand difference	0.0%
Non-domestic heat demand difference	13%
Un-occupancy (Census 2021)[T56]	6%
% non-domestic properties with no archetype	27%

Table 2.1.3: Demand differences between DESNZ's statistics and building profiles
*DESNZ's statistics report gas consumption which was used as a proxy for heat demand

No.	Description
1	Detached - after 1930 - medium/high efficiency
2	Detached - low efficiency
3	Terrace - medium efficiency
4	Terrace - before 1930 - low efficiency
5	Semi-detached - after 1930 - low efficiency
6	Semi-detached - after 1930 - high efficiency
7	Semi-detached - before 1930 - low efficiency
8	Semi-detached - before 1930 - high efficiency
9	Flat (any floor) - high efficiency
10	Top floor flat - low efficiency
11	Bottom floor flat - low efficiency
12	Office
13	Retail
14	Hotel/Hostel
15	Leisure/Sports Facility
16	Schools, nurseries And Seasonal Public Buildings
17	Museums/Gallery/Library/Theatre/Hall
18	Health Centre/Clinic
19	Care Home
20	Emergency Services, Local Gov Services, Law, Military
21	Hospital
22	Warehouse
23	Restaurant/Bar/Café
24	Religious building
25	Transport Hub/Station
26	University Campus
27	Other non-domestic

Table 2.1.4: Summary of building archetypes used

2. The current local energy system

Methodology – transport energy demand

Here we explain the approach taken to assess the transport demand baseline. The outputs of this baselining are regional mileage demand maps and the transport values in the baseline Sankey diagrams per local authority.

We used data from Transport for Wales (TfW) transport models[TC12] to estimate annual road mileage data between different parts of a local area. TfW's data provided the number of trips between two different transport zones (defined by TfW) on an average day according to vehicle type. In this data, a trip is defined by the transport zone where a vehicle's journey starts and the transport zone where it ends; therefore vehicles which pass through a transport zone without stopping are not counted. We estimated the route distance to be 130% longer than the distance between each area's centre point. This 'route indirectness' factor was based on Arup work from a previous local area energy plan in Wales. We then scaled up that daily mileage value to an annual mileage value.

We then geospatially mapped these annual mileage values from the TfW zones to substation zones. We summed over vehicle types to produce the map shown on the right in Figure 2.1.3.

We also estimated the energy consumption in kWh associated with these mileage values using vehicle type-specific kWh/mile factors, derived from external sources of miles per gallon provided in Table 2.1.5. The sum of this over a local authority resulted in the transport demand value for the baseline Sankey diagram.

Exclusions

Note that trips by rail are not included. Rail is considered a national asset.

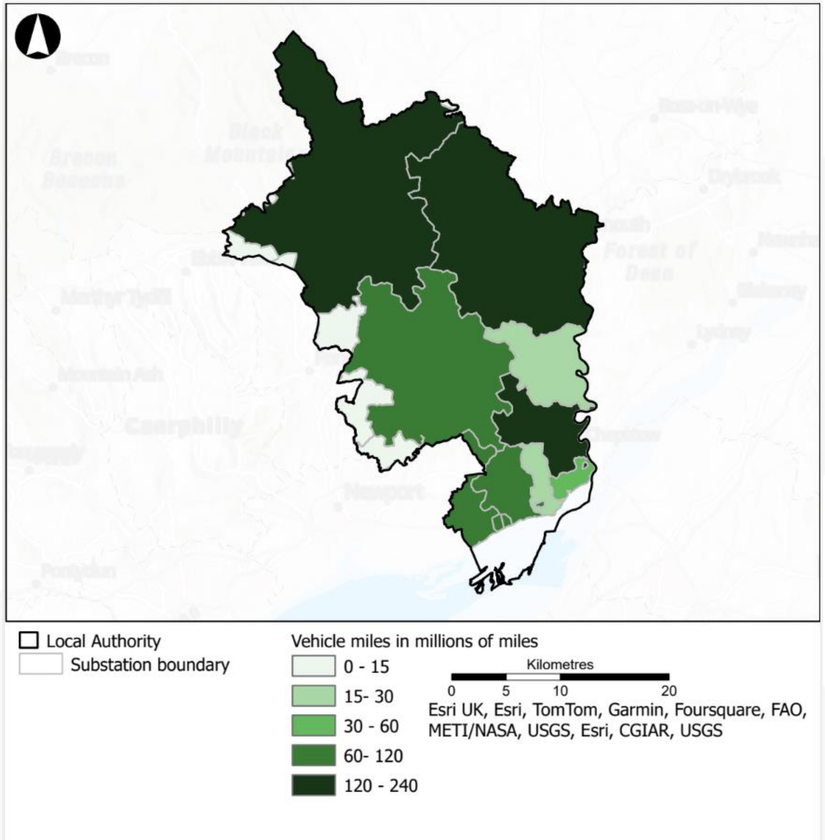


Figure 2.1.3: Estimated annual mileage (million miles / year) for all vehicles in Monmouthshire by substation zone (2015)

2. The current local energy system

Methodology – transport energy demand

Data validation

We compared our baseline results against two datasets: our mileage values were compared against the Department for Transport (DfT) road traffic statistics[T13], and the energy consumption values were compared against the DESNZ sub-national road transport fuel consumption statistics[T14].

The mileage comparison is on the right, which compares total mileage of all vehicles. We found our estimates to be broadly consistent with the DfT dataset – in some cases above and in some cases below, meaning the differences are likely due to differing levels of route directness in different local authorities.

The TfW dataset was used for our analysis because it was prepared on a zonal basis for each Local Authority, which provided more detail compared to the DfT road traffic statistics which were prepared by Local Authority area.

Please see the energy consumption comparison on the next page.

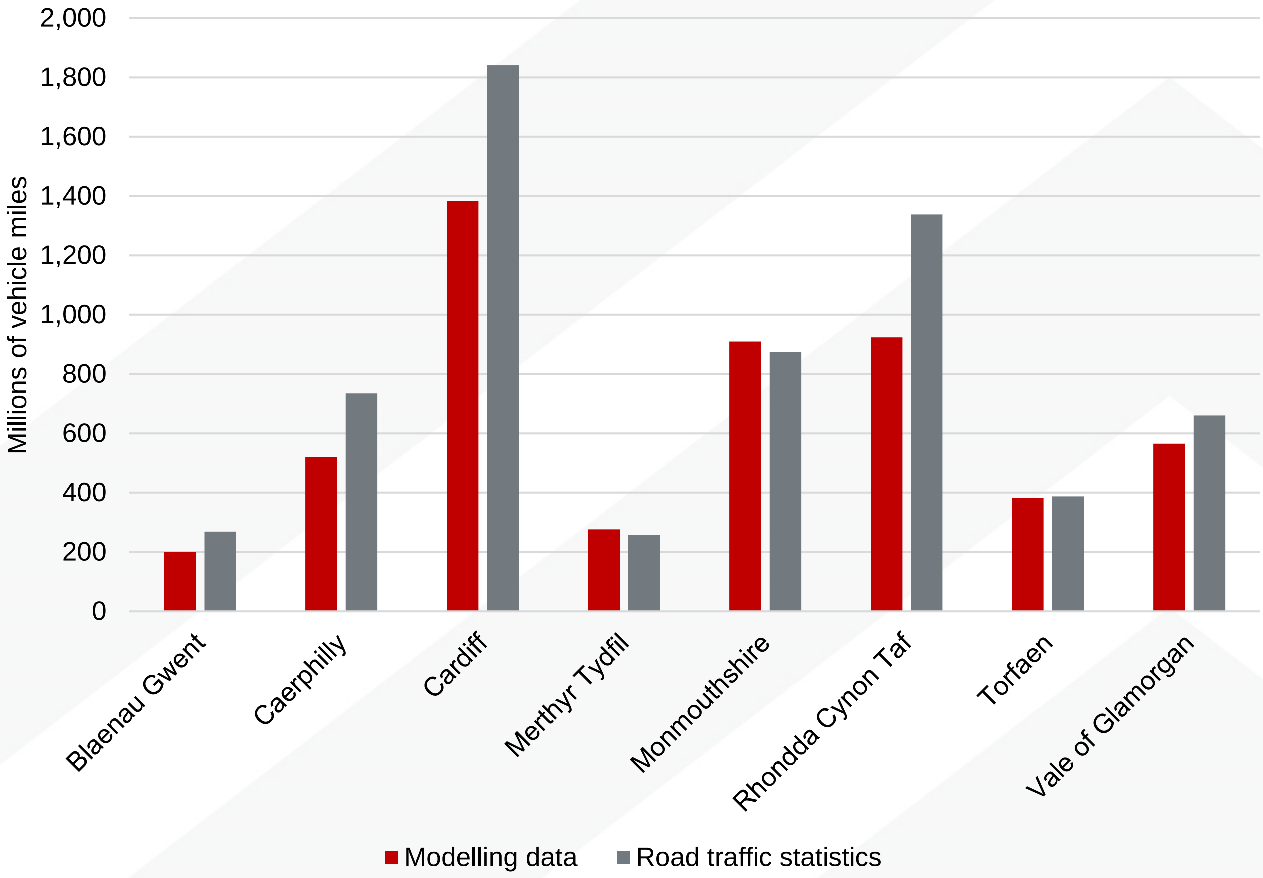


Figure 2.1.4: Comparison of modelling results against DfT road traffic statistics

2. The current local energy system

Methodology – transport energy demand

The energy consumption comparison is on the right, showing the total energy consumption as estimated by our method and by the DESNZ sub-national fuel consumption statistics[T14]. Our estimates were found to be very consistent with the DESNZ dataset.

Mapping of local electric vehicle charge points

In the baseline maps, we mapped local charge points according to the postcodes supplied in the National Chargepoint Registry[T15] and, where provided, local authority records. We are currently reviewing extra data provided by local authorities.

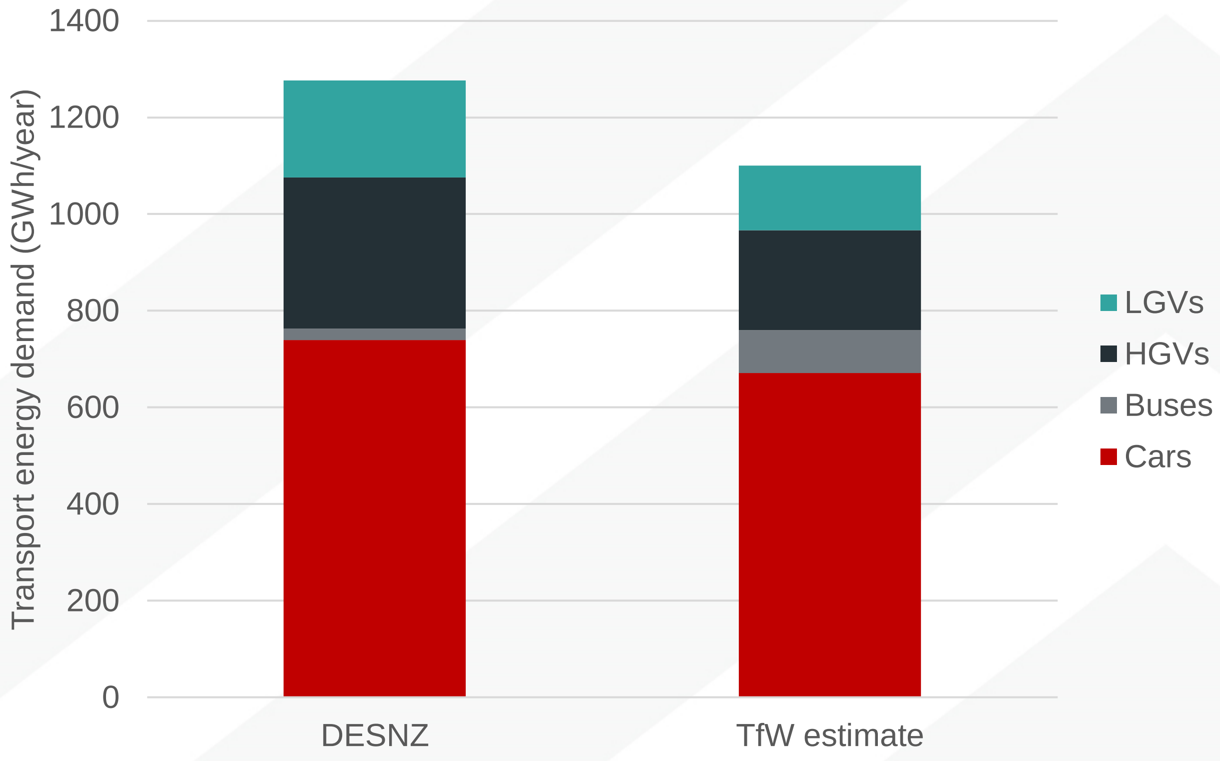


Figure 2.1.5: Annual transport energy consumption; our analysis based on TfW data compared to DESNZ (formerly BEIS) sub-national fuel consumption statistics

2. The current local energy system

Methodology – transport

Data input	Data source	Data type	Data quality
Demand tables	Transport for Wales (TfW) South East Wales Transport Model (SEWTM)[TC12].	Primary	Total number of trips between TfW zones for a typical 24-hour period only. Trip distances not available.
Miles per gallon values for cars and LGVs	Env0103: Average new car fuel consumption: Great Britain. Assumes average age of 10 years for cars and 9.3 years for LGVs[T16].	Secondary	“Obtained under consistent, carefully controlled laboratory conditions and do not reflect external factors”.
Miles per gallon values for HGVs	Env0104: Average heavy goods vehicle fuel consumption: Great Britain. Assumes average age of 11 years[T17].	Secondary	“Obtained under consistent, carefully controlled laboratory conditions and do not reflect external factors”.
Miles per gallon values for buses	Transport for London press release (2014)[T18].	Secondary	Does not differentiate between diesel and petrol. Data source is a press release based on London buses; not UK-wide dataset. The miles per gallon value may differ significantly between driving in London and driving in less urban parts of Wales.
Number of diesel vehicles and total number of vehicles	Vehicle licensing statistics data tables (veh0105)[T19].	Secondary	All non-diesel vehicles assumed to be petrol.
Postcodes of charge points	National Chargepoint Registry (NCR)[T15].	Primary	Relies on updates by contributors.

Table 2.1.5: Transport baseline data sources

2. The current local energy system

Methodology – industry energy demand

We identified industrial demands in each local authority using the large point sources database from the National Atmospheric Emissions Inventory (NAEI)[T20]. This includes spatial coordinates for each point source that could be used to locate industrial sites.

The NAEI database also contains information on the emissions generated by each site. For this baseline analysis, we only considered carbon dioxide emissions.

To estimate the energy from emissions at each industrial site, we divided emissions by the appropriate carbon emissions factor[T21].

We sent industry stakeholders a request for information (RFI) to obtain primary data for the site's annual electricity and gas consumption, to validate calculated industrial energy demands.

Where industrial organisations with large energy demands in Monmouthshire did not respond to this information request, we used the NAEI emissions to provide a proxy for the energy used by the site. When calculating energy demand, we only considered carbon emissions in the conversion from carbon emissions to energy demand.

Data validation

There was no information on the industrial sites at other sources for cross-referencing.

Exclusions

We omitted national assets connected to the transmission network, as well as assets that did not have any available data.

Data input	Data source	Data type	Data quality
Point source data	NAEI, 2020[T20]	Primary	Only carbon emissions were considered. Other emission types were discarded

Table 2.1.6: Baseline data sources (industry)

Sponsors: Delivery partners:

2. The current local energy system

Methodology – local energy generation

We mapped generators identified in the renewable energy planning database (REPD)[T22] to modelling zones in geographic information systems (GIS) using address or postcode.

We cross-checked data against the energy generation in Wales (EGW)[T23] 2021 report to capture any operational generators that were not captured in renewable energy planning database (REPD) or NGED's embedded capacity register (ECR)[TC24] This was the latest report available at the time of developing the baseline.

As the EGW dataset includes ground-mounted generators connected to the transmission network, we cross-checked any additional generators identified in EGW against the transmission embedded capacity register (TEC)[T25] to ensure only generators connected to the distribution network were captured.

Exclusions

Offshore wind generators were not captured. Generators with capacities exceeding 100MW were not captured. Generators that did not include an electricity capacity or postcode/address were not included.

Data input	Data source	Data type	Data quality
Installed renewable electricity capacity (MWe) for ground-mounted solar PV, commercial rooftop solar PV, onshore wind, hydropower, biomass, AD, landfill gas, sewage gas, energy from waste, natural gas, oil.	REPD (January 2023) [T22] ECR (April 2023) [TC24] EGW (2021) [T23] Council-supplied data (where available)	Primary	Distribution-connected generators only. REPD: Renewable generators greater than 150kW*, UK wide, updated quarterly. ECRs: Generators or storage greater than or equal to 1MW, DNO supply area, updated monthly. EGW: Generators connected to distribution or transmission network, Wales-wide, updated annually.
Thermal generator installed capacity (MWth)	EGW (2021) [T23]	Secondary	Generators listed by outward code (first half of postcode) as no full postcode available.
Domestic rooftop solar PV	EGW (2021) [T23] Council-supplied data (where available)	Secondary	Rooftop solar PV data was compiled using feed-in-tariff registers and other micro-generator databases. Generators listed by outward code as no full postcode available.

**the minimum threshold for installed capacity was 1MW until 2021, at which point it was lowered to 150kW. This means that projects below 1MW that were going through the planning system before 2021 may not be represented in the REPD.*

Table 2.1.7: Baseline data sources (local energy generation)

2. The current local energy system

Methodology – greenhouse gas emissions

Generation-based emission factors are factors that measure greenhouse gas (GHG) emissions (in CO_2 equivalent) per unit of electricity generated. These were used in this analysis by multiplying the fuel feedstock for each technology in the scope of modelling, with the relevant emission factor.

GHG emission factors and their relevant sources are presented in Table 2.1.8. Each emission factor is a 2023 estimation except for electricity, where a projection was used to reflect grid decarbonisation.

Exclusions

Emissions associated with the extraction, transportation and distribution of the fuel sources are not considered. Lifecycle emissions of generation facilities are also excluded. Renewable energy generators that generate electricity with no intermediary (e.g. solar PV, wind etc.) are modelled as having no associated GHG emissions.

Technology	Value	Units	Source
Biomass	0.0119	kgCO_2e/kWh	DESNZ, 2023 (Average of 4 biomass fuels: wood logs, wood chips, wood pellets, grass/straw)[T21]
Coal	0.3226	kgCO_2e/kWh	DESNZ, 2023 (Coal - Industrial, Gross CV) [T21]
Diesel	0.2391	kgCO_2e/kWh	DESNZ, 2023 (Liquid fuels - Diesel (average biofuel blend), Gross CV) [T21]
Electricity grid	0.045	kgCO_2e/kWh	National Grid FES 2023 (averaged scenario, without BECCS). Also includes projection to 2050 TC35
Landfill gas	0.0002	kgCO_2e/kWh	DESNZ, 2023 (Biogas - Landfill gas) [T21]
Natural gas	0.1843	kgCO_2e/kWh	DESNZ, 2023 (Gaseous fuels - natural gas, Gross CV) [T21]
Oil/LPG	0.2413	kgCO_2e/kWh	DESNZ, 2023 (Average of LPG and Fuel Oil, Gross CV) [T21]
Organic matter	0.0002	kgCO_2e/kWh	DESNZ, 2023 (Biogas - Biogas) [T21]
Petrol	0.2217	kgCO_2e/kWh	DESNZ, 2023 (Liquid fuels - Petrol (average biofuel blend), Gross CV) [T21]
Sewage gas	0.0002	kgCO_2e/kWh	DESNZ, 2023 (Biogas - Biogas) [T21]
Waste incineration	0.038	kgCO_2e/kWh	DESNZ, 2023; Tolvik, 2021[T26]

Table 2.1.8: Baseline emission factors (local energy generation)

Monmouthshire LAEP – Technical Report

2. The current local energy system (stage 3)

Analysis

2. The current local energy system

Analysis - local context

Monmouthshire is located in the southeastern region of Wales, sharing borders with the southwestern part of England and the Midlands. Encompassing an area of around 880 square kilometres, the county has a relatively low average population density of 1.1 persons per hectare. In 2021, the population reached around 93,000[TL01]. Monmouthshire is a predominantly rural area, with only 53% of the population living in urban areas [TL02] Abergavenny, Chepstow, Monmouth, Caldicot, Usk and Magor are Monmouthshire's main settlements[TL02] .

Monmouthshire's landscape features designated areas such as the Wye Valley Area of Outstanding Natural Beauty and the Brecon Beacons National Park. There is a high proportion of agricultural land, with 16.7% being dedicated to crops and horticulture [TL02]. Both designated and cultivated land pose a challenge for renewable energy deployment due to the planning restrictions imposed on grade 1 to 3a land.

Transport networks

Monmouthshire benefits from a well-developed road network, including the A40, A48 and other arterial routes and motorways that connect Monmouthshire with Cardiff, Bristol, Gloucester and Newport. Nearly half of Monmouthshire's economically active population take advantage of the road infrastructure to out commute, drawn to higher paid jobs outside the county. This trend contributes to the high prevalence of private car ownership and longer commuting distances [TL02].

Fuel poverty and deprivation

In 2022, around 10% of households in Monmouthshire were deemed to be living in fuel poverty in comparison to 14% of households across Wales[T27]. A household is regarded as being in fuel poverty if they are unable to keep their home warm at a reasonable cost. In Wales, this is measured as any household that would have to spent more than 10% of their income on maintaining a satisfactory heating regime. According to the Welsh Index of Multiple Deprivation 2019 (WIMD), across Monmouthshire, 27% of the 56 LSOA areas were ranked in the 50% most deprived, with no LSOAs in the 10% most deprived[T28].

Local economy

Tourism and agriculture are both important sectors in Monmouthshire. In 2020, the sectors with the largest number of enterprises were 'professional, scientific and technical' (17.5% of all enterprises) and 'agriculture, forestry and fishing' (15.3% of all enterprises) [TL03]. In 2022, 2.34 million tourists generated £285 million for the local economy, which supported 3,356 jobs[TL04].

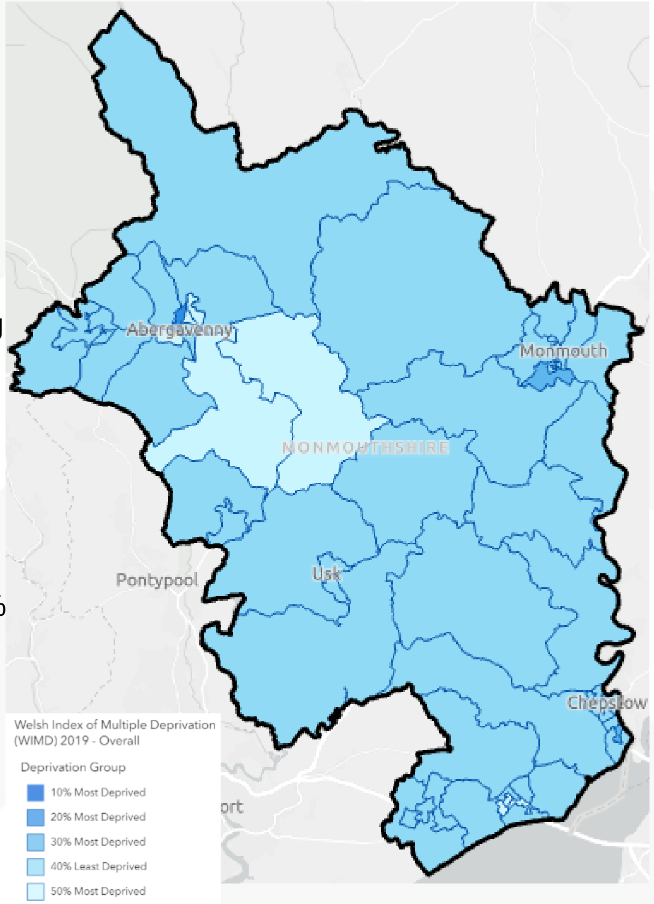


Figure 2.2.1: Index of Multiple Deprivation by LSOA in Monmouthshire in 2019

2. The current local energy system

Analysis – greenhouse gas (GHG) emissions by sector

The figures presented here are emissions produced by the local energy system, as defined in Section 2. The emissions shown in Figure 2.2.2 include:

- Buildings: emissions from heating and electricity use from all buildings
- Transport: emissions from road vehicles including cars, vans, lorries, and buses. Trains are not included.
- Energy: emissions from electricity plants fired by fossil fuel
- Industry: emissions from the large industry sites identified from the NAEI emissions dataset

In 2023, greenhouse gas (GHG) emissions in Monmouthshire were 440 ktCO_2e. GHG emissions per capita were 4.6 tCO_2. The largest GHG contributors were:

- Road vehicles: 52% (230 ktCO_2e) of total GHG emissions are from the use of petrol and diesel in road vehicles.
- Buildings: Fuels consumed to meet electricity and gas demands in buildings account for 47% (200 ktCO_2e).

Note: The emissions in Figures 2.2.2 and 2.2.3 exclude emissions from waste and land use, land use change and forestry (LULUCF).

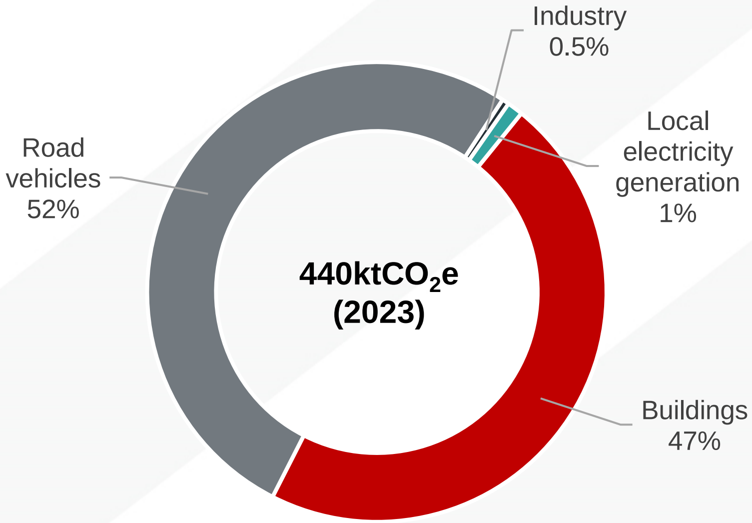


Figure 2.2.2: CO_2 emissions by sector in 2023[22]

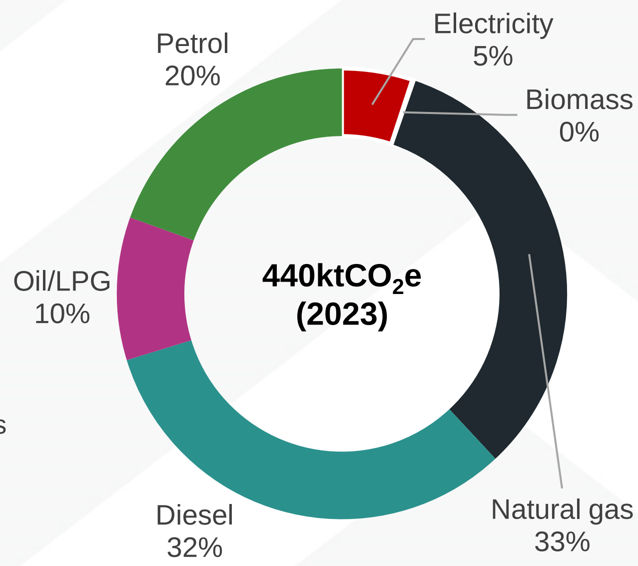


Figure 2.2.3: CO_2 emissions by fuel type in 2023[22]

2. The current local energy system

How to read a Sankey diagram

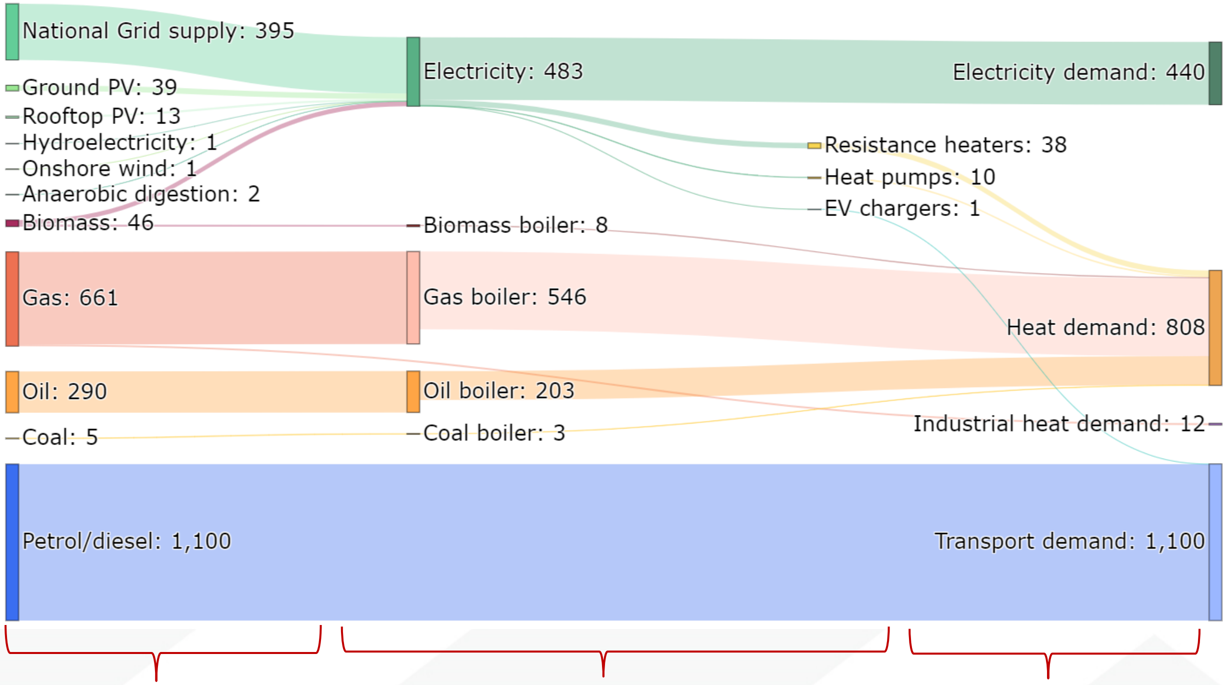
Baseline energy flows – Sankey diagram

Sankey diagrams are a way of visualising energy transfer from energy sources to energy demands via energy vectors or conversion technologies.

They are read from left to right and show a snapshot of a scenario in time e.g., 2050

Energy transfers are drawn to scale and so are helpful to identify the size of each transfer and compare different scenarios.

This page and the following, reflect the energy baseline in Monmouthshire in 2023, apart from the transport (2015) and industry data (2019). Even though the transport and industry data are older (pre-covid, and before 2023), they should still be accurate enough to be used in this analysis. The datasets used were the most recent versions at the time of the data collection.



1. Where the energy comes from
This side represents the different **energy sources**, including generation technologies and imports from the national grid.

2. How the energy is being converted

3. Where the energy is being used
This side represents the **final demands** for each energy vector: heat demand, electricity, demand, transport demand.

Figure 2.2.4: How to read a Sankey diagram

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Delivery partners: ARUP, Carbon Trust, Prifddinas Ranbarth Caerdydd Cardiff Capital Region

2. The current local energy system

The baseline analysis for Monmouthshire provides insight into the existing energy system in 2023.

Most of the **electricity** within the system was supplied by the National Grid, accounting for 82% of total electricity consumed. Monmouthshire has a diverse mix of energy generators serving electricity demand, with the most significant contribution from biomass, ground-mount and rooftop solar PV. Almost all electricity was used for electricity demand, exclusive of electricity used for heating and transport.

Heating accounted for 34% of total energy demand across Monmouthshire. Whilst the majority of heating demand was being served by gas (661GWh), there was a considerable contribution from oil boilers (290GWh). The remaining heat demand was provided by coal (5GWh).

Transport had the highest energy demand of all components. This can be attributed to long commuting distances and high levels of private car ownership. Almost all vehicles in Monmouthshire utilise internal combustion engines (ICEs).

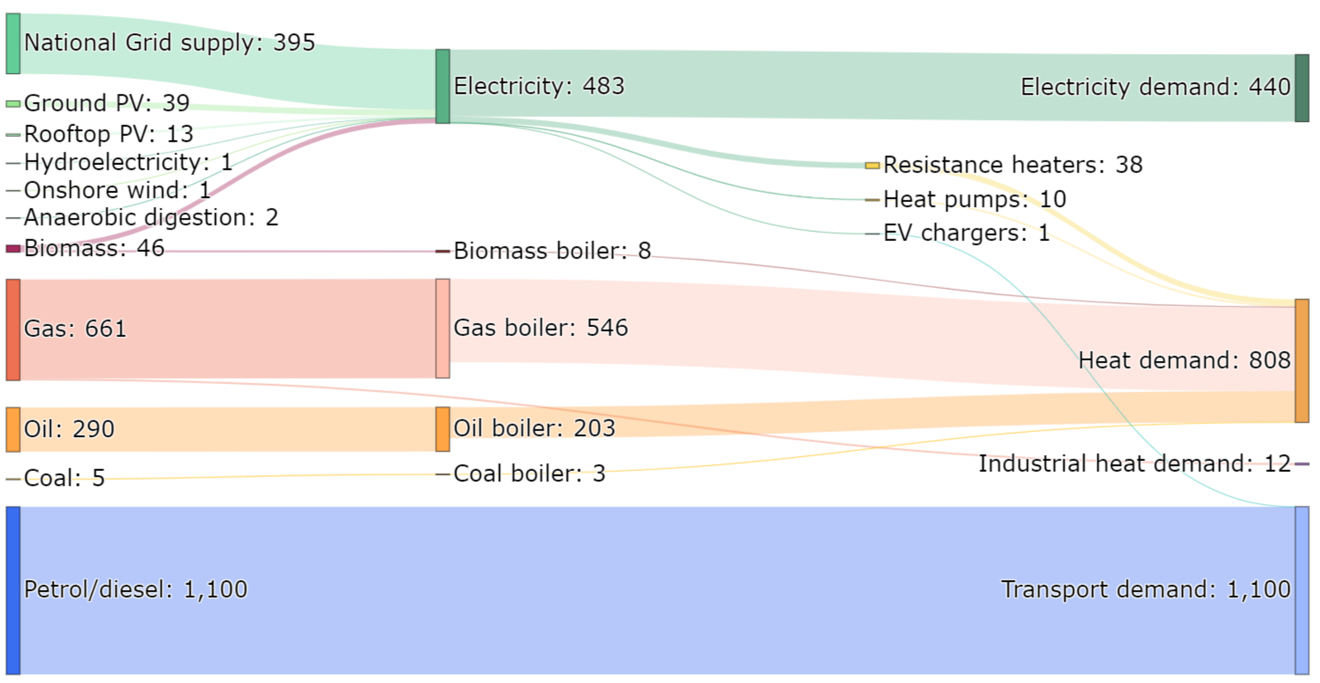

Figure 2.2.5: Baseline Sankey representing energy flows in Monmouthshire in GWh/year (2023)

2. The current local energy system

Analysis – buildings energy demand – domestic

In 2023, buildings in Monmouthshire contributed 200ktCO_2e to the total emissions, accounting for 47% of the overall emissions. In total roughly 45,000 domestic buildings are present in Monmouthshire, including 6,800 terraced houses, 13,000 semi-detached, 19,000 detached and 5,000 flats. Unoccupied buildings in Monmouthshire account for 6% of the total stock, this is slightly below the Welsh average of 7%.

In 2023, properties here exhibited above average levels of insulation, influencing their overall energy performance. These distinctions are shown in the EPC ratings[T07], with 48% of properties achieving A-C ratings, above the Welsh average of 40%. Approximately, 75% of Monmouthshire's domestic properties are connected to the gas grid, below the Welsh average of 82%. The remaining 25% are off-gas, with approximately 16% of properties using oil/LPG.

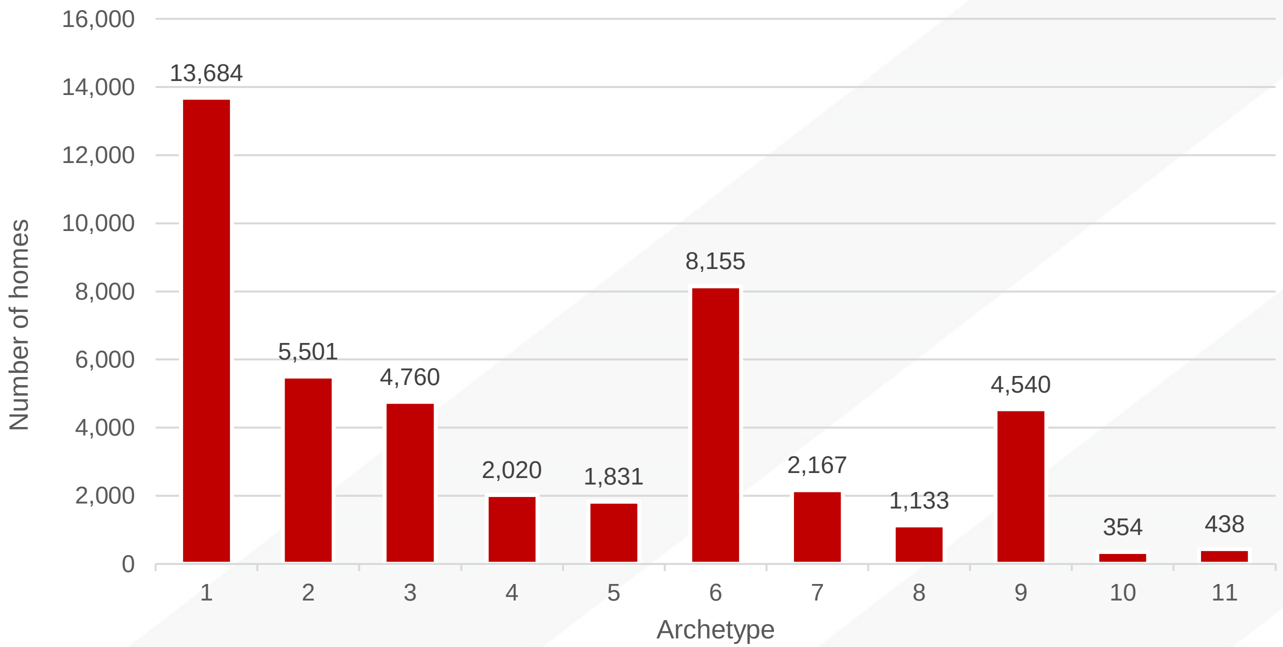

Figure 2.2.6: Summary of domestic properties by archetype

No.	Description
1	Detached - after 1930 - medium/high efficiency
2	Detached - low efficiency
3	Terrace - medium efficiency
4	Terrace - before 1930 - low efficiency
5	Semi-detached - after 1930 - low efficiency
6	Semi-detached - after 1930 - high efficiency
7	Semi-detached - before 1930 - low efficiency
8	Semi-detached - before 1930 - high efficiency
9	Flat - high efficiency
10	Top floor flat - low efficiency
11	Bottom floor flat - low efficiency

Table 2.2.1: Summary of archetypes (domestic)

2. The current local energy system

Analysis – buildings energy demand – non-domestic

In 2023, there were around 3,900 non-domestic properties in Monmouthshire, with offices and retail being the predominant business types, accounting for 24% and 23% of non-domestic buildings respectively. Other prominent archetypes included warehouses (319), hotels (274) and restaurants (274).

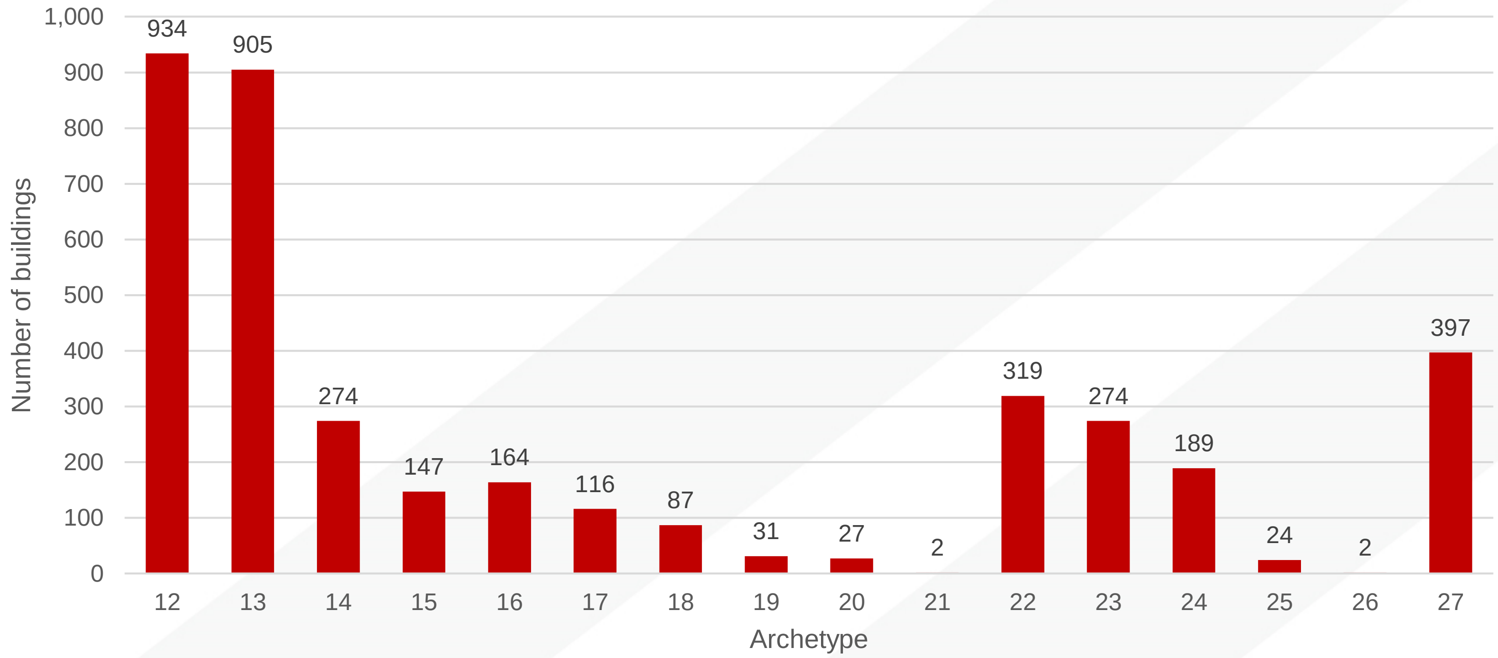

Figure 2.2.7: Distribution of non-domestic properties by archetype

No.	Description
12	Office
13	Retail
14	Hotel/Hostel
15	Leisure/Sports Facility
16	Schools, nurseries And Seasonal Public Buildings
17	Museums/Gallery/Library/Theatre/ Hall
18	Health Centre/Clinic
19	Care Home
20	Emergency Services, Local Gov Services, Law, Military
21	Hospital
22	Warehouse
23	Restaurant/Bar/Café
24	Religious building
25	Transport Hub/Station
26	University Campus
27	Other non-domestic

Table 2.2.2: Summary of archetypes (non-domestic)

2. The current local energy system

Analysis – monthly buildings energy demand profile

Demand for different sources of energy varies month-by-month and this can influence how we design a net zero local energy system to meet demand. Figure 2.2.8 presents a breakdown of electricity and heat demand in Monmouthshire by month, for the year 2023. Whilst electricity demand remains consistent throughout the year, the demand for heating fluctuates, showing a notable increase during the colder months (November – March). As temperatures drop, the need for heating within buildings increases.

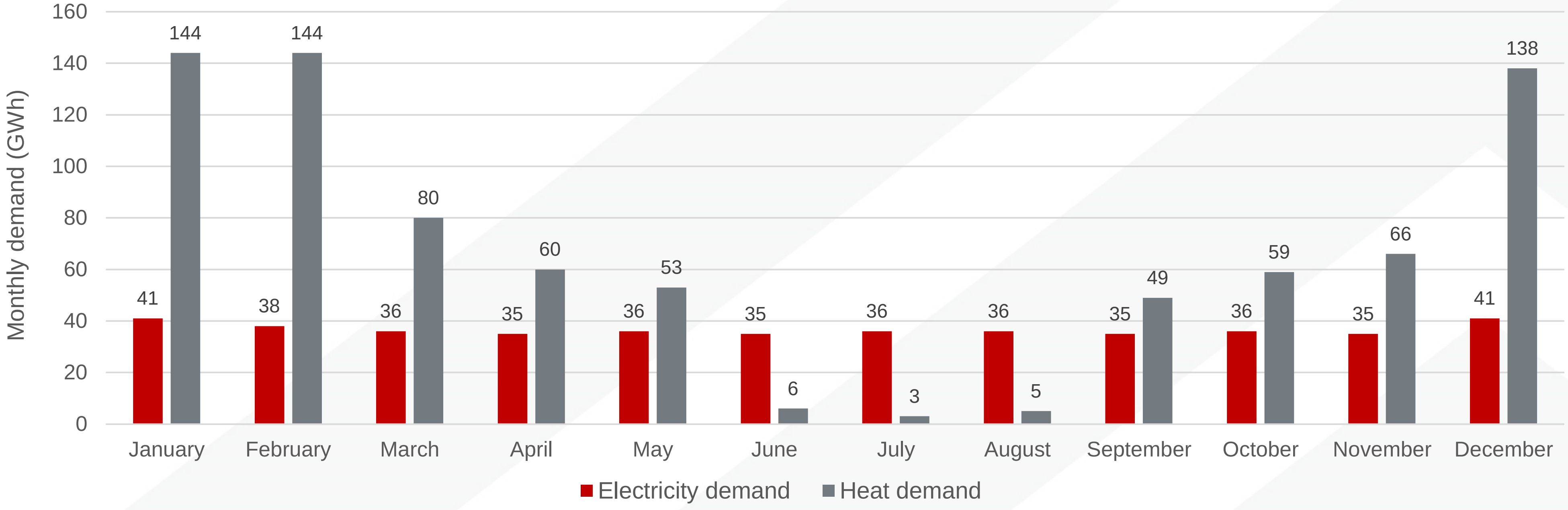

Figure 2.2.8: Monthly buildings energy profile for Monmouthshire (2023)

2. The current local energy system

Analysis – buildings energy demand (domestic and non-domestic)

Primary substation service areas covering urban settlement areas like Abergavenny and Monmouth are recorded to have higher electricity and gas consumptions, as indicated in Figures 2.2.9 and 2.2.10. This is likely due to the higher concentration of buildings in urban towns and cities. These areas tend to have increased energy needs driven by factors such as greater demands for heating and cooling, higher appliance usage, and more extensive infrastructure networks.

BAE Systems was identified by the NAEI as a large industrial site in Monmouthshire, with an estimated fossil fuel consumption of 12 GWh. This facility in Glascoed manufactures defence, aerospace and security solutions. A more detailed description of Monmouthshire's industrial landscape is provided on page 49.

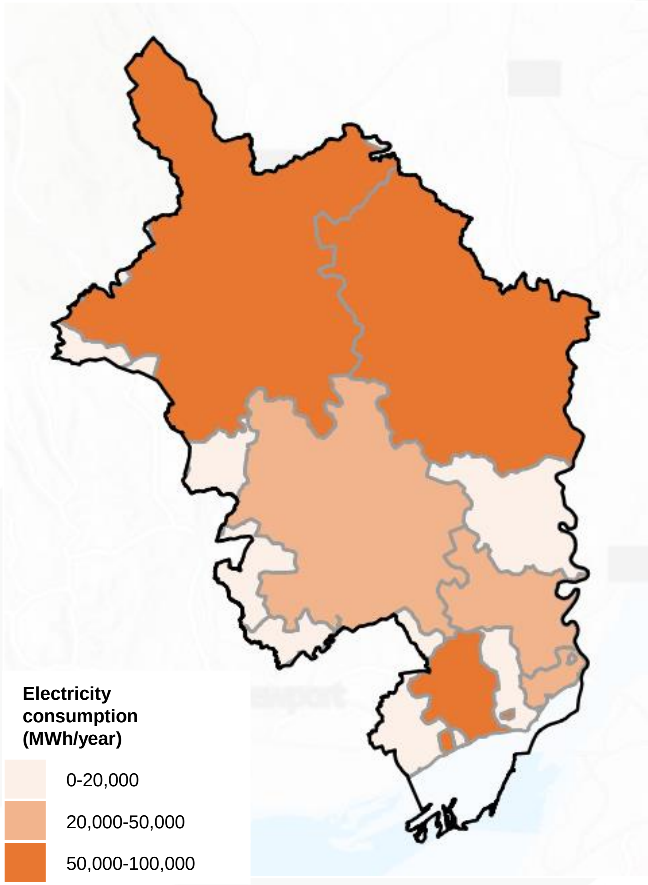

Figure 2.2.9: Electricity consumption (MWh/year) (domestic and non-domestic properties) by substation zone across Monmouthshire (2023)[T07]. Data is based on meter level electricity consumption data

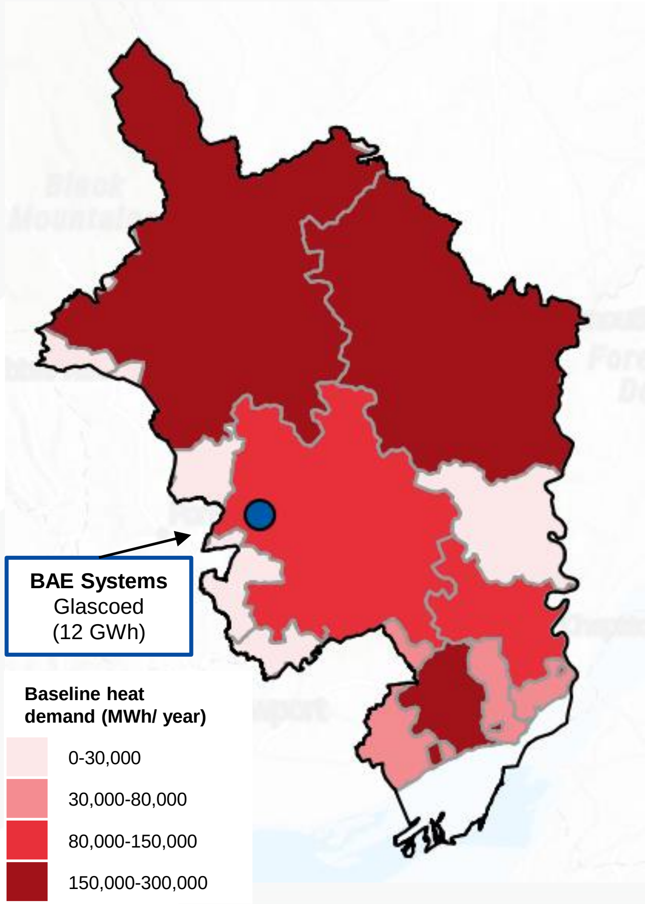

Figure 2.2.10: Major industrial loads (2019) and heat demand (2023) by substation zone across Monmouthshire. The data is based on meter level gas consumption (MWh/year)

2. The current local energy system

Analysis – buildings energy efficiency

Figure 2.2.11 shows poor energy efficiency of domestic buildings in the northern and eastern regions of Monmouthshire, and in areas surrounding Abergavenny. Poor energy efficiency can be linked to factors such as older building stock, socioeconomic constraints and limited access to government incentives and awareness programmes.

The majority (62%, 19,516 properties) of homes in Monmouthshire had an EPC rating of D and below. England and Wales's average EPC rating in 2019 is a band D.

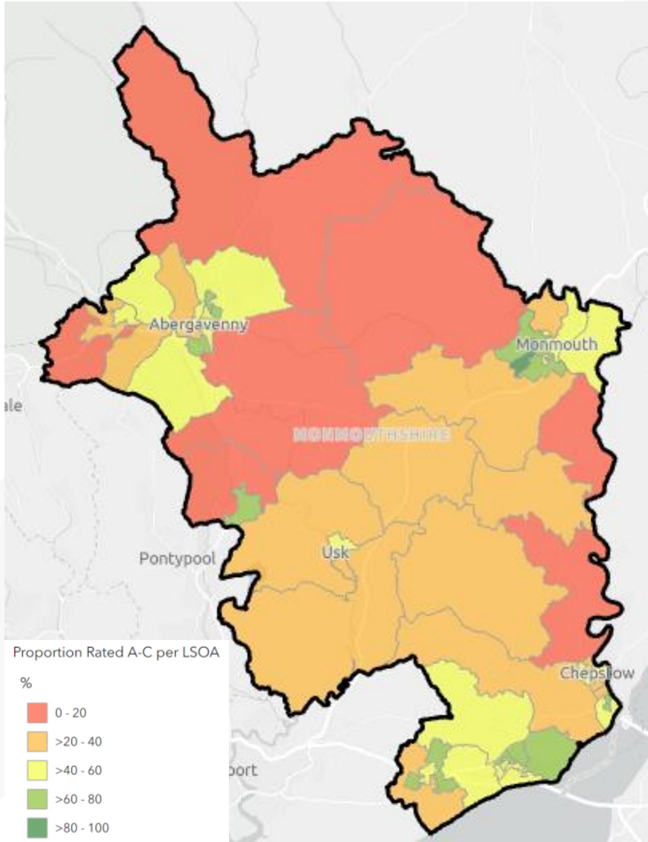

Figure 2.2.11: Energy efficiency of domestic properties across Monmouthshire by LSOA, rated EPC A-C (2023)

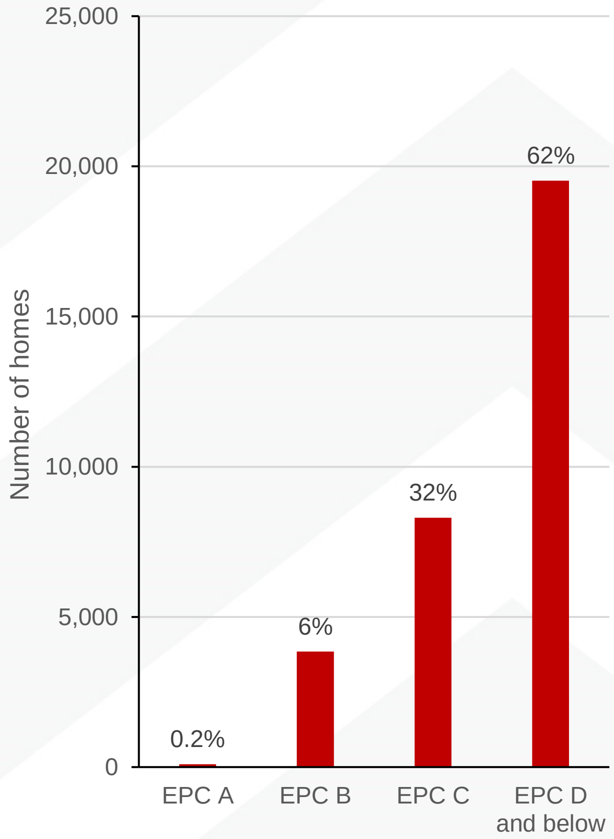

Figure 2.2.12: Proportion of domestic homes by EPC rating in Monmouthshire (2023)

2. The current local energy system

Analysis – transport energy demand

In 2023, road vehicles in Monmouthshire contributed 230ktCO_2e to the total emissions, accounting for 52% of the overall emissions. The primary sources of these emissions stem from cars, highlighting the need for sustainable transportation solutions.

Monmouthshire's transport landscape, influenced by its predominantly rural nature, varies significantly. Rural areas like Usk and Raglan see a reliance on private vehicles due to limited public transport options, longer travel distances to essential services, and the practical necessity of cars.

Cars were the main source of transport emissions accounting for 78% and 713ktCO_2e. HGVs accounted for 4% of emissions and 33ktCO_2e, despite only accounting for 3.7% of mileage due to their higher emissions intensity [T11].

In Monmouthshire, 0.41% of vehicles are electric or hybrid, surpassing the Wales-wide average of 0.26%. Monmouthshire displays a distinctive pattern of car ownership when compared to the national average. 85% of households in the area own cars, with an average of 1.4 cars per household, which is above the national average of 1.2.

To support the growing EV fleet, Monmouthshire County Council has invested in EV charging infrastructure. According the National Chargepoint Registry[T15], there were 42 EV charge points in Monmouthshire in May 2023. These points are distributed in areas with high EV concentration and along major transportation routes to facilitate convenient charging for residents and visitors.

Monmouthshire County Council is planning to invest further in enhancing public transport infrastructure. Examples of projects include improving T7 Express bus service and assessing potential new station locations. Schemes such as these aim to offer residents efficient and sustainable commuting alternatives, reducing reliance on private vehicles. The Council is also working with the Burns Delivery Unit to support them in delivering a new Walkway Station in Magor.

The Local Transport Strategy contains Monmouthshire County Council's actions that aim to improve public transport and enhance active travel. A Regional Transport Plan is also being developed by the CCR with support from Monmouthshire County Council.

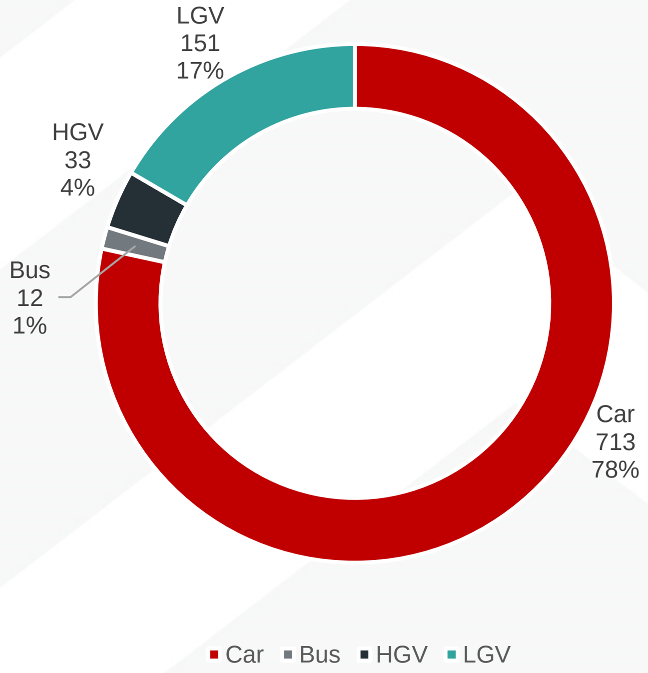

Figure 2.2.13: Total mileage (million miles / year) by vehicle type (2015)

monmouthshire
sir fynwy

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Welsh Government

Delivery partners:

ARUP

CARBON TRUST

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2. The current local energy system

Analysis – transport energy demand

Consumption is highest in the northern region and in the LSOAs surrounding Usk. In rural areas, high fossil fuel consumption can often stem from a widespread distribution of amenities, which means people must travel longer travel distances. Additionally, limited public transport options means there is a greater dependence on private vehicles.

Figure 2.2.14 spatially displays the locations of chargepoints installed in 2023. From the maps, it is evident there are clusters of chargepoints installed in urban areas or in close proximity to arterial roads.

It is important to note that the chargepoints shown are from 2023 extract of the National Chargepoint Registry (NCR)[T15] and do not include private installations, leading to an underestimation of the total number in Monmouthshire.

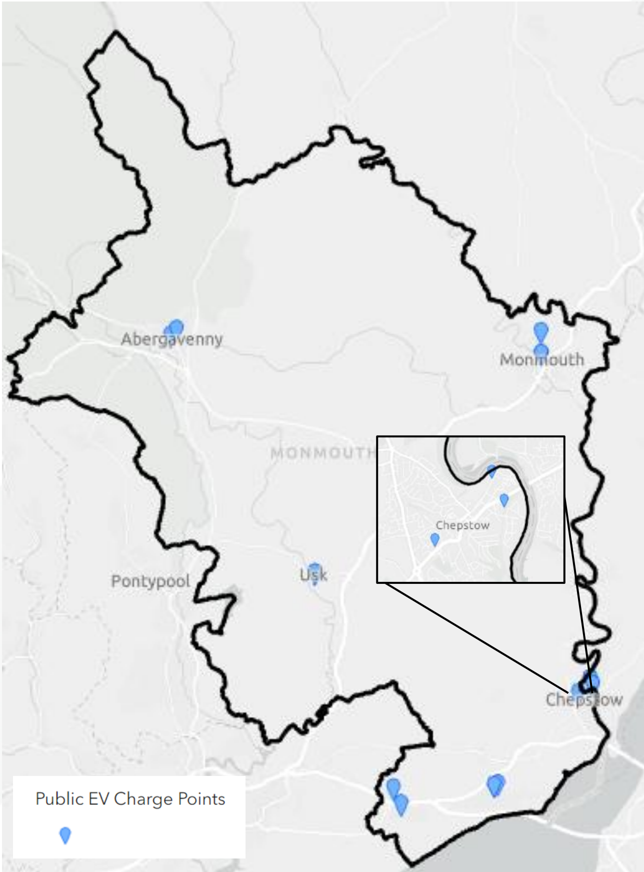


Figure 2.2.14: Public EV chargepoints registered on the National Chargepoint Registry[T15] across Monmouthshire (2023)

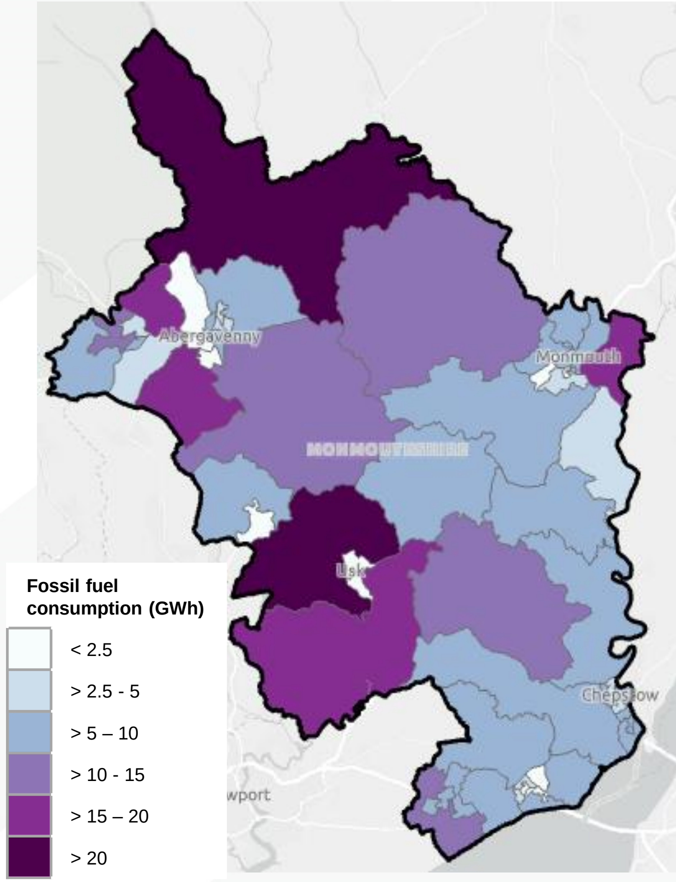


Figure 2.2.15: Transport energy consumption (combined total across cars, light goods vehicles (LGV) and heavy goods vehicles (HGV) by LSOA (2023)

2. The current local energy system

Analysis – industrial energy demand

The industrial landscape in Monmouthshire is a pivotal component of its economic framework, encompassing a diverse range of sectors and activities.

Emissions from industrial activities contribute to Monmouthshire's carbon footprint, totalling 2.2tCO_2e[T49]. Further detailed analysis and data on emissions from industries is integral to understanding the environmental impact and sustainability challenges posed by this sector.

Monmouthshire hosts a diverse array of industries that play a fundamental role in its economic vitality. The nature of industrial sites in Monmouthshire varies, with a mix of fragmented sites and industrial clusters.

Across Monmouthshire, several key industrial sites serve as economic anchors and employment hubs. These sites are strategically located and encompass various sectors, including brewing, agriculture and manufacturing. Highlighting these industrial centres provides insight into their significance in driving local economic growth and job opportunities.

The Magor Brewery was identified in the NAEI as large point source emitter, which suggests that it is a significant industrial site. Located in Caldicot, the brewery offers an opportunity for decarbonisation, both at the site and across Monmouthshire. Budweiser Brewing Group, operators of the Magor Brewery, has developed a proposal alongside Protium to deploy a zero emission Hydrogen Production Facility, powered by renewable energy generation[TL05]. This system will not only power the brewery's production but also provide zero carbon energy for essential logistics assets. Furthermore, any excess hydrogen generated at this facility could serve as a fuel for public HGV consumption (e.g. buses), thereby advancing both the brewery's and the wider Monmouthshire region's progress towards carbon neutrality. For the LAEP, the brewery was considered a national asset and excluded from the modelling.

BAE Systems is a global company that offers defence, aerospace, and security solutions. It operates a facility in Glascoed, supplying defence stocks to the UK Ministry of Defence. Whilst no site-specific decarbonisation plans have been published, BAE Systems does share information about its company-wide sustainability targets, aiming for a 90% reduction in greenhouse gas emissions by 2050[TL06].

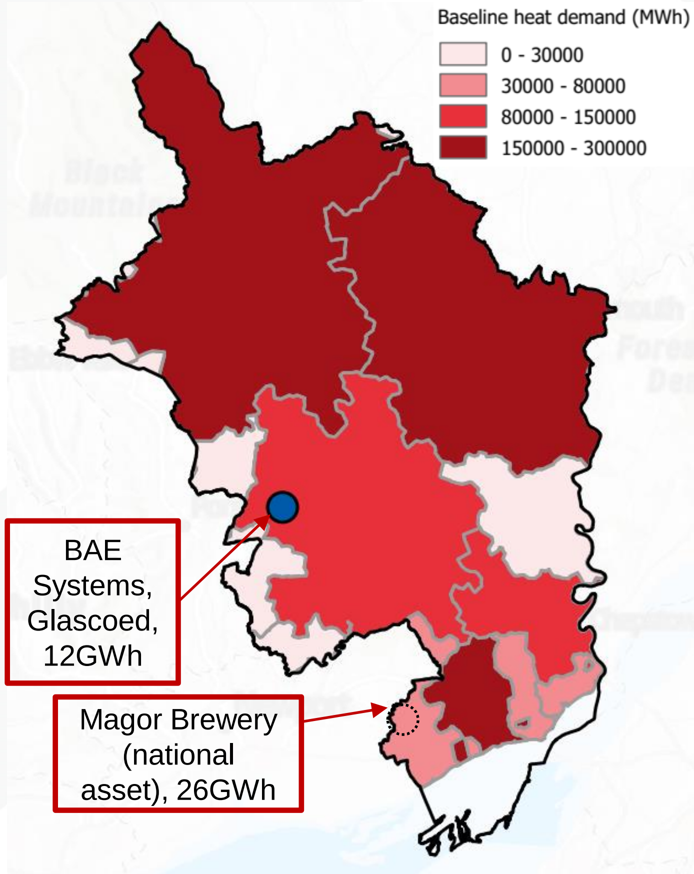


Figure 2.2.16: Major industrial loads (2019) and gas consumption (2023) by substation zone across Monmouthshire. The data is based on meter level gas consumption (MWh/year)

2. The current local energy system

Analysis – electricity generation in 2023

In 2023, Monmouthshire had a renewable electricity generation capacity of 47 MW. These generators play an important role in meeting the energy demands of the region's residents, businesses, and industries. Assets over 100 MW are not in scope of this LAEP because these are considered national assets.

Solar power plays a vital role in the local energy mix. The total installed capacity of solar PV in Monmouthshire is 40 MW, with the majority (39 MW) being attributed to six ground-mounted solar farms. Unlocking the full potential for increased solar output in Monmouthshire is proving a challenge. Government guidance to protect agricultural land from development, combined with grid constraints and considering public acceptance, make securing planning permissions for solar development a complex and demanding process.

Monmouthshire has various other types of renewable generators, including wind, hydroelectric and anaerobic digestion. These sources further diversify the energy mix, ensuring reliability and sustainability.

In addition to these renewable sources of generation, Monmouthshire has a gas generation site located in Monmouth, with an installed capacity of 3.2 MW.

While Monmouthshire is a significant contributor to its electricity needs through local generation, it also imports a portion of its electricity to meet the overall demand, totalling 395 GWh in 2023. This importation ensures a reliable and continuous supply of power.

See overleaf for a map of existing electricity generation in Monmouthshire

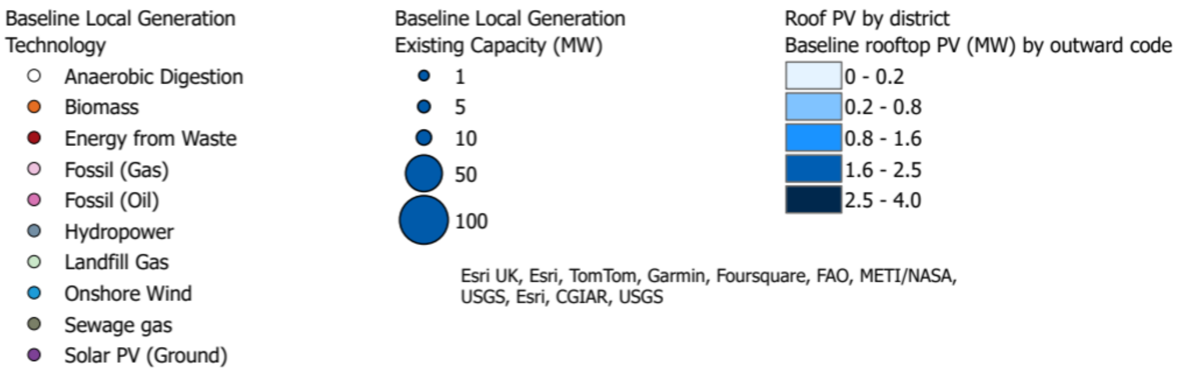
Figure 2.2.17: Example of renewable energy generation – ground mounted solar PV

2. The current local energy system

Analysis – energy generation in 2023

Rooftop solar PV

As of 2023, the total rooftop solar PV capacity across Monmouthshire was 17 MW, roughly equivalent to 7% of homes. This estimate is based on the assumption that there are 45,000 homes in Monmouthshire and that the average rooftop solar PV system is 4 kWp.



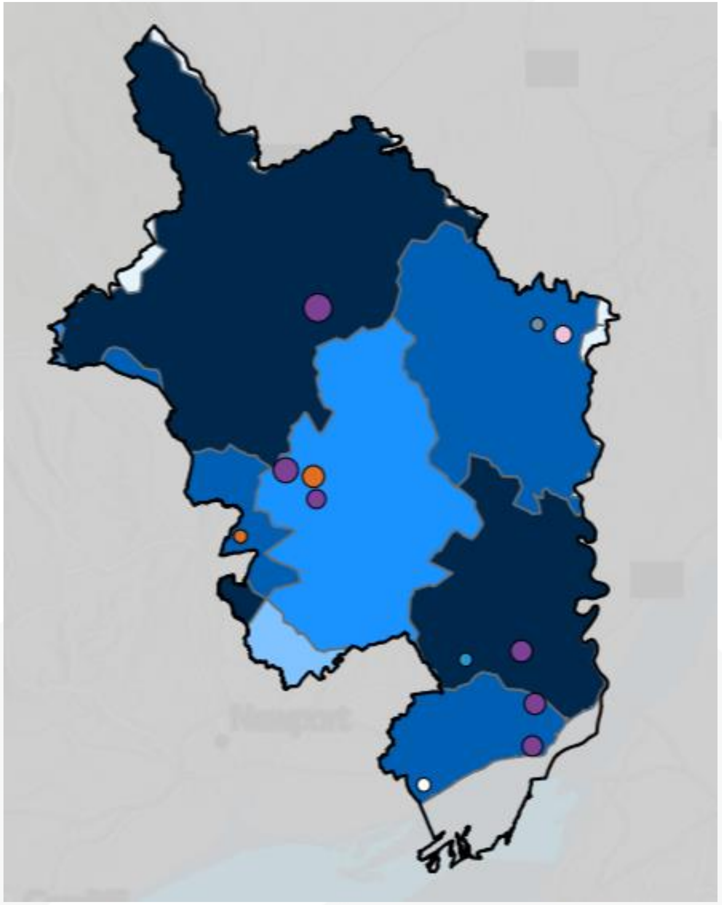


Figure 2.2.18: Local energy generators and their respective capacities (MW) and domestic and non-domestic rooftop solar PV (MW) by outward code (2023)

2. The current local energy system

Monmouthshire's energy baseline

Networks and infrastructure

Figures 2.2.19 and 2.2.20 display primary substation supply and demand headroom across Monmouthshire, providing an insight to the network capacity in 2023. This metric offers an overview of the electricity network's capacity, highlighting areas where constraints may be present.

In 2023, substation demand headroom was lower in Monmouthshire's main settlements, such Abergavenny, Monmouth and Chepstow. The higher concentration of buildings in these urban areas leads to an increased demand for electricity, which in turn could result in reduced substation capacity.

Headroom provides insights into the distribution networks (11 kV) capacity however, constraints can occur upstream (at transmission network level) and downstream (at lower voltage network level) of primary substations. It is therefore important to note that Figures 2.2.19 and 2.2.20 may not show the full extent of Monmouthshire's electricity network constraints.

Note: Headroom is an indicative measure of a primary substation's capacity. In more general terms, it's the ability of that substation to handle the total flow of electricity through it.

Generation headroom

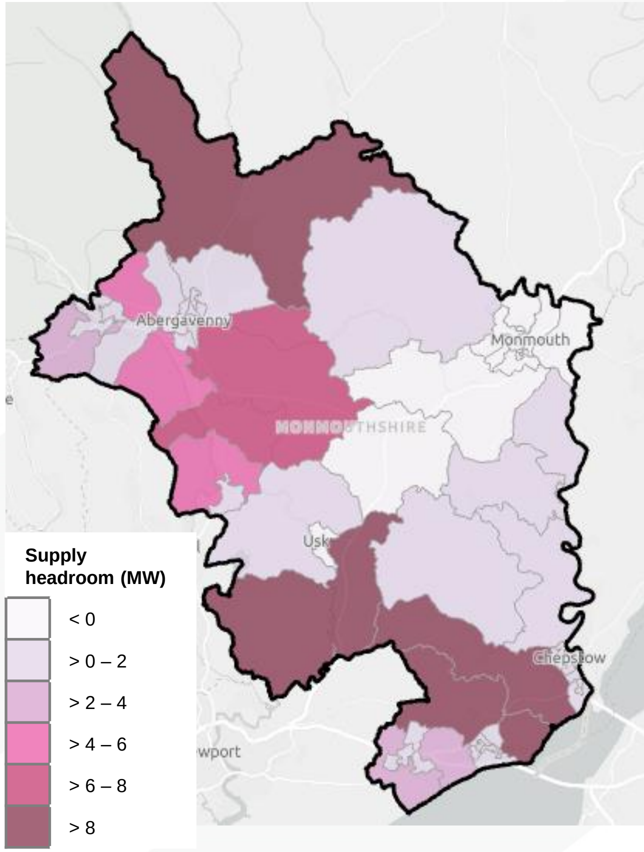


Figure 2.2.19: Electricity generation headroom by LSOA

Demand headroom

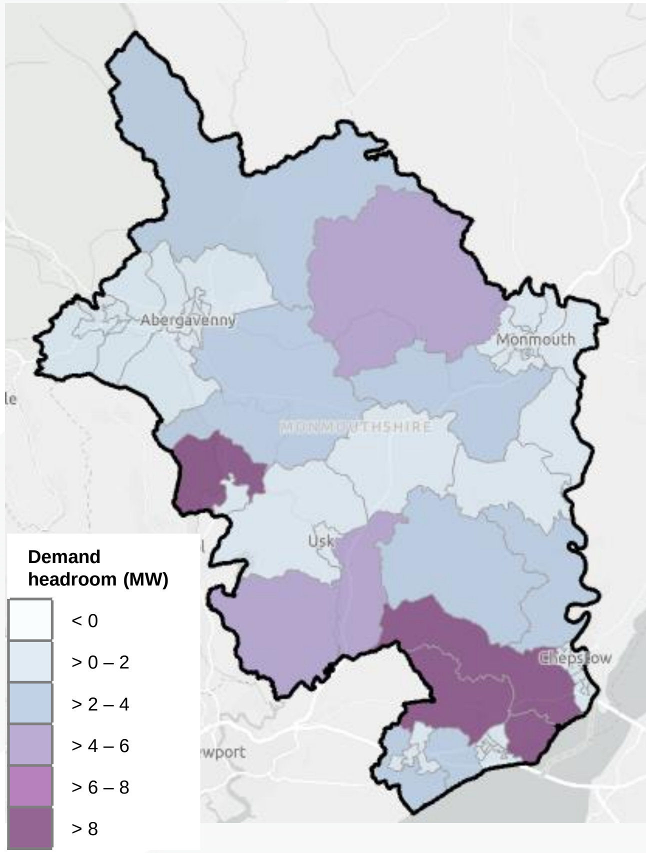


Figure 2.2.20: Electricity demand headroom by LSOA

3. The current local energy system

Analysis – off-gas grid buildings (domestic only) shows extent of gas distribution network

In Monmouthshire, 25% of properties are not connected to the gas network, with 63% of off-gas homes using oil or liquified petroleum gas for heating. Figure 2.2.21 shows that central and eastern regions of Monmouthshire have a higher percentage (60-80%) of off-gas properties. Notably, oil is the primary off-gas heating fuel used in these areas, as shown in Figure 2.2.22.

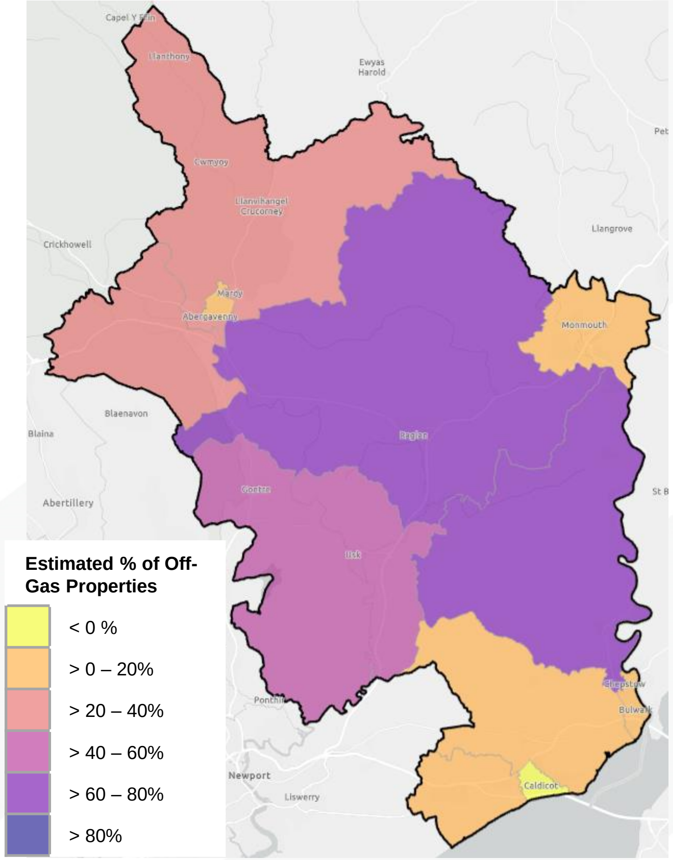


Figure 2.2.21: % of properties that are not connected to the gas distribution network across Monmouthshire (2023) by MSOA

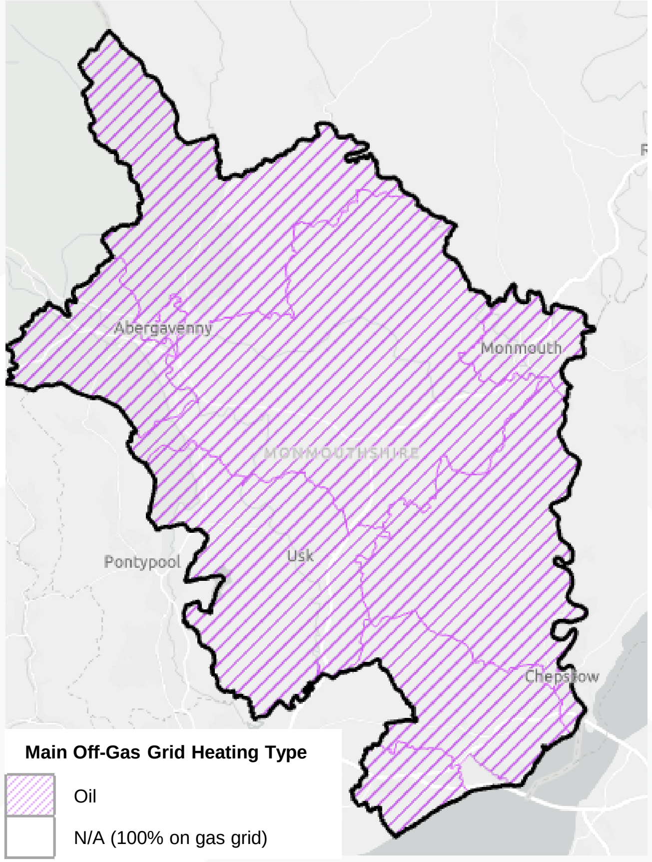


Figure 2.2.22: Main heating type of domestic buildings that are not connected to the gas distribution network across Monmouthshire (2023) by MSOA

Monmouthshire LAEP – Technical Report

3. The future local energy system (stage 4-5)

3. The future local energy system

Methodology overview

This section is structured as follows:

Scenario analysis

This section presents an overview of the future energy scenarios chosen and how they were agreed with stakeholders. It describes our scenario modelling methodology, including data sources and assumptions and the criteria used to optimise each future energy scenario. We then discuss the key findings from scenario analysis in more detail, exploring the energy system components that constitute each proposed future energy system and what similarities and differences there are between scenarios, and the impact this has on network infrastructure requirements and energy needs.

Deployment modelling

Scenario analysis highlighted energy system components that played a role in all future energy scenarios and could therefore be defined as "low-regret energy system components to focus on for deployment. We created a deployment model to understand the deployment profiles for these components, accounting for broader local and regional strategic objectives and national targets that had been discussed in stakeholder workshops. The outputs helped define the scale of change required to achieve net zero energy system, and to set a level of ambition from which the action plan could be based.

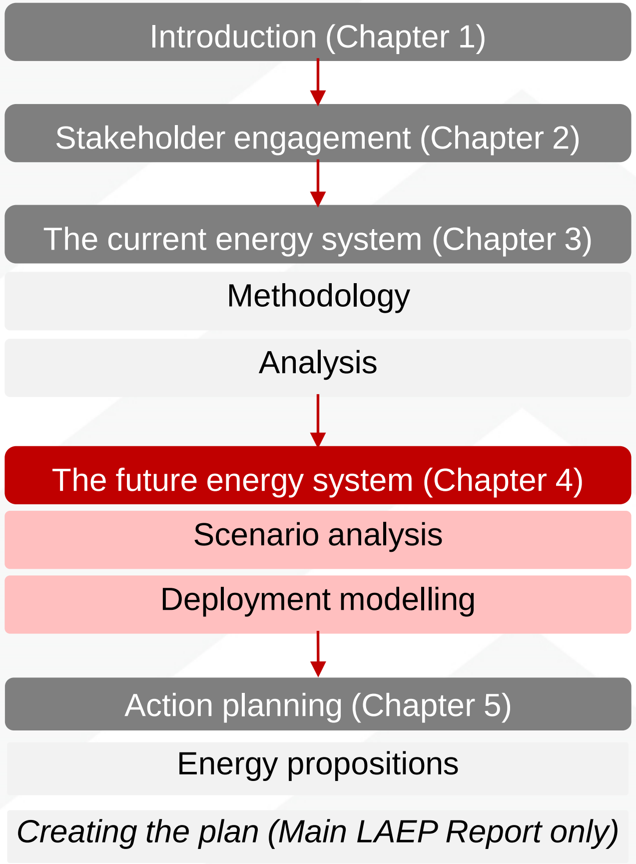


Figure 3.0.1: Flow diagram showing the chapters and sub-chapters in this report (the chapter that follows is highlighted in red)

Monmouthshire LAEP – Technical Report

3. The future local energy system (stage 4-5)

Methodology

3. The future local energy system

Scenario analysis

Methodology - overview

The process of creating scenarios involves considering different versions of possible futures. Some of these may seem unlikely or even surprising, yet they could still be possible. Other scenarios explore the possible outcomes of choices the world already appears to be making. By exploring multiple scenarios, we can reveal patterns in supply trends, energy sources and renewable technologies that play a part in multiple energy futures and use this to inform the Monmouthshire's investment decisions and prioritisation when planning for the energy transition.

What is the purpose of scenario analysis?

Scenario analysis is used to explore how different assumptions about the future can impact how a particular desired outcome is achieved. The future for Monmouthshire's local energy system consists of many different dependencies, making it challenging to predict how it might look in the future. Therefore, we used scenarios to explore how different potential energy futures might influence how a net zero local energy system is achieved. It's important to note that at this stage of LAEP we are not trying to define a preferred future energy system but evaluating a range of potential future energy systems. This identifies certain technologies or demand reduction interventions that are prevalent in multiple energy futures, and those that only appear in one or two, helping us to determine the uncertainty and risk associated with deploying certain technologies or interventions to make informed decisions on a suitable, credible approach to achieving a net zero energy system.

This analysis was presented to stakeholders to support a decision about what ***energy propositions*** Monmouthshire might focus on as "low-regret, near-term energy propositions" and those that have a higher risk and uncertainty associated with them based on the modelling results. This information was then taken forward for further consideration alongside broader plan objectives and local and regional strategic priorities to inform Monmouthshire's routemap and Action Plan.

As part of this analysis, we also tested different sensitivities to understand the impact of uncertainty and certain modelling parameters on the scenario outcomes. The findings are reported in the following section.

What future energy scenarios were chosen?

Using the outcomes of Workshop 2 (Strategic options and priorities workshop), future energy scenarios and their associated assumptions were agreed with the primary stakeholders, CCR representatives and the LAEP technical advisor. To allow for the comparison of results at the national and regional levels, two of the five scenarios were chosen to be tested across all Welsh Local Authorities, and two scenarios were chosen to be tested in all Local Authorities within the region. See Figure 3.1.1 overleaf for a description of each scenario and its scope. The final scenario was agreed by Monmouthshire County Council and was informed by Monmouthshire County Council's existing principles, strategic objectives and energy priorities.

3. The future local energy system

Scenario analysis

Methodology - overview

National	Do nothing	• A scenario for comparison which considers committed activities, and assumes that current and consulted upon policy goes forward and remains consistent. • This scenario provides a cost counterfactual. • There is no decarbonisation target for this scenario, and we do not use it in optimisation modelling.
National	National net zero	• Uses the lowest cost and carbon combination of technologies to meet Wales' 2050 net zero target. • Assumes a moderate level of energy demand reduction across the system. • Model is allowed to import and export to the electricity grid, this assumes that the electricity grid is decarbonised and reinforced to allow for the demands, likely to be a combination of offshore wind, hydrogen CCGT, grid level battery storage, nuclear (these are considered as national assets and outside the scope of the LAEP).
Regional	Low demand	• Considers the lowest future energy demand across different sectors. • Explores the impact of energy-reducing initiatives (home fabric improvements) and uptake of active travel and public transport use. • Model finds the lowest cost and carbon combination of technologies to meet predicted future energy demand. • Import and export of electricity as National Net Zero
Regional	High demand	• Considers the highest future energy demand across sectors. • Model finds the lowest cost and carbon combination of technologies to meet predicted future energy demand. • Import and export of electricity as National Net Zero
Local	High Hydrogen	• Considers the lowest plausible future energy demand across different sectors. • Explores impact of energy-reducing initiatives such as home fabric improvements and uptake of active travel and public transport use. • Considers hydrogen for heavy goods vehicles.

Figure 3.1.1: Summary of future energy scenarios

3. The future local energy system

Scenario analysis

Methodology – modelling parameters

We developed a set of modelling parameters that describe certain characteristics of the future local energy system and how different factors could affect it in the future in each scenario. We set parameters for:

Technologies considered: we identified a list of viable technologies for the model to consider in the optimised future energy scenarios. These technologies were reviewed by primary stakeholders to ensure that they accurately reflected technologies the local area were likely to consider in the future based on the political context. For each technology, we collected key information defining costs, deployment and relationships with other technologies.

Capital and operational costs: we considered costs associated with capital and the operation of the asset over its lifetime as the main parameter for the model to optimise.

Emission factors: emissions factors associated with the operation of the asset over its lifetime were given a weighted cost and considered as part of the optimisation.

We translated the assumptions associated with each future energy scenario into Calliope[T30], an open-source, linear programming tool which was used to solve for the most cost- and carbon-effective future energy system in each scenario.

The methodology used to define these parameters is described in the following section.

Future energy demand profiles: we estimated future energy demand profiles by applying the assumptions made about how energy demand for different energy resources might change in each scenario. See the following pages for more details.

Maximum and minimum capacities for renewable technologies: we used maximum theoretical capacities to make sure the optimisation of supply reflected real-world constraints such as available land. Where there was a project pipeline and/or installed capacity, these were assumed to be built as a minimum capacity.

Geographic boundary: the geographic boundary specified what future energy demand should be included in any given future energy scenario. With each substation being used as the locational points for the model to solve.

Time: we modelled the future local energy system by building an annual profile divided into 8,760 hourly periods. We ran models using 1-hr, 3-hr or 24-hr time periods, to better understand the sensitivities of the results on the time resolution chosen. Where the model was large (i.e. has a lot of substations), we could not always run an hourly model, but over the 150 model runs undertaken on this project we are confident of the impact of the timestep on the model outputs. The model runs presented in this report are 3 hour runs.

3. The future local energy system

Scenario analysis

Methodology – optimisation modelling

Once the modelling parameters had been set, we then used the Calliope model to optimise the future supply profiles using the "objective functions" of cost and carbon emissions. This instructs the Calliope model to search for the future supply profile that minimises cost and carbon emissions across the hypothetical year of supply and consumption in 2050 for each scenario. The results give the scale of each of the technologies that are chosen in the most cost and carbon effective potential future.

We reviewed the scenarios alongside primary stakeholders, and, in some cases, the assumptions were updated based on local preferences. The main adjustments requested were to the maximum theoretical capacities for renewable energy generation, which is discussed in more detail in later sections.

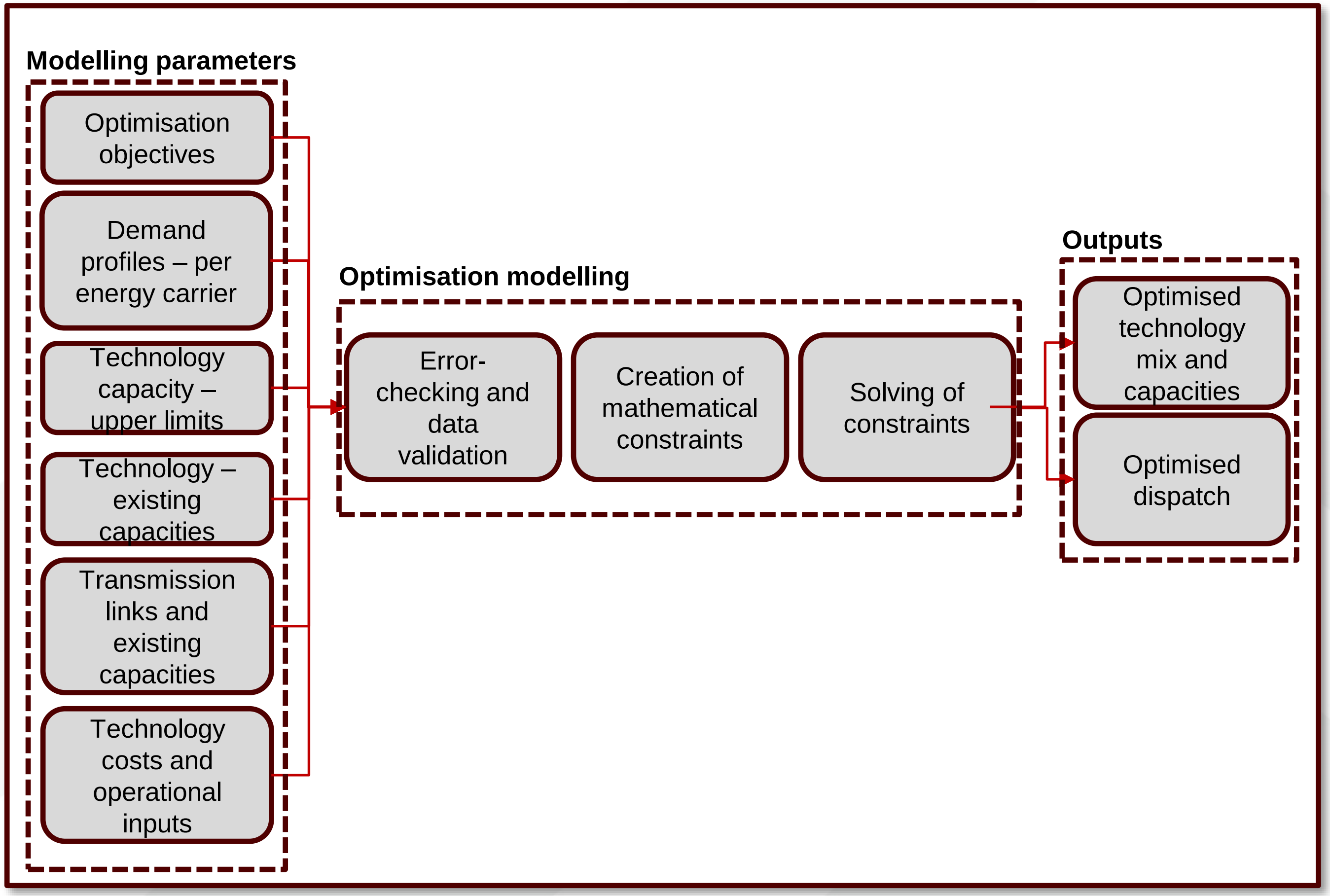


Figure 3.1.2: Optimisation modelling input data and desired outputs

3. The future local energy system

Scenario analysis

Methodology - technologies considered

The scope of technologies included in the energy system model are broadly categorised as supply, demand, conversion, transmission, storage.

Figure 3.1.3 overleaf shows the technologies and carriers (energy vectors) that were modelled for Monmouthshire's LAEP.

For each technology we collected key information defining costs, deployment and relationships with other technologies. The key parameters collected are summarised in Table 3.1.1. Alongside the baseline information collated on demands, existing energy assets and potential renewable locations and capacities, this information was loaded into a database. Automated python scripting was used to handle this data and transform it into formatted model inputs in preparation for running the model. This approach ensuring efficiency and consistency, and minimised opportunities for manual errors.

There are challenges to projecting out many of the technological data parameters, and some will carry greater confidence than others. Novel technologies, for example, might have a wider spread of potential costs in 2050 depending on the source consulted. For quality assurance purposes, sources of costs and details of any data transformations taken to normalise all units were stored alongside their values in the database.

Technology data parameters
Technology costs • Capex (£/kW capacity) • Opex (£/kWh output)
Technology emissions • Operational carbon emissions (tCO_2e/kWh)
Technology fundamental parameters • Efficiencies where applicable (%) • Technology lifetime (years)
Technology constraints • Maximum theoretical renewable energy technology capacity, where applicable (kW) • Minimum renewable energy technology capacity, from baseline assessment (kW) • Minimum connection capacities between modes for transmission technologies

Table 3.1.1: Technology parameters

3. The future local energy system

Scenario analysis

Methodology - technologies considered

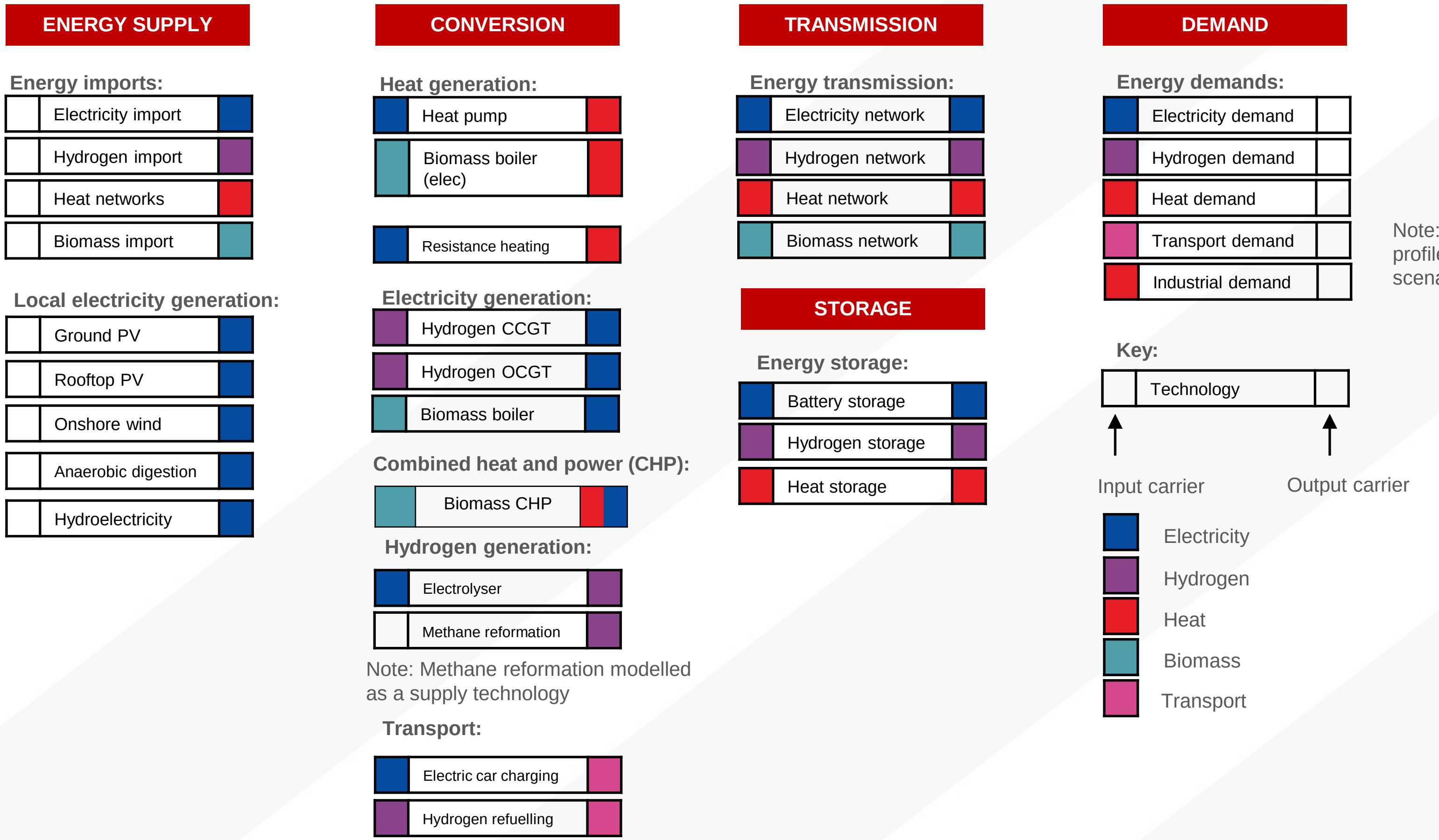


Figure 3.1.3: Technologies included in optimisation modelling

3. The future local energy system

Scenario analysis

Methodology - future energy demand for buildings

We produced two scenarios for the buildings sector – high and low demand. The high demand scenario represents the most cost-optimal route to upgrade all buildings to the insulation associated with the current EPC C rating. Similarly, the low demand scenario represents a high-cost route to upgrade all buildings to the insulation associated with the current EPC A rating. The national net zero scenario aligns with the more pragmatic high demand scenario. The local scenario also matches the high/low demand scenario.

To produce the scenarios, we chose packages of retrofit measures for each of the 27 archetypes in each scenario. The retrofits are summarised in Table 3.1.2 for domestic buildings and in Table 3.1.3 (overleaf) for non-domestic buildings (see Appendix B3 for more detail). Electricity and heat profiles, generated at the archetype level, were reduced in line with RdSAP-modelled changes to building thermal properties and aggregated to substation areas.

The rate of installations in the near-term considers the targets and initiatives of the Welsh authorities, as well as the major housing associations operating across Wales.

		High building demand	Low building demand
	Scenario application	**National Net Zero, High Demand and High Hydrogen scenarios**	**Low Demand**
DOMESTIC	**Electricity demand**	No change from baseline	5% reduction from smart appliances
DOMESTIC	**Heat demand**	Cost-optimal fabric measures applied to upgrade all buildings below EPC C with insulation measures associated with an EPC C-rated property. 12,000 retrofits to 2050	All buildings below EPC A upgraded to EPC A with insulation measures associated with an EPC A-rated property. 39,000 retrofits to 2050
DOMESTIC	**New development build rate**	LDP housing targets extrapolated to 2050. 28% increase in number of homes from 2023 to 2050	Average historic build rate applied to 2050. 15% increase in number of homes from 2023 to 2050
DOMESTIC	**New development energy efficiency**	2025 building regulation standard	Net Zero buildings with solar PV and battery storage
DOMESTIC	**Weather profile**	4 days with temperature profiles equivalent to the 'Beast from the East' (extreme weather event in 2018 with -7°C lowest temp)	2 days with Beast from the East (-7°C lowest temp) temperature profiles
DOMESTIC	**Interventions for retrofit considered**	Options dependent on archetype	**High demand interventions**, plus additional measures. See Appendix B3 for more details on measure applied Options dependent on archetype

Table 3.1.2: Assumptions for domestic buildings in each future energy scenario

3. The future local energy system

Scenario analysis

Methodology - future energy demand for buildings (continued)

To upgrade buildings to EPC C, the most cost-effective combination of measures was selected e.g., prioritising loft and cavity wall insulations.

For the domestic profiles, SAP modelling was consolidated with smart meter data in the network planner profiling tool developed by Hildebrand which improves the accuracy of profiles by factoring in diversity.

New developments were also added to the 2050 energy system by projecting housing and commercial growth in line with LDP targets for high demand, and historic rates of growth for the low demand scenario.

New domestic and commercial growth were spatially mapped based on the location of existing domestic and commercial properties. Large new developments (>500 homes) were mapped separately to their precise substations.

Limitations

The number of insulation retrofits required is based on the insulation in the current building stock. This method is limited by the coverage of EPC (approx. 60% of buildings) and the archetype approach of grouping similar buildings that may have slightly different levels of insulation.

EPC rating is correlated, but not representative of the efficiency of a building. Therefore, the number of properties receiving retrofit measures does not necessarily correspond to the number of properties below EPC A or EPC C.

The model limits non-domestic archetypes to one profile for each scenario. Energy density ranges is a limitation for all archetypes but particularly for non-domestic archetypes which can vary massively.

		High building demand	Low building demand
	Scenarios application	**National Net Zero, High Demand and High Hydrogen scenarios**	**Low Demand**
NON-DOMESTIC	**Electricity demand**	No change from baseline	5% reduction from smart appliances
	Heat demand	Cost-optimal fabric measures applied to upgrade all buildings with a rating of EPC C and below with insulation measures associated with EPC C-rated properties	All buildings below EPC A upgraded with insulation measures associated with EPC A-rated properties
	Employment site allocation	LDP employment land allocations/jobs projection (proxy) extrapolated to 2050. 65% increase in commercial floorspace from 2023 to 2050	LDP employment land allocations/jobs projection (proxy) extrapolated to 2050. 19% increase in commercial floorspace from 2023 to 2050
	Weather profile	4 days with temperature profiles equivalent to the 'Beast from the East' (extreme weather event in 2018 with -7°C lowest temp)	2 days with Beast from the East (-7°C lowest temp) temperature profiles
	Interventions for retrofit considered	**Same as domestic**, plus MEV/MVHR ventilation	**Same as domestic**, plus MEV/MVHR ventilation

Table 3.1.3: Assumptions for non-domestic buildings in each future energy scenario

3. The future local energy system

Scenario analysis

Methodology – future energy demand for transport

The methodology used here closely aligns with the baseline methodology. The key difference is that the output was a year-long hourly demand profile in kWh.

Like the baseline analysis, we used the South East Wales Transport Model (SEWTM)[TC12] to determine transport demand across Monmouthshire. These models provided the number of trips between two different transport zones (defined by TfW) on an average day. In this data, a trip is defined by the transport zone where a vehicle's journey starts and the transport zone where it ends; therefore vehicles which pass through a transport zone without stopping are not counted. We estimated the route distance to be 130% longer than the distance between each area's centre point. This 'route indirectness' factor was based on Arup work from a previous local area energy plan in Wales. We then scaled up that daily mileage value to an annual mileage value and geospatially mapped these values to substation zones.

To determine the proportion of vehicles that converted to either electric or hydrogen, we applied National Grid's Future Energy Scenarios (2022) - Leading the Way[T31] percentages to the baseline annual mileage figure. Refer to Table 3.1.4 for electric and hydrogen vehicle percentages per vehicle type.

Then, we applied growth factors for each vehicle type to the baseline annual mileage data obtained from the SEWTM to account for modal shifts. The selection of growth factors varied based on the specific scenario considered. Table 3.1.5 presents the growth factors applied to each scenario.

Finally, we applied a transport profile to the annual mileage figure, resulting in an hourly demand profile over the course of the year. This profile was then converted into an hourly demand in kWh using the miles per kWh values specific to different vehicle types.

Vehicle type	% Electric (mileage)	% Hydrogen (mileage)
Cars	100	0
Buses	85	15
Vans	100	0
Heavy Goods Vehicles (HGVs)	86	14

Table 3.1.4: Assumptions for vehicle fuel type in the High and Low Demand future energy scenarios

3. The future local energy system

Scenario analysis

Methodology – future energy demand for transport - continued

	High transport demand	Low transport demand	High hydrogen transport demand
Scenario application	High Demand scenario	National Net Zero and Low Demand scenarios	High Hydrogen scenario
Fuels of vehicles	National Grid's FES (2022) - Leading the Way	National Grid's FES (2022) - Leading the Way	National Grid's FES (2022) – System Transformation
Transport energy demand	Mileage for: Cars – 8% increase Buses – 5% decrease HGVs: 6% increase LGVs: 15% increase All the above changes are from National Grid's FES (2022) - Falling Short scenario.	Mileage for: Cars – 13% decrease from Llwybr Newydd adjusted by LA-specific car dependency factor. The car-dependency factor was developed to reflect that rural areas may achieve less than the nationwide target while urban areas may achieve more. Buses – Increases in proportion with the reduction in car journeys, scaled by the bus share of sustainable transport options and greater average bus occupancy compared to cars. HGVs - Increase by 6% (National FES)(2022) - Leading the Way) LGVs – Increase by 15% (National Grid's FES (2022) - Leading the Way)	Mileage for: Cars - <1% increase Buses - <1% decrease HGVs: 6% increase LGVs: 15% increase All the above changes are from National Grid's (FES) (2022) - System Transformation scenario.

Table 3.1.5: Assumptions for future transport energy demand in each future energy scenario

3. The future local energy system

Scenario analysis

Methodology– future energy demand profile for industry

The 2020 NAEI (National Atmospheric Emission Inventory) Point Sources dataset[T20] was used as the primary source. The sites within this dataset were subsequently categorised as using high-grade heat or low-grade heat processes.

For industries using high-grade heat processes, we identified their link to chemical processes. Where this data was accessible (through the RFI), we determined the proportion of emissions attributed to these chemical processes. These emissions were excluded from our calculations as they are deemed out of scope, and unavoidable.

In cases where quantifiable data for non-process operational emissions was made available, we assumed that all such emissions would transition from gas to electricity by 2050, while we assumed that operational emissions associated with processes would transition from gas to hydrogen by 2050 was assumed. In cases where quantifiable data for non-process operational emissions was not accessible, we assumed that operational processes accounted for the entirety of the site's emissions, resulting in a complete transition to hydrogen.

For industries using low-grade heat, the only variation in the methodology was the assumption that all operational emissions (process and non-process) would shift from gas to electricity, rather than hydrogen.

Accordingly, we calculated the expected consumption of kilowatt-hours (kWh) of electricity and hydrogen by each site in the year 2050, assuming no growth in emissions. Note that this reflects total fuel consumption, rather than heat or electricity demand at the site. Any efficiency improvements were offset by considerations related to growth. This annual value was converted into an hourly timeseries using Arup's industrial usage profiles.

Limitations

Companies that owned the industrial sites in Monmouthshire were sent an RFI, requesting the sites annual electricity and gas consumption and expected change in fuel consumption for 2050. This was not provided; therefore, these assumptions need verification with the owners.

3. The future local energy system

Scenario analysis

Methodology – maximum potential capacities for renewable generation

The maximum theoretical amount of renewable resource (onshore wind, ground-mounted PV, and rooftop PV) was included in the energy model as the sum of the baseline capacity (discussed previously in Section 2) and the 2050 renewable resource (discussed below) for each technology. However, with discussion with the stakeholders and council, this was decreased from 145.2km^2 to 33km^2 .

2050 renewable resource – onshore wind and ground-mounted PV

The maximum available resource was calculated using local authority-specific renewable and low carbon energy assessments (RLCEA) and/or local development plans (LDP). These areas are shown in Figure 3.1.4. A full breakdown of sources and associated shapefiles used during the mapping exercise is presented in the Appendix B5. Overlapping areas were calculated to ensure capacities were not double-counted.

Where insufficient data was available to estimate solar and wind resources, a Welsh-wide study completed by Arup in 2019[T47], which ultimately fed into the Future Wales: the national plan 2040 [T32], was used.

Following the mapping of available resource areas, wind and solar capacity factors (MW/area) were used to estimate available capacity (MW) at the local authority and substation-level.

2050 renewable resource – rooftop PV

Maximum available new resource for rooftop PV capacity was estimated using roof-area at the LA- and substation-level.

Pipeline projects

Pipeline projects were compiled using the REPD[T22] and ECR[TC24] datasets. Where relevant, Local Authority projects which have had planning permission granted (not necessarily an accepted grid connection) were included in the dataset.

We did not directly include the capacity of the pipeline projects in the energy modelling process, as the pipeline capacities did not influence either the minimum or maximum capacities allowed in the energy models. However, the pipeline projects were included in the deployment modelling process, discussed further in Section 2.

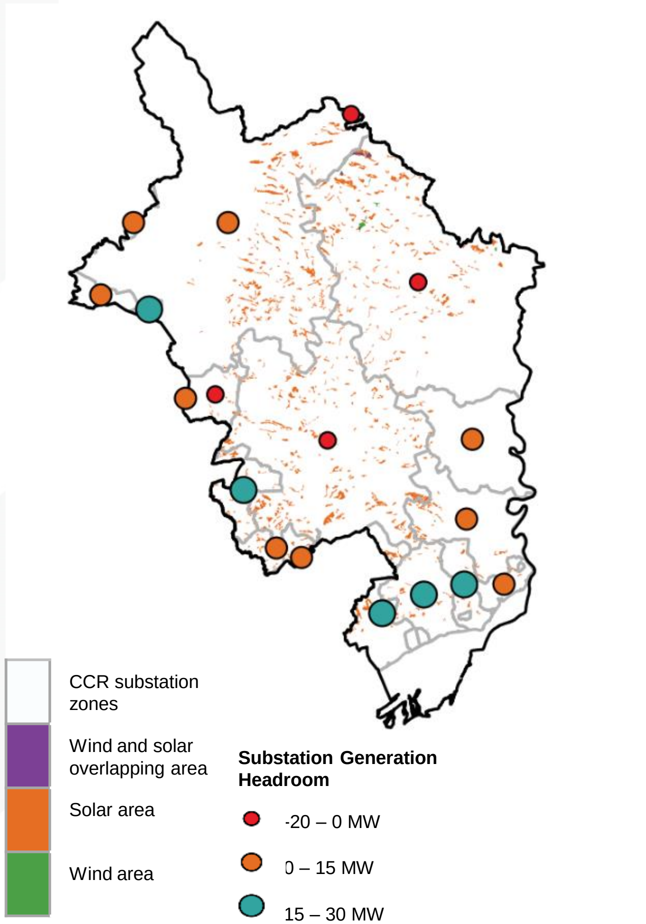


Figure 3.1.4: Areas suitable for wind and solar development

3. The future local energy system

Scenario analysis

Methodology – maximum potential capacities for renewable generation

Seasonality and daily fluctuations

To capture fluctuations in solar and wind power, hourly resource profiles were used for wind speed[T45] and solar irradiance[T46]. Both profiles were based on conditions at the centre of a local authority. For wind speed, the hourly profile was based on a height of 80 metres and used the MERRA-2 atmospheric model[T54]. For solar irradiance, the hourly profile assumed an optimal slope and azimuth, and used the PVGIS-SARAH2 radiation database[T55].

3. The future local energy system

Scenario analysis

Methodology – electricity infrastructure

The electricity distribution network was structured into three distinct levels:

1. Grid-level: This level operated at an extra high voltage of 132kV.
2. Primary-level: This level operated at a high voltage of 33kV.
3. Consumer-level: This level operated at a low voltage of 11kV.

To transition between these levels, two types of transformers were used grid transformers (located at grid substations) and primary transformers (located at primary substations). Figure 3.1.5 illustrates the flow of electricity between these substations in the model.

Each modelling zone was connected to a primary substation and grid substation, as well as a pseudo-substation.

Primary substation

Each modelling zone was part of a primary substation service area. The capacity of the primary substation[TC06] was split proportionally between its modelling zones by area. Note that substation data was provided in MVA, and we used a power factor of one to convert this to MW. For modelling purposes, the portion of the primary substation capacity allocated to a zone was located at the zone centroid.

Grid substation

To facilitate grid import, each zone was connected to a grid substation, either directly or via other primary substations, via the following:

1. We plotted the locations of grid substations. For each primary substation service area which had a grid substation physically located within it, each constituent zone was allocated a grid substation in the model.
2. Modelling zones were interconnected with other zones that shared the same grid substation.
3. Finally, any zone not yet connected to a grid substation directly was linked to the closest connected zone, based on the Pythagorean distance between their centroids.

Pseudo-substation

We assigned each modelling zone an additional pseudo-substation, a theoretical primary substation with unlimited capacity. In conjunction with costs per kW (rules of thumb provided by the DNOs; real-world costs are likely to differ depending on the network), this enabled capacity expansion (with associated cost considerations) when required.

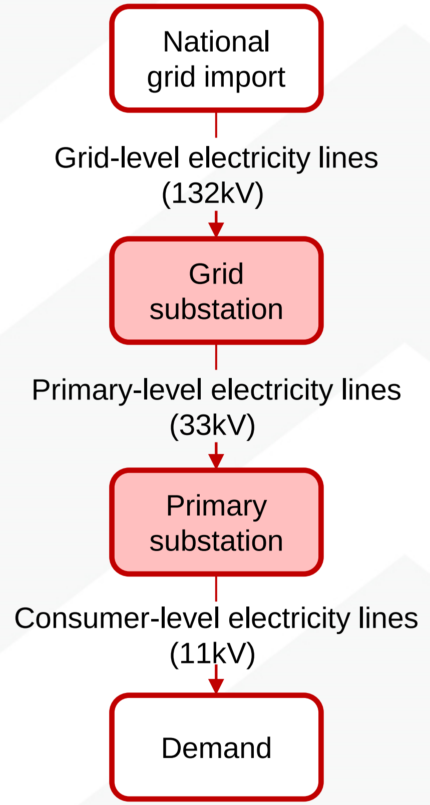


Figure 3.1.5: Modelled electricity flow for each zone

3. The future local energy system

Scenario analysis

Methodology – gas infrastructure

We assumed that in all future energy scenarios for 2050, there is no longer a demand for gas, coal and other fossil fuels, as this demand has been replaced by renewable forms of energy. Gas blending was also excluded because we modelled the 2050 scenario, and we assumed the network will be fully hydrogen at this point. In Monmouthshire, hydrogen was not considered for heating buildings.

Hydrogen demand is modelled at the same level of granularity as other supply technologies and therefore "modelling zones" align to the substation zones used to model electricity infrastructure and supply.

We set assumptions about future hydrogen demand (for combustion) which has been described in earlier sections. There is a high level of uncertainty around where hydrogen will be produced and how it will be supplied in 2050, and as a result, is left undefined in the future energy scenarios. This means that any hydrogen demand can be met by hydrogen from electrolysis within the system or from a "hydrogen import" which could be blue or green hydrogen either within or external from the local authority using the existing gas network.

We calculated the conversion of the baseline gas flow rates into hydrogen capacity.

We then established modelling zones by mapping PRI nodes with specific zones, allowing for the allocation of import and export activities based on the pipes entering and exiting each modelling zone. We used optimisation modelling to find the most cost and carbon-effective way to meet this future demand.

Exclusions

We excluded decommissioning of the gas networks from our modelling. While decommissioning will play a large role in the total cost of the hydrogen transition - current estimates for the average cost in Great Britain suggest a magnitude of £1k/household[T33] to £2.3k/household[T34]- it is still an area of great cost uncertainty[T33], especially since the data available is not specific to Monmouthshire or Wales.

	Low hydrogen	High hydrogen
Scenario application	National Net Zero, Low Demand and High Demand scenarios	High Hydrogen scenario
Industry	High-grade heat met by hydrogen (low-grade heat met by electricity)	High- and low-grade heat met by hydrogen
Transport	Proportion of vans and HGVs use hydrogen	Proportion of vans and HGVs use hydrogen
Domestic / commercial heat	Hydrogen not considered for domestic/commercial heat (apart from in the hydrogen scenario)	Hydrogen not considered for domestic/commercial heat (apart from in the hydrogen scenario)

Table 3.1.6: Summary of assumptions related to hydrogen demand applied to future energy scenarios

3. The future local energy system

Scenario analysis

Methodology – heat networks

What are heat networks?

Heat networks are one of the options for supplying heat to buildings in the future local energy system. Heat networks supply heat to buildings through hot water pipes buried in the ground from a centralised heat source. Centralised heat sources in decarbonised heat networks may be heat pumps (boosting heat from sources like air, ground, water, or waste heat), or hydrogen boilers.

Heat networks offer benefits such as reducing electricity infrastructure requirements and costs by enabling use of higher temperature heat sources at specific locations, which increase heat pump co-efficient of performance (COP), and offering large thermal stores, which can shift the timing of heat pump usage. Large centralised plants in heat networks can also offer economies of scale. However, networks can be very complex projects to deliver, and network pipework is highly expensive to build, meaning that they require high heat demand density to offer lower cost heating than alternatives like decentralised heat pumps.

How were heat networks modelled?

To determine which buildings should be supplied by heat networks rather than decentralised heat pumps in a future, optimised energy system, Arup used its proprietary HeatNet tool to assess where networks could offer a lower levelised cost of heat (LCoH) than decentralised heat pumps. The tool builds a digital representation of the local road network and uses a specialised algorithm to evaluate the combination of pipework routes and connected heat loads that maximises the amount of connected demand while minimising pipework length and maintaining a LCoH lower than the value for decentralised ASHPs. The LCoH is evaluated through a built-in discounted cashflow model.

We integrated the HeatNet results into the wider analysis by allowing the heat networks to displace the equivalent capacity of heat pumps selected by the Calliope optimisation at each substation. This was carried through capacities and energy analysis but was not carried through to grid upgrade requirements. Thus, the grid upgrade requirements presented herein can be seen as a worst-case scenario, as heat networks (often able to use higher-temperature heat sources and consequently often more efficient than decentralised heat pumps) may lighten the electrical demand.

Mapping heat sources

To capture the full potential of heat networks, location-specific waste heat sources, their temperature and their supply potential were mapped across Monmouthshire for including in the model. This includes waste heat generated by national assets, since the waste heat is a locally available resource. In addition to these sources, hydrogen boilers were made available to the model at industrial sites expected to transition to hydrogen in the future, and unlimited 'location agnostic' heat pumps (i.e. plant that can be installed largely regardless of location – like ASHPs) with lower COPs were made available without requiring networks to route to specific locations

There is are limited opportunities for the development of large-scale heat networks in Monmouthshire due to its predominantly rural nature and low building density. Previous studies, such as a 2021 report by Sustainable Energy, have similarly highlighted a lack of potential for heat network development.

3. The future local energy system (stages 4-5)

Analysis

3. The future local energy system

Analysis

Comparing future energy scenarios – annual energy flows

We have explored several future energy scenarios to help us create a strategic plan of action for decarbonising the local energy system. The following Sankey diagrams are an output from our modelling and show four potential future energy systems for Monmouthshire. These hypothetical future energy systems are a result of modelling a cost- and carbon-optimised system based on a set of pre-defined modelling parameters and assumptions about the future energy system in the local area. They were optimised for each 24-hour interval that made up a period of one year (more details can be found in Chapter 3: The future energy system (methodology). There are an infinite number of potential energy futures, but these scenarios have been used to explore what some of these futures could mean for the local energy system and understand the characteristics of these systems to inform the priorities for Monmouthshire's near-term action plan.

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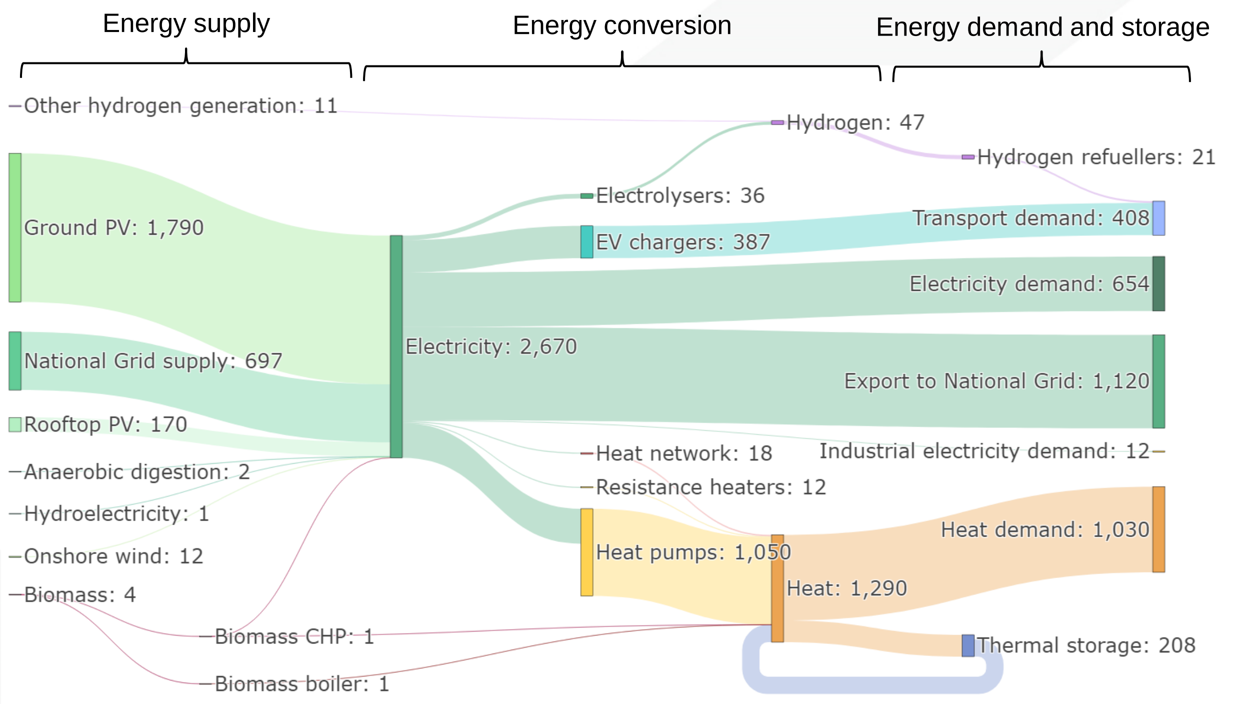
3. The future local energy system

Analysis

National Net Zero scenario - Energy flows (GWh, 2050)

Figure 3.2.1 is an output from our modelling and shows a potential future energy system for Monmouthshire under the National Net Zero scenario. This energy system results from modelling to create the most cost and carbon optimal system. We ran the model for four scenarios to support our decision making. This optimisation modelling informs the deployment pathways as well as the action plan. The National Net Zero scenario (shown below) aligns with trends in both the High and Low Demand scenarios, presented in Figures 3.2.2 and 3.2.3, respectively. Note that this Sankey diagram does not present the final plan for Monmouthshire's future energy system.



Hydrogen imports and hydrogen generated from electrolysis serve could transport demand.

Significant increase in renewable energy generation, especially ground-mount PV (45x higher than baseline).

Electricity supplied by the National Grid could increase by 1.7x compared to the baseline.

Smaller contribution from biomass, which serves both electricity and heat demand.

Majority of transport demand could be met electricity supplied through EV chargers. Hydrogen refuellers meets 5% of demand.

Significant portion, (42%) of the generated electricity is surplus and is subsequently exported.

Heat supplied could be mostly met by heat pumps (97%) , with smaller contributions from heat networks (1.7%) , resistance heaters (1.1%), biomass boilers (0.2%).

Annual electricity use could be 5.5 times larger than the baseline due to electrification of heating, transport and industry and a large potential to export.

Figure 3.2.1: Annotated Sankey diagram showing energy flows in the National Net Zero scenario (GWh in 2050)

3. The future local energy system

Analysis

High Demand scenario - Energy flows (GWh, 2050)

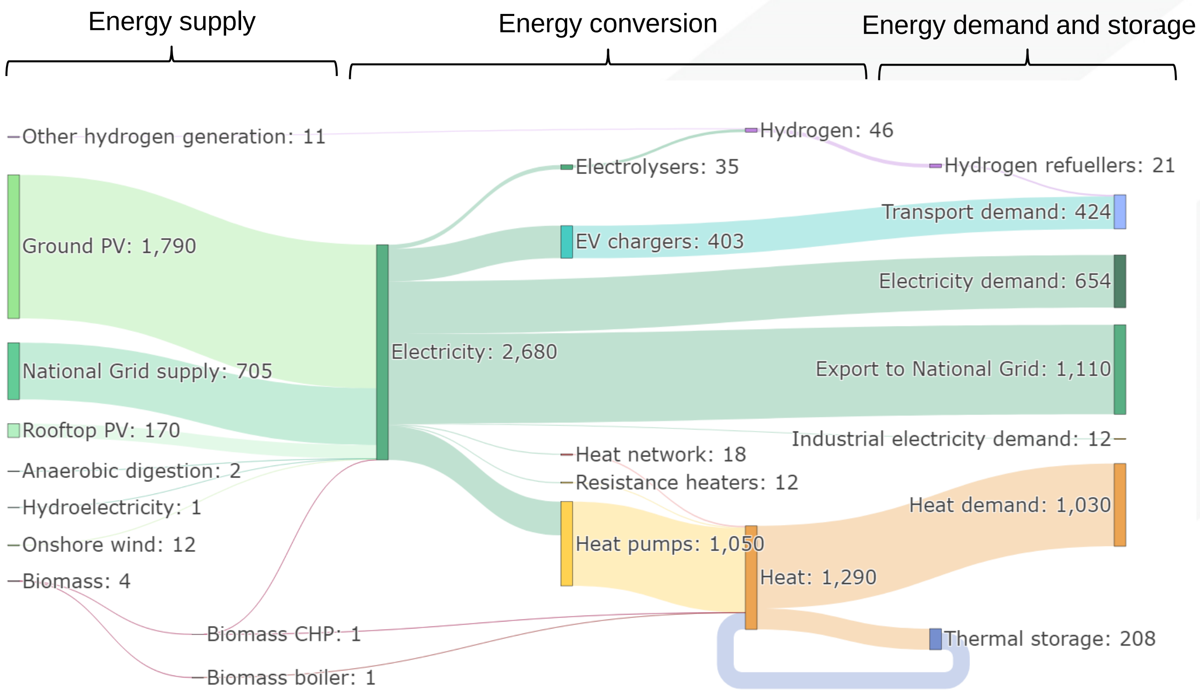
The Sankey diagram in Figure 3.2.2 represents Monmouthshire's future energy system in the High Demand scenario. The trends presented are similar to the National Net Zero scenario (refer to Figure 3.2.1 on page 75), with identical electricity and heat demand results. The amount of electricity supplied by the National Grid is slightly higher to serve a greater transport demand.

Hydrogen imports and hydrogen generated from electrolysis serves transport demand.

Significant increase in renewable energy generation, especially ground-mount PV (45x higher than baseline).

Electricity supplied by the National Grid increased by 1.8x compared to the baseline.

Smaller contribution from biomass, which serves both electricity and heat demand.



Majority of transport demand met electricity supplied through EV chargers. Hydrogen refuellers meets 5% of demand.

Significant portion, (41%) of the generated electricity is surplus and is subsequently exported.

Heat supply is predominately met by heat pumps (97%) , with smaller contributions from heat networks (1.7%) , resistance heaters (1.1%), biomass boilers (0.2%).

Annual electricity use could be 5.5 times larger than the baseline due to electrification of heating, transport and industry and a large potential to export.

Figure 3.2.2: Annotated Sankey diagram showing energy flows in the High Demand scenario (GWh in 2050)

3. The future local energy system

Analysis

Low Demand scenario - Energy flows (GWh, 2050)

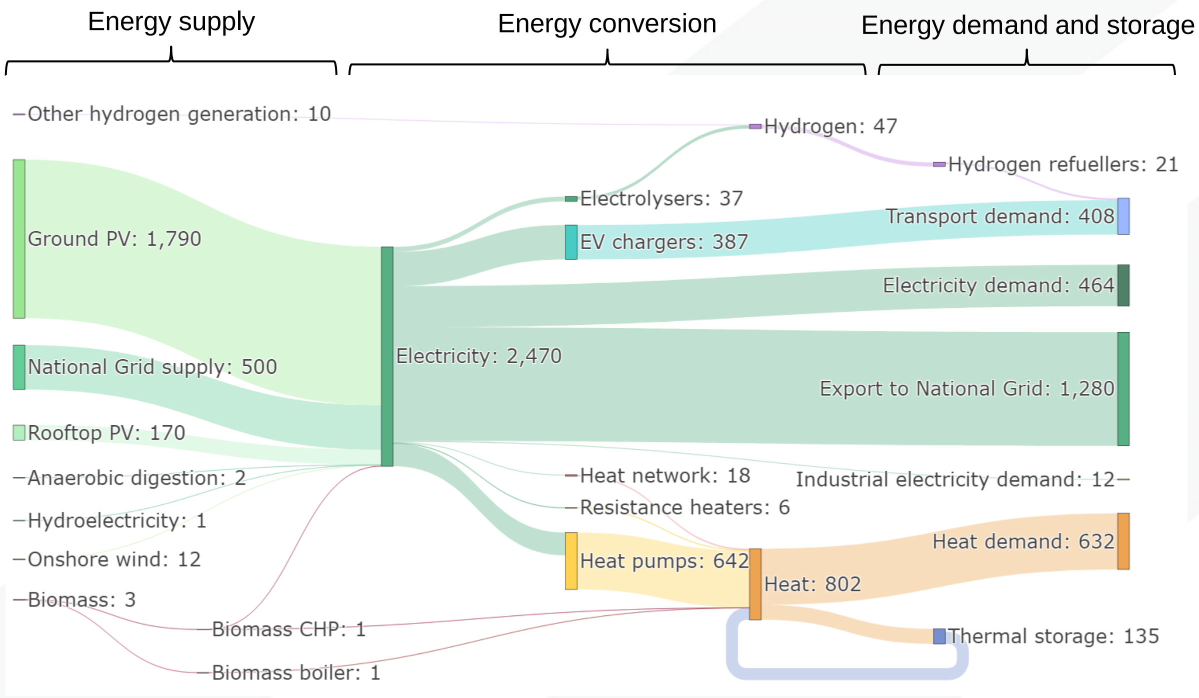
Figure 3.2.3 presents the future energy system under the Low Demand scenario. Transport, heating, and electricity demands are lower compared to the National Net Zero and High Demand scenarios. This reduction in demand can be attributed to higher rates of building retrofits, lower levels of building development and greater use of active travel.

Hydrogen imports and hydrogen generated from electrolysis serves transport demand.

Significant increase in renewable energy generation, especially ground-mount PV (45x higher than baseline).

Electricity supplied by the National Grid increased by 1.2x compared to the baseline.

Smaller contribution from biomass, which serves both electricity and heat demand.



Majority of transport demand met electricity supplied through EV chargers. Hydrogen refuellers meets 5% of demand.

Significant portion, (51%) of the generated electricity is surplus and is subsequently exported.

Heat supply is predominately met by heat pumps (96%) , with smaller contributions from heat networks (2.7%) , resistance heaters (0.9%), biomass boilers (0.3%).

Annual electricity use could be 5.5 times larger than the baseline due to electrification of heating, transport and industry and a large potential to export.

Figure 3.2.3: Annotated Sankey diagram showing energy flows in the Low Demand scenario (GWh in 2050)

3. The future local energy system

Analysis

High Hydrogen scenario - Energy flows (GWh, 2050)

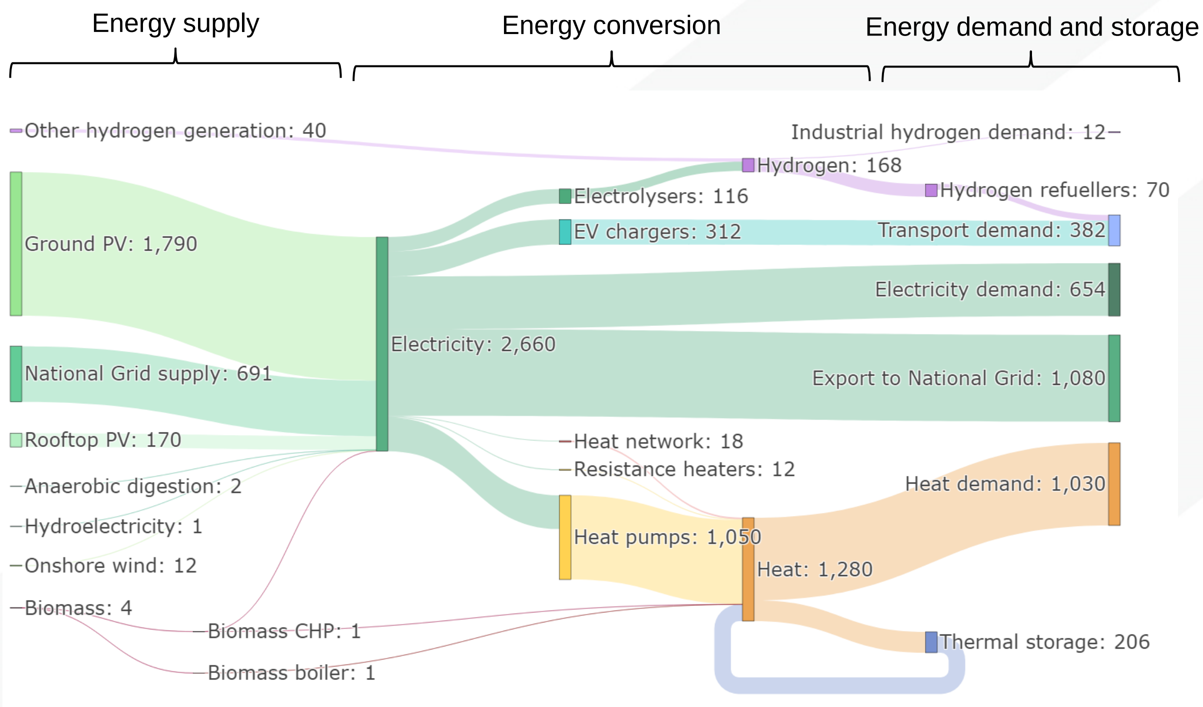
Figure 3.2.4 presents the High Hydrogen scenario's future energy system. In this scenario, transport, electricity and heat energy demands are similar to the National Net Zero and High Demand scenarios. However, there is an increased use of hydrogen which meets some of the energy demand for industry and transport. This hydrogen is primarily provided using electrolysers, with a small amount of import.

Hydrogen imports and hydrogen generated from electrolysis serves transport and industry demand.

Significant increase in renewable energy generation, especially ground-mount PV (45x higher than baseline).

Electricity supplied by the National Grid increased by 1.7x compared to the baseline.

Smaller contribution from biomass, which serves both electricity and heat demand.



Majority of transport demand met electricity supplied through EV chargers. Hydrogen refuellers meets 18% of demand.

Significant portion, (41%) of the generated electricity is surplus and is subsequently exported.

Heat supply is predominately met by heat pumps (97%) , with smaller contributions from heat networks (1.7%) , resistance heaters (1.1%), biomass boilers (0.2%).

Annual electricity use could be 5.5 times larger than the baseline due to electrification of heating, transport and industry and a large potential to export.

Figure 3.2.4: Annotated Sankey diagram showing energy flows in the High Hydrogen scenario (GWh in 2050)

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3. The future local energy system

Analysis

Comparing future energy scenarios

Table 3.2.1 summarises Monmouthshire's optimisation modelling results. Key findings include:

- **Generation:** Electricity generated from ground-mounted solar and rooftop PV increases significantly across all scenarios. Onshore wind generation also increases but to a lesser degree. Biomass use for electricity generation decreases as to reach Net Zero by 2050, Monmouthshire's electricity system will be more dependent on lower cost renewables such as wind and solar.
- **Demand:** Transport decarbonises across all scenarios due to the roll out of EVs displacing petrol and diesel vehicles. Heat demand decarbonises primarily through the roll out of heat pumps. Whilst other heating technologies, such as heat networks and resistance heaters also contribute, their usage is comparatively smaller.

It's important to emphasise that these scenarios are hypothetical and used as a guide to inform the LAEPs action plan. Common trends across the scenarios help shape the direction our strategy should take. In practice, factors such as site availability, suitability and competing land uses will need to be considered. The figures shown in Table 3.2.1 therefore represent maximum values.

Key: **Increase** in use of technology ↑ | **Decrease** in use of technology ↓

Energy components	Baseline	National Net Zero	High Demand	Low Demand	High Hydrogen
Ground-mount PV	39 GWh	↑ to 1,790	↑ to 1,790	↑ to 1,790	↑ to 1,790
Rooftop PV	13 GWh	↑ to 170	↑ to 170	↑ to 170	↑ to 170
Onshore wind	1 GWh	↑ to 12	↑ to 12	↑ to 12	↑ to 12
Biomass	46 GWh	↓ to 4	↓ to 4	↓ to 3	↓ to 4
Anaerobic digestion	2 GWh	= no change	= no change	= no change	= no change
Hydrogen import	0 GWh	↑ to 11	↑ to 11	↑ to 10	↑ to 40
Electrolyser	0 GWh	↑ to 36	↑ to 35	↑ to 37	↑ to 116
Import from Grid	395 GWh	↑ to 697	↑ to 705	↑ to 500	↑ to 691
EV chargers	1 GWh	↑ to 387	↑ to 403	↑ to 387	↑ to 312
Refuellers	0 GWh	↑ to 21	↑ to 21	↑ to 21	↑ to 70
Heat pumps	10 GWh	↑ to 1,050	↑ to 1,050	↑ to 642	↑ to 1,050
Heat networks	0 GWh	↑ to 18	↑ to 18	↑ to 18	↑ to 18
Resistance heaters	38 GWh	↑ to 12	↑ to 12	↑ to 6	↑ to 12
Biomass boilers	8 GWh	↓ to 1	↓ to 1	↓ to 1	↓ to 1

Table 3.2.1: Scenario results comparison showing annual electricity generation (GWh) in 2050

3. The future local energy system

Analysis

Electricity generation and consumption

The optimised generation and dispatch of electricity to meet demand over the modelled year in the low and high demand scenarios is shown in Figure 3.2.5.

Electricity consumption for EVs, electrolysers, industry and non-industrial electricity demand (such as in homes) stays consistent throughout the year. Electrified heat demand is the largest consumer of electricity in the colder winter months, with less demand in the summer. There is a significant export of electricity in Monmouthshire, primarily in the summer months when electricity generation from solar PV is greater.

Most of the electricity demand is met through Solar PV and national grid import. In the summer months, solar PV forms most of the generation, whereas in the winter energy is primarily imported from the grid. Other generation technologies such as wind and hydroelectricity play a far smaller role in meeting the electricity demand in Monmouthshire.

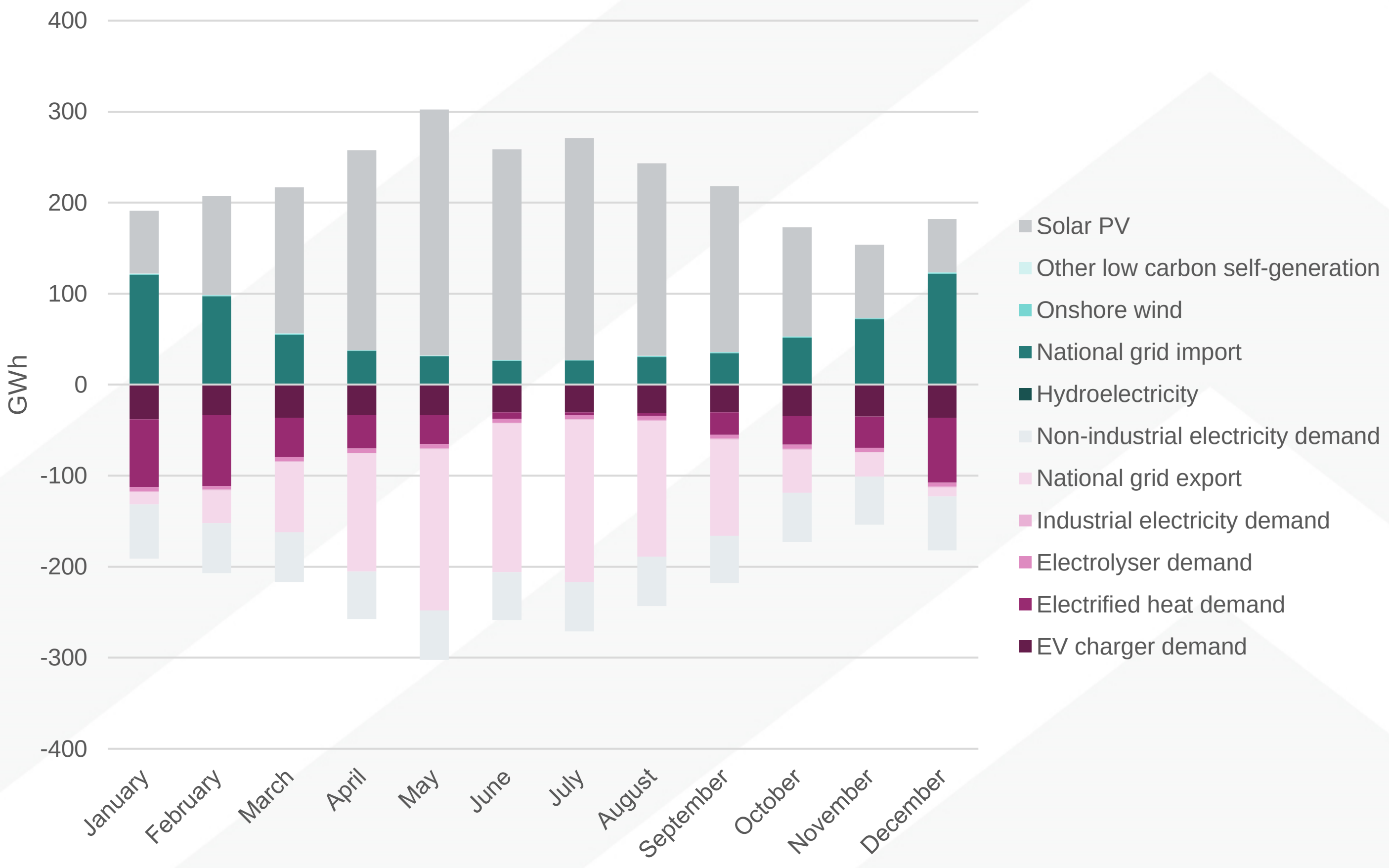


Figure 3.2.5: Monthly electricity generation and consumption in the High Demand scenario

3. The future local energy system

Analysis

Comparing future energy scenarios - Buildings

Figure 3.2.6 compares the scenario results for retrofit and changes to heating type.

The Low Demand scenario, which prioritises insulation retrofit, shows that the overall buildings heat demand in 2050 would be significantly less than in the three other modelled scenarios.

There is a clear diversification of generation technologies and a steady shift away from gas and oil-fired generation to widescale adoption of renewable generation, primarily heat pumps, resistance (direct electric) heating and heat networks.

Heat storage is also deployed to increase resilience of heating systems and utilise times of excess energy that can be used at peak times or when generation is lower.

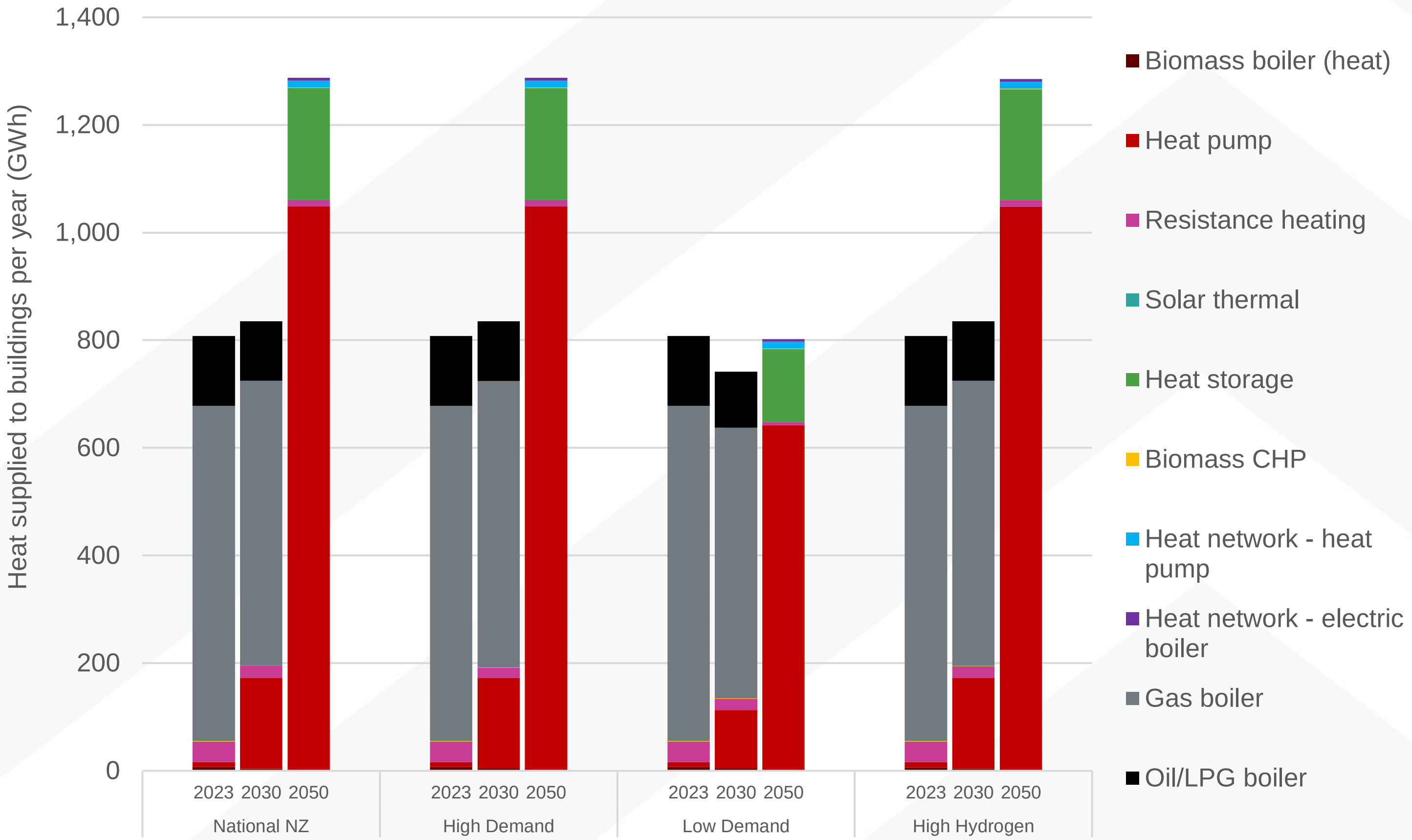


Figure 3.2.6: Evolution of heat technologies in buildings by scenario in 2023, 2030 and 2050

3. The future local energy system

Analysis

Comparing future energy scenarios - Buildings

Table 3.2.2 shows the number of existing homes that would need different types of retrofit in the National Net Zero, High and Low Demand scenarios. It can be seen that for both the National Net Zero and High Demand that around 14% of homes would need roof insulation, 4% would need cavity wall insulation and 13% would need floor insulation.

For the Low Demand scenario, 74% of homes would need floor insulation, 23% would need solid wall insulation and 83% would need triple glazing windows installed.

The following five maps, Figures 3.2.7 through 3.2.11, in the subsequent pages, show where insulation measures (cavity wall, solid wall, floor, loft and triple glazing) could be deployed, aggregated to substation zone in the Low Demand scenario. As mentioned in the methodology (pages 63-64), the measures deployed would depend on how technically viable it is in each housing archetype. Scenario modelling explores what deployment of these measures looks like in two scenarios:

- **High Demand:** measures deployed are the most cost-effective (high demand)
- **Low Demand:** best practice insulation upgrades to improve the heat loss value to the typical efficiency of an EPC C/A.

Overall, the maps show that a higher number of insulation measures would be installed in the Abergavenny Primary and Monmouth substation zones. This is likely due to:

- Relatively high housing density and commercial activity in these areas – this means greater opportunity for installation.
- The existing energy performance of buildings in each area which means there is greater room for improvement compared to other areas.

Metric	Unit	National Net Zero	High Demand	Low Demand
Existing homes	#	45,000	45,000	45,000
Cavity wall insulation	#	1,800	1,800	1,800
Cavity wall insulation	% of total homes	4%	4%	4%
Floor insulation	#	5,900	5,900	33,000
Floor insulation	% of total homes	13%	13%	74%
Loft insulation	#	6,400	6,400	6,400
Loft insulation	% of total homes	14%	14%	14%
Solid wall insulation	#	-	-	10,000
Solid wall insulation	% of total homes	-	-	23%
Triple glazing	#	-	-	38,000
Triple glazing	% of total homes	-	-	83%

Table 3.2.2: Number of energy efficiency installation types required in each scenario

3. The future local energy system

Analysis

Comparing future energy scenarios - Buildings

Figure 3.2.7 shows that most buildings needing loft insulation are located in the Abergavenny substation zone. In Figures 3.2.7 to 3.2.11, this substation zone has a high number of energy efficiency measures installed, under the Low Demand scenario.

Figure 3.2.8 shows that the Caldicot and Abergavenny Primary substation zones require significant deployment of cavity wall insulation, with over 500 installations required.

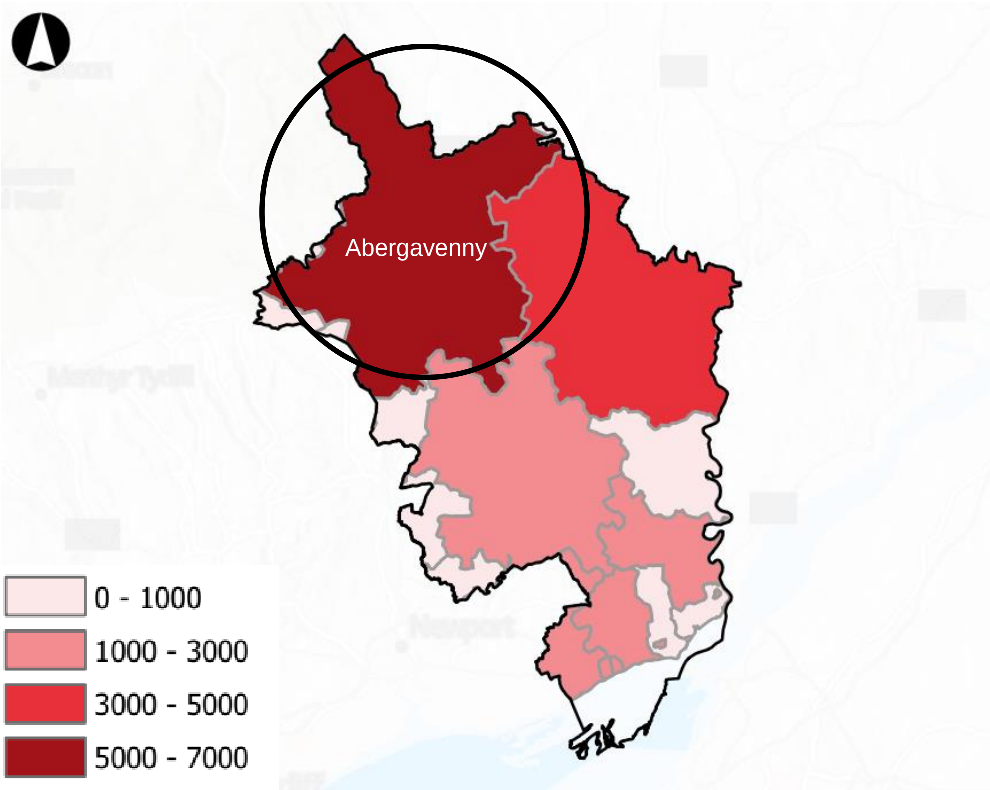


Figure 3.2.7: Low Demand – loft insulations needed per substation zone

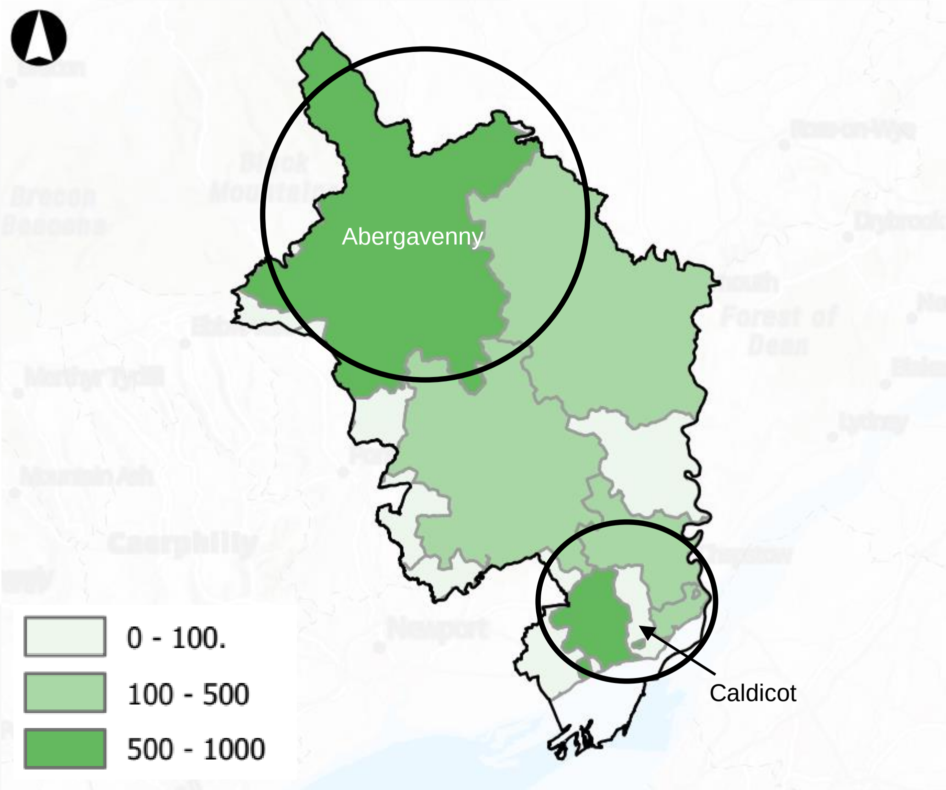


Figure 3.2.8: Low Demand - cavity walls needed per substation zone

3. The future local energy system

Analysis

Comparing future energy scenarios - Buildings

Figure 3.2.9 shows that the Abergavenny Primary substation zone host over 3,000 homes which need solid wall insulation.

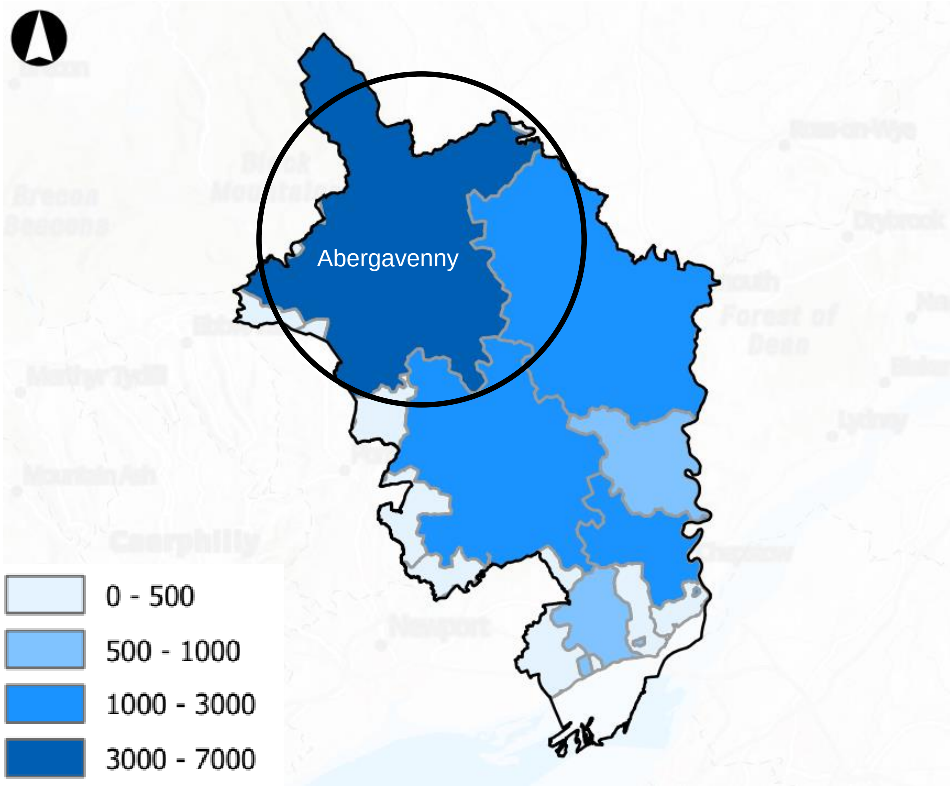


Figure 3.2.9: Low Demand – solid wall insulations needed per substation zone

Figure 3.2.10 shows that the number of floor insulation installation is greater in Abergavenny Primary and Monmouth substation zones.

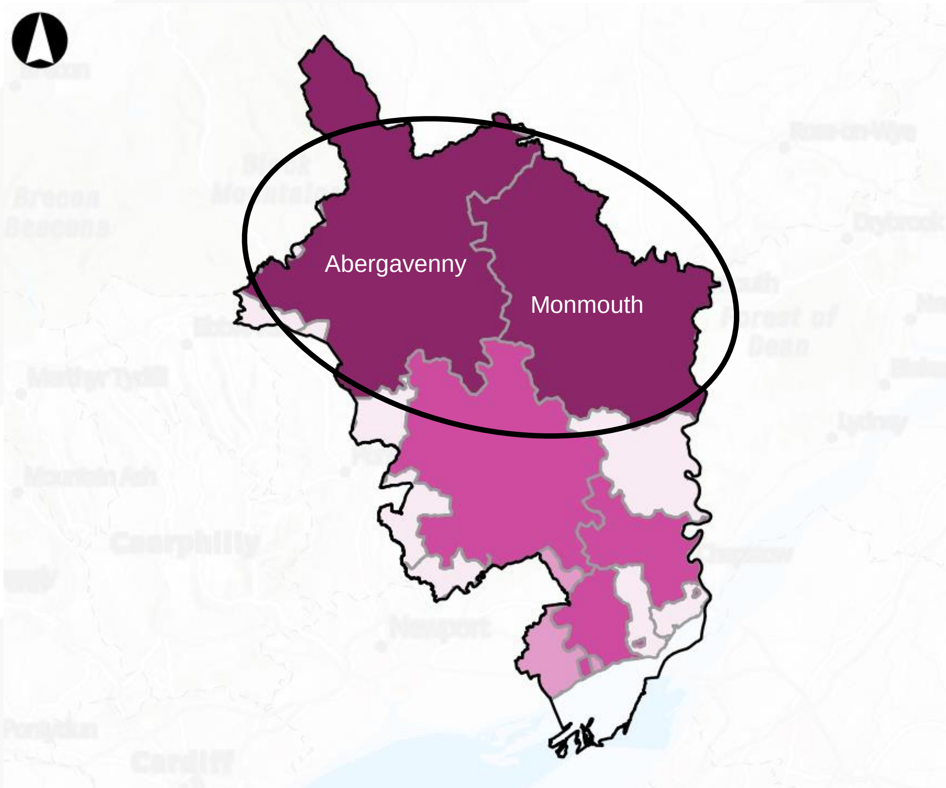


Figure 3.2.10: Low Demand – floor insulations needed per substation zone

3. The future local energy system

Analysis

Comparing future energy scenarios - Buildings

Figure 3.2.11 shows triple glazing is most required in the Abergavenny Primary substation zone, with significant deployment in the Monmouth, Chepstow and Caldicot substation zones.

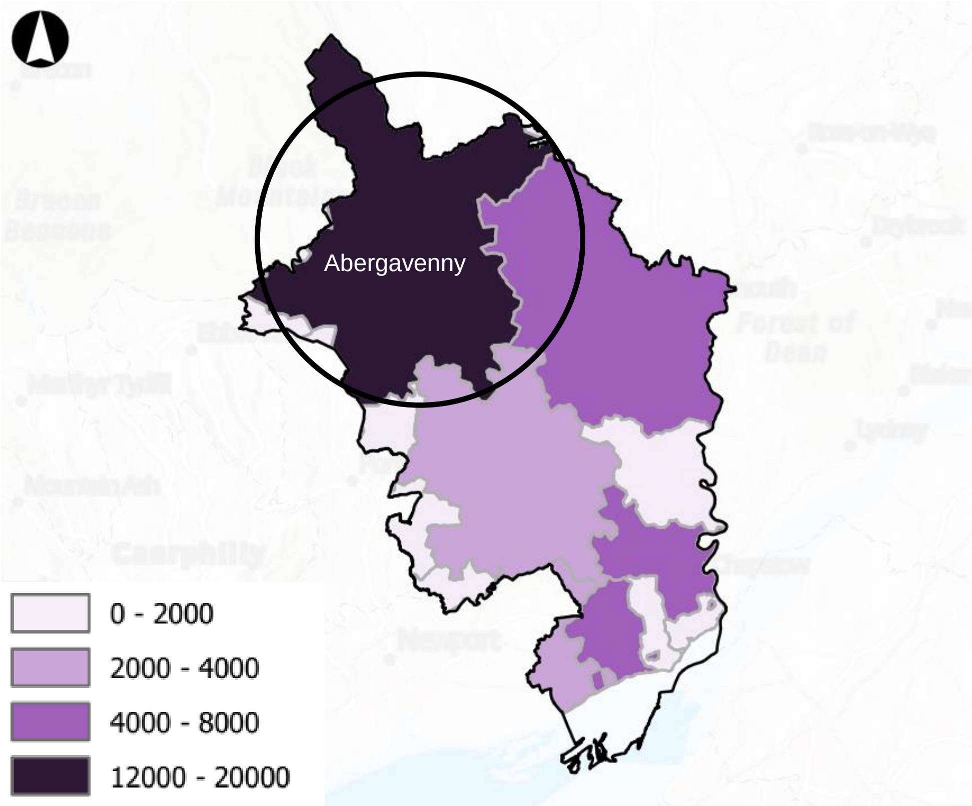


Figure 3.2.11: Low Demand – triple glazing needed per substation zone

Figure 3.2.12 shows where listed buildings are located, these are generally in centre and north of the county, and reflect the areas that require the highest amount of retrofit in Figures 4.2.7 to 4.2.11. These buildings are more likely to be challenging to retrofit due to their protected status.

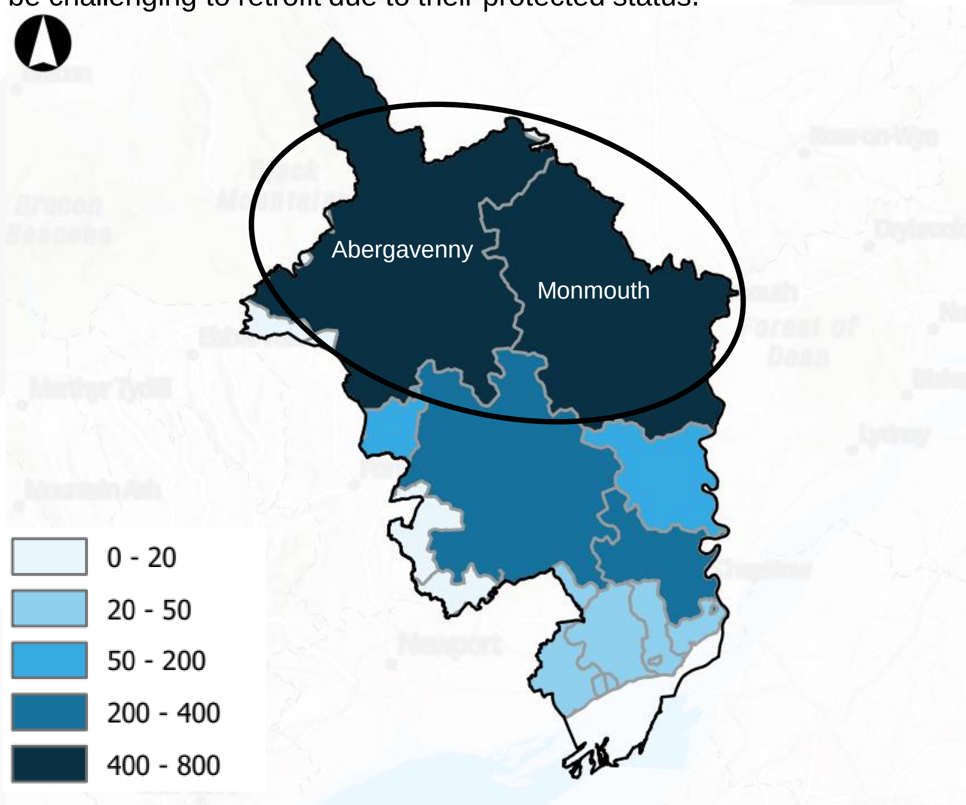


Figure 3.2.12: Listed buildings

3. The future local energy system

Analysis

Comparing future energy scenarios - Heat networks

Potential heat network opportunity areas have been identified where heat networks may be able to deliver heating at lower cost than individual air source heat pumps (ASHPs). This usually occurs near areas with concentrated heat demands, i.e. industrial sites, high density housing areas, or where waste heat could be captured and fed into network.

In Monmouthshire, Caldicot has been identified as a potential location for a heat network. The business park in this area houses several industrial units, including Daqs Air Conditioning Systems and Microchip Technology. Furthermore, Caldicot East, which is conveniently located near this proposed heat network, has been designated as a Preferred Strategic site. This will be a mixed-use development, encompassing residential, employment, retail, and leisure facilities. The diverse mix of buildings could lead to an increased concentration of demand, thereby enhancing the viability of a heat network in this area.

A 2021 Heat Mapping study by Sustainable Energy similarly found limited potential for large-scale heat networks in Monmouthshire. However, the study identified Duffryn as a prioritised site for heat network development, which could potentially be economically viable with the support of grant funding.

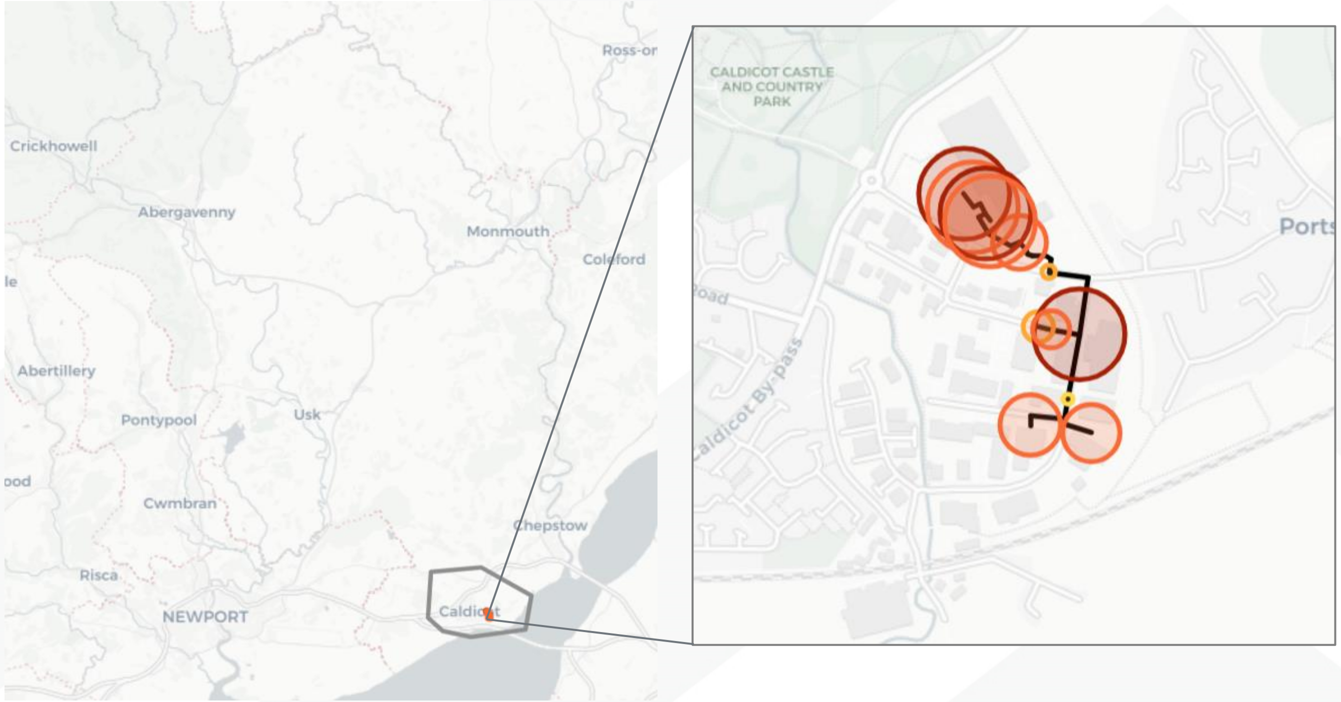


Figure 3.2.13: Map of identified zones for heat network potential

Sponsors: Delivery partners:

3. The future local energy system

Analysis

Comparing future energy scenarios - Transport

In the 2050 future energy system, overall transport demand remains relatively similar to the baseline, with active travel and public transport playing a greater role. The overall miles per year increases in the High Demand scenario (to 990 million miles) and increases slightly in the Low Demand and High Hydrogen scenarios (to 930 million miles). Note that Low Demand and National Net Zero are assumed to have the same 2050 mileage.

Figure 3.2.14 shows the total number of vehicle miles covered in one year by vehicle type and scenario.

The mileage for each vehicle type (i.e. cars, LGVs, HGVs, buses) remains similar across the scenarios, however the fuel type varies. In the High and Low Demand scenarios, electrification of cars, buses, LGVs and HGVs is prevalent, with small amounts of hydrogen powered HGVs and buses present. In the High Hydrogen scenario, electrification is still deployed, but a slightly larger proportion of hydrogen powered vehicles are seen, mostly for larger vehicles such as LGVs, HGVs and buses.

There are a number of factors which could influence the uptake of hydrogen HGVs. For example, hydrogen refuelling can be done in 3-8 minutes, compared to at least 60 minutes needed for rapid charging, or overnight for standard charging. Secondly, hydrogen HGVs are projected to have up to 50% range advantage over battery electric models (800km against 1,200km). These factors suggest that hydrogen HGVs could occupy a large share of the market in the future.

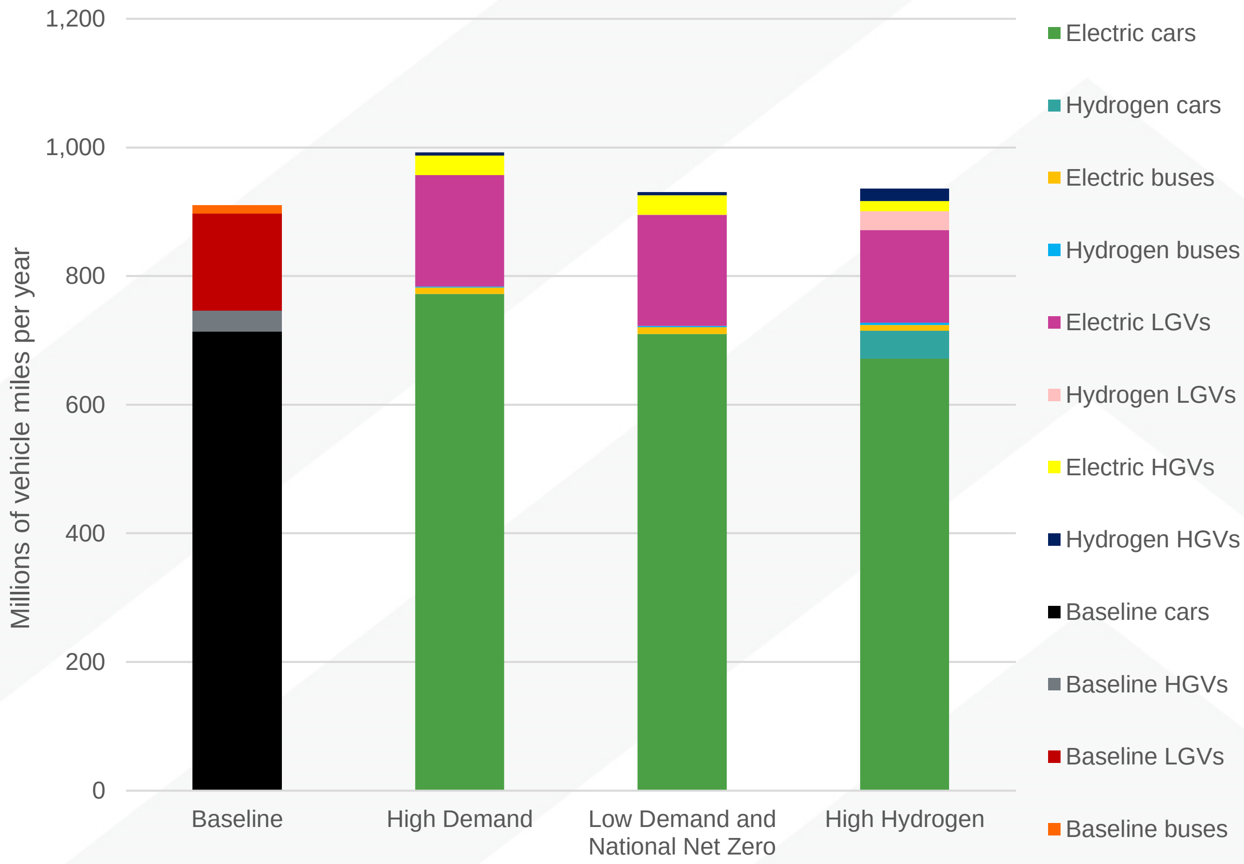


Figure 3.2.14: Total annual vehicle miles in 2050 by scenario and vehicle type

3. The future local energy system

Analysis

Comparing future energy scenarios - Onshore renewables

Our modelling indicates a significant expansion of ground-mounted solar PV generation. This is due to the technology being considered as the most cost-effective and carbon-efficient solution to meet the forecasted energy demands. Across all the optimised scenarios, including the National Net Zero, Low Demand, High Demand, and High Hydrogen, 100% of the land deemed as suitable for ground-mounted solar PV was utilised in the model, with the generation capacity in 2050 equating to 1.8GW. Rooftop solar PV and onshore were also deployed in all scenarios, at 172MW and 3.9MW, respectively.

The other technologies are limited to the same capacity as the baseline as we do not expect their deployment will increase.

In practice, ramping up the deployment of renewable energy technologies to meet the modelled 2050 scenarios is unrealistic. The current capacities of renewable energy generators fall significantly short of the levels projected for 2050.

The deployment of renewable energy technologies is further explored in Section 4, page 117.

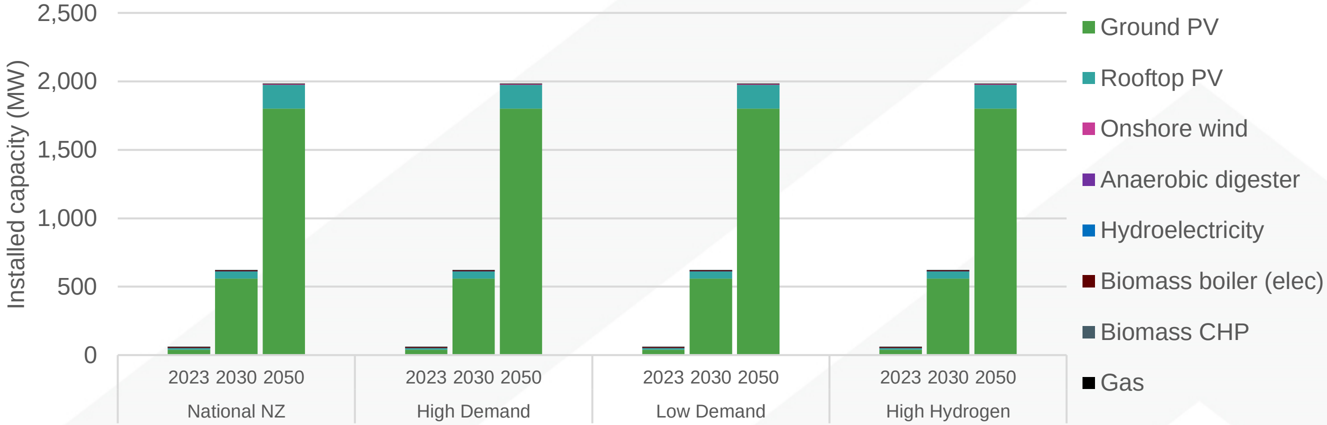


Figure 3.2.15: Future capacity of onshore renewables in each scenario

Renewable technology baseline assessment	Existing capacity (MW)	Additional capacity needed to 2050 (MW)	Total maximum 2050 theoretical capacity across scenarios (MW)
Ground solar PV	39	1,760	1,800
Onshore wind	0.23	3.7	3.9
Anaerobic digestion	0.36	0.0	0.36
Hydroelectricity	0.15	0.0	0.15
Rooftop solar PV	13	160	170

Table 3.2.3: Existing and maximum future capacity of onshore renewables

3. The future local energy system

Analysis

Comparing future energy scenarios - Electricity infrastructure - upgrades

The modelling results provide insights to the anticipated future requirements for electricity infrastructure upgrades, considering the current capacities of primary substations.

In Monmouthshire, the two substations serving the northern region (Abergavenny Primary and Monmouth) are projected to require the most significant upgrades. This is likely because their service areas cover two urban areas, Abergavenny and Monmouth. By 2050, with the ongoing development, the transition towards electric vehicles, and the adoption of electric heating technologies, power demand is likely to increase. Furthermore, the region has substantial solar and wind potential (as shown in Figure 3.1.4), further emphasising the need for reinforcement to unlock this potential capacity.

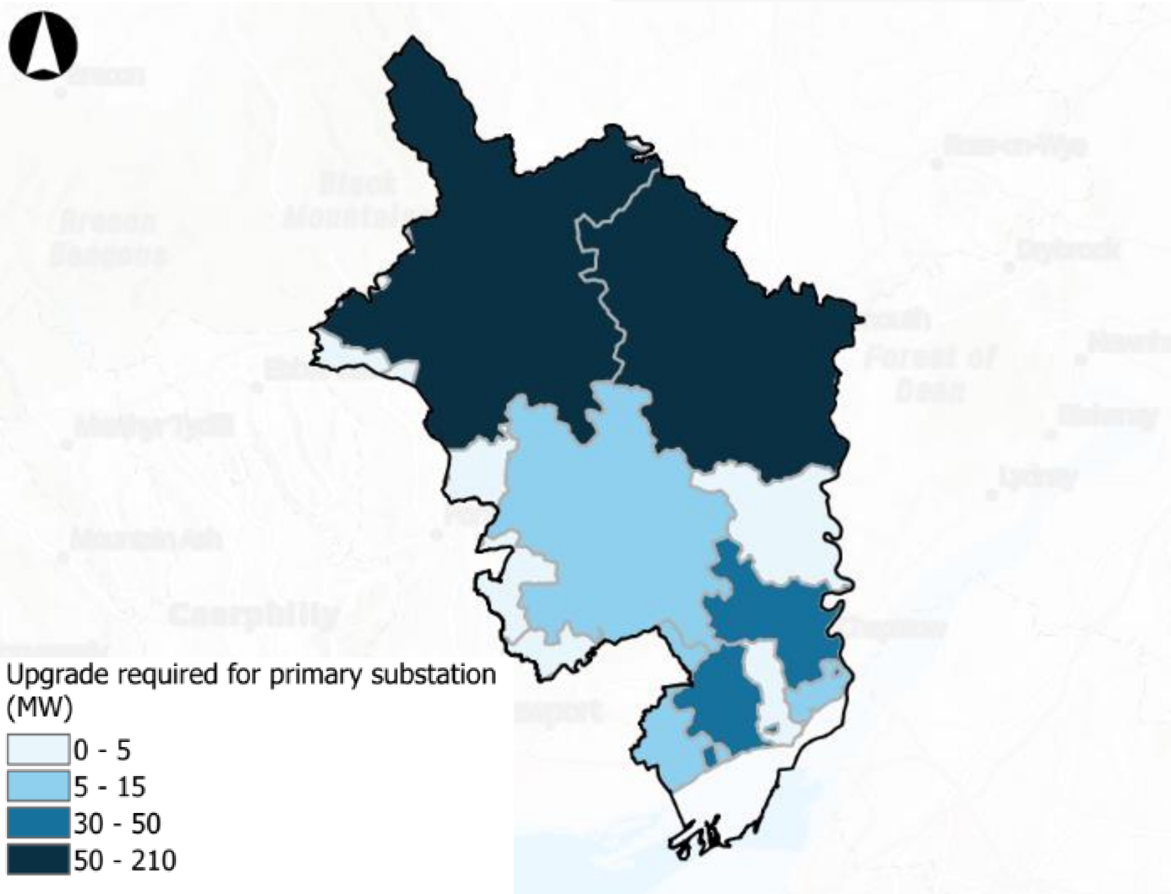


Figure 3.2.16: Map of electricity network upgrades in the High Demand scenario

3. The future local energy system

Analysis

Uncertainties and limitations

There are numerous uncertainties that may impact the future local energy system between now and 2050. These uncertainties could influence the CAPEX, OPEX, and carbon emissions associated with delivering the future local energy system.

It is important to acknowledge these uncertainties in the LAEP to ensure that it is adaptable, and resilient to any negative impacts, uncertainties could lead to.

This analysis also highlights how the modelling associated with the LAEP are not designed to be used in isolation, and should be combined with other evidence, as they cannot cover all potential future outcomes.

Uncertainty	GHG emissions	CAPEX	OPEX	Other notes
Lower uptake / roll-out of renewables	↑	↓	↑	If there is a lower roll out of solar or wind, the model maximises other renewables up to their maximum capacities and then imports electricity from the national grid.
Lower uptake / roll-out of retrofits	↑	↓	↑	Higher consumer bills and more capex spent on deploying heat pumps, likely to result in poor consumer perception
Lower uptake / roll-out of heat pumps	↑	↓	?	More chance of hydrogen scenario. OPEX changes would depend on future costs of electricity, gas (and potentially hydrogen)
Lower uptake / roll-out of demand side management	↑	↑	↑	Higher energy infrastructure costs. Greater cost to consumers.
Lower uptake of EVs	↑	↓	?	OPEX changes would depend on future costs of diesel/petrol and electricity
Higher uptake of hydrogen	↓	?	↑	Higher uptake of hydrogen could facilitate a faster transition to net zero, with less pressure on the electricity network
Increased grid electricity import prices	?	?	↑	Likely to drive more demand side management in area– if this occurs, carbon emissions and infrastructure investments would reduce. However, increase grid electricity prices might also slow down electrification and decarbonisation
Reduced gas prices	↑	?	↓	Less people switch to heat pumps, more chance of hydrogen scenario CAPEX impact would depend on cost of heat pumps
Increased CAPEX for electrical reinforcement	↑	↑	↑	Could slow down electrification, with impact on overall GHG emissions. Could increase cost of electricity for consumers.
More extreme weather	?	↑	↑	More extreme cold days mean higher heat pump capacities would be required. More hot summer days could lead to increased cooling, with increase in OPEX. Overall emissions remain similar if annual average temperatures are unvaried.

Table 3.2.4: Impact of key sensitivities on the future local energy system

3. The future local energy system

Analysis

Trends from optimisation model runs

Having run over 150 models across multiple Local Authority areas, we observed several trends. Where it has not been possible to undertake modelling at a 1-hour timestep, we can be confident what the impact would be. We have also observed how the system changes when we remove the electricity import. The diagram in Figure 3.2.17 demonstrates what we have found over the multiple model runs that we have undertaken.

What does the model always do?

- Maximises onshore renewables (solar PV and wind)
- Chooses heat pumps as the dominant heating technology
- Chooses to meet 10% of transport demand using hydrogen, and 90% with electricity (except for in the High Hydrogen scenario)
- Imports electricity to meet demand where renewable energy generation is not available
- Export surplus electricity generated

How does the timestep influence the system?

- If we use a more granular time resolution for modelling (e.g. 24-hour to 1-hour timesteps):
- The size of the electricity system increases
- Thermal storage increases
- The model sometimes chooses to add battery storage

What does the model do if electricity imports are restricted?

- Increases any renewables that haven't already reached their theoretical maximum capacity
- Builds hydrogen CCGT to meet electricity demand when renewable energy generation is not available
- Prioritises electrolysers to generate hydrogen but sometimes chooses a combination of electrolysers and hydrogen imports to meet hydrogen demand.

Figure 3.2.17: Trends from optimisation model runs

3. The future local energy system (stages 4-5)

Deployment modelling

3. The future local energy system

Deployment modelling

Methodology

We developed a deployment model to determine the rate at which specific technologies could be deployed between the baseline year and 2050. Exploring how quickly different solutions could be deployed and comparing this to the pace of change required helps us gauge what is achievable and what else is needed to facilitate the changes required. The model can also help us break down the changes required into appropriate time periods and provides a way to monitor progress.

The deployment pathways for each energy system component describes the technological changes required over time. From this, we were able to compare how GHG emissions would change over time against national emissions reduction targets and indicate the capital investment requirements between the baseline year and 2050.

Figure 3.3.1 shows how assumptions were applied to near-term and long-term deployment trajectories. Near-term indicates the period for which local and national policy can be applied which is generally 2023-2030 but can vary depending on technology.

Table 3.3.1 summarises the data sources used to inform deployment rates for different technologies that were assessed in our optimisation modelling.

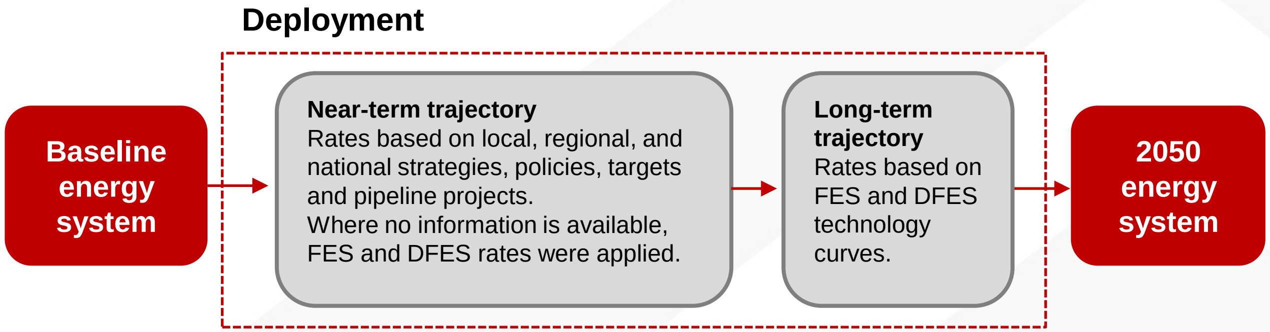


Figure 3.3.1: Deployment model overview of assumptions used to determine rates

Data source	Description
National Grid's Future Energy Scenarios (FES)[T31]	FES are a range of forecasted net zero technology trajectories to 2050 for the electricity system in Great Britain. They consider national policies and ambitions for an extensive list of supply and demand technologies at the distribution level.
Distribution Future Energy Scenarios (DFES)[TC35]	DFES projects the FES technologies at a more granular resolution (primary and secondary substation zones).
National policies and ambitions review	A review of national strategies to do with the energy system was carried out to support the deployment modelling. E.g. no new gas boilers or fossil vehicles by 2035.
Local authority strategies and plans e.g. local development plans (LDP)	A review of local strategies and plans was carried out to support the deployment modelling. E.g. transport strategies containing a target number of chargepoints for an area.
Stakeholder engagement	Information captured in Welsh LAEP programme workshops.

Table 3.3.1: Summary of data sources used to inform deployment modelling

3. The future local energy system

Deployment modelling

Impact on total energy demand (GWh)

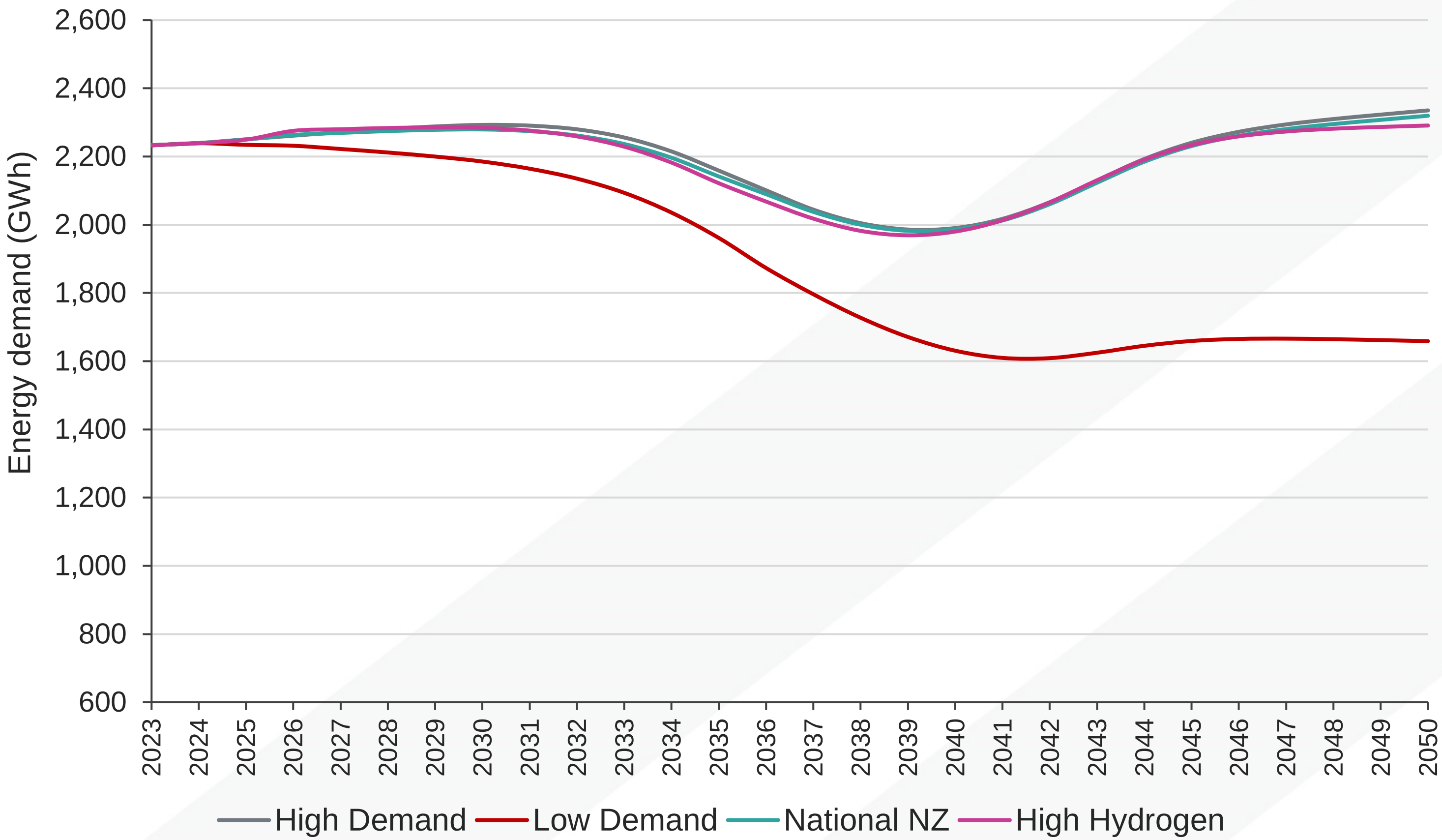


Figure 3.3.2: Change in total energy demand by scenario (GWh)

Between 2042 and 2050, energy demand in the High Demand, National Net Zero and High Hydrogen scenarios increases due to growth in housing and commercial property outweighing the energy reductions achieved through energy efficiency measures. The transition to EVs also slows down during this period. From 2042, we also see the introduction of hydrogen vehicles, which contribute to an increase in demand.

Total energy demand decreases to lower levels in the Low Demand scenario, primarily driven by improvements in buildings' energy efficiency to achieve heat demands that are associated with homes with EPC A ratings.

3. The future local energy system

Deployment modelling

Energy demand from buildings (GWh)

Buildings energy demand increases overall because the evidence assumes an increase in the number of homes and commercial buildings between now and 2050. However, the average heat demand of each individual property decreases from approximately 12,000 to 11,000kWh$_{heat}$/home in the High Demand, National Net Zero and High Hydrogen scenarios, and to 8,000kWh$_{heat}$/home in the Low Demand scenario for domestic properties.

For non-domestic properties, the heat demand decreases from 130 to 120kWh$_{heat}$/m^2 in the High Demand, National Net Zero and High Hydrogen scenarios, and to 100kWh$_{heat}$/m^2 in the Low Demand scenario.

National Net Zero, High Demand and High Hydrogen scenarios all plot the same curve, since the data input is the same.

The Low Demand scenario sees the smallest increase in electricity demand, and a decrease in heat demand to 2050. This is due to the focus of prioritising reducing heat demand through improving insulation in existing and new buildings.

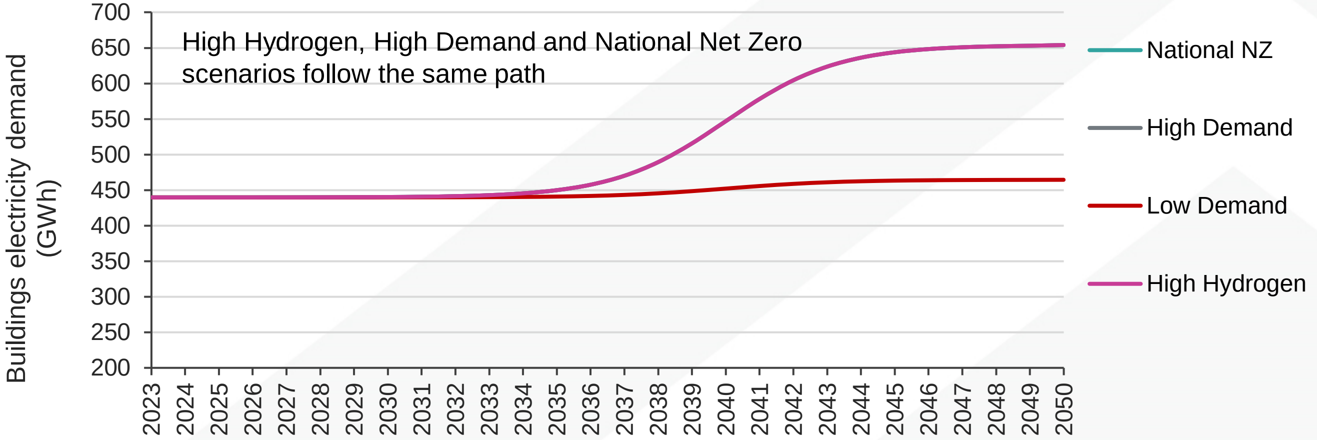


Figure 3.3.3: Projected electricity demand for buildings in each scenario

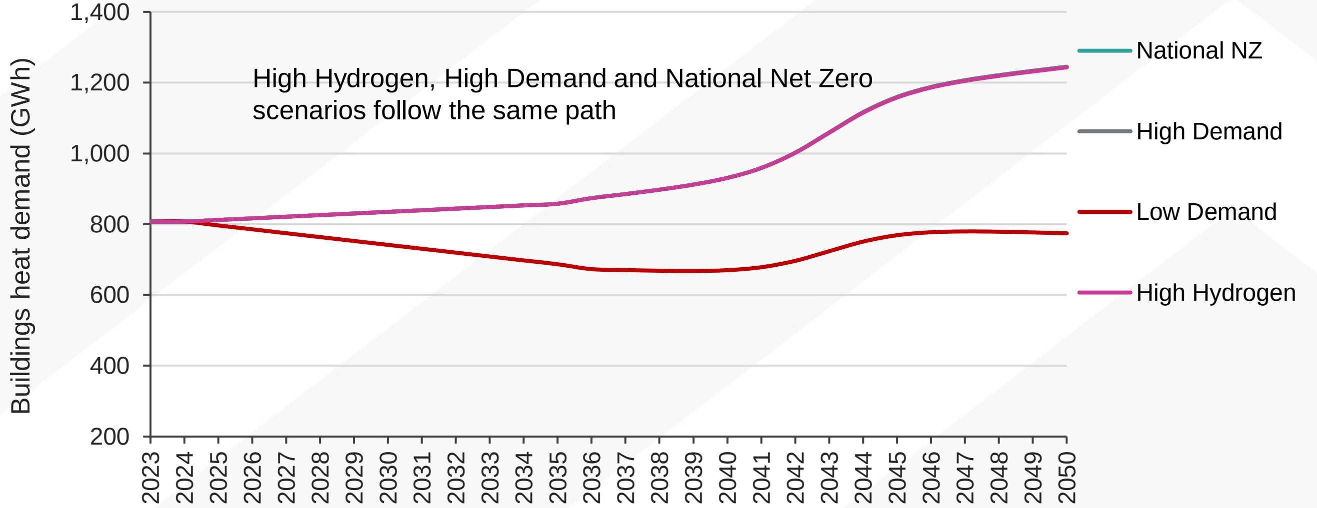
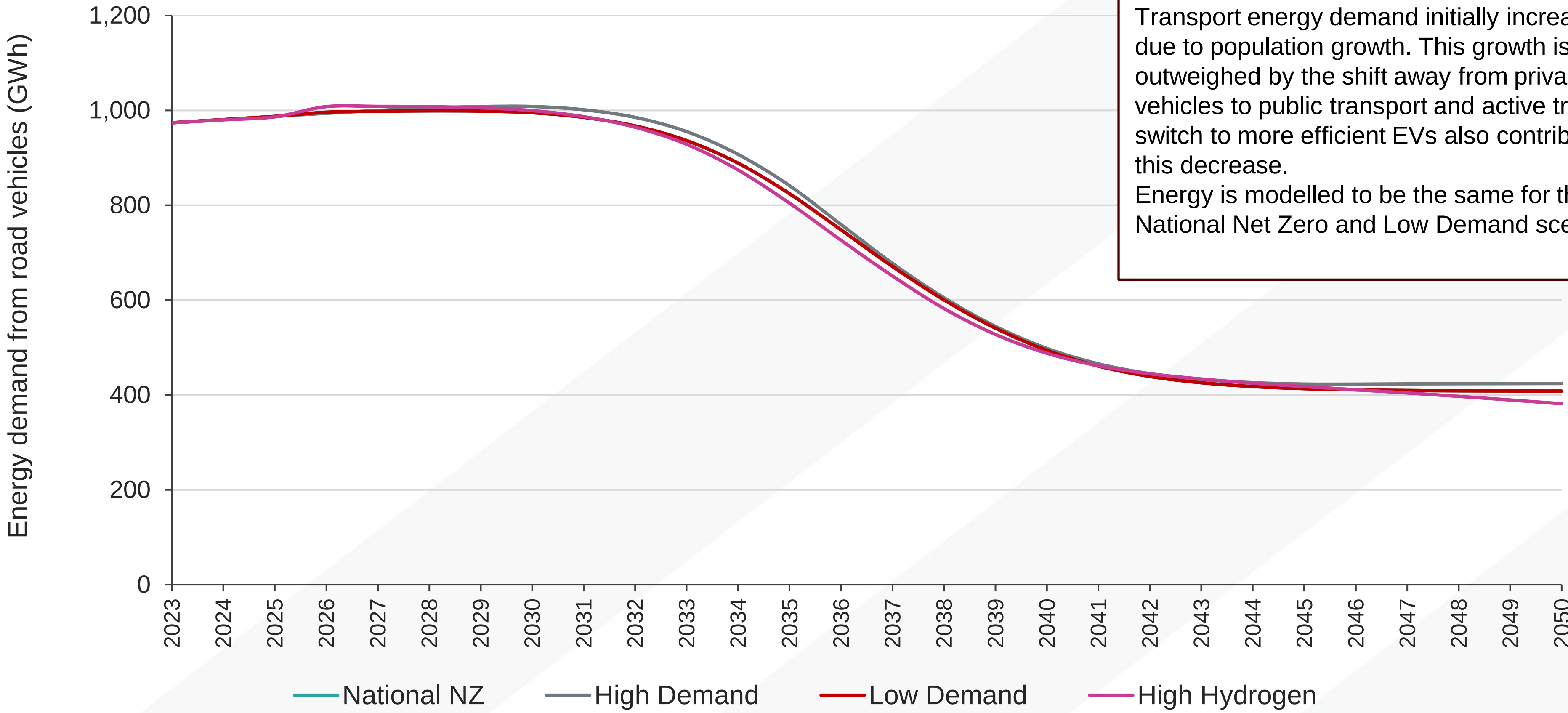


Figure 3.3.4: Projected heat demand for buildings in each scenario

3. The future local energy system

Deployment modelling

Energy demand from transport (GWh)



Transport energy demand initially increases as due to population growth. This growth is then outweighed by the shift away from private vehicles to public transport and active travel. A switch to more efficient EVs also contributes to this decrease.
Energy is modelled to be the same for the National Net Zero and Low Demand scenario.

Figure 3.3.5: Evolution of heat technologies in the National Net Zero scenario

3. The future local energy system

Deployment modelling

Summary of deployment for low-regret energy system components

Deployment modelling can help us better understand what the impacts of each scenario are over time. It provides a starting point to frame the challenge and for more detailed analysis. We have included theoretical pathways which have a high degree of uncertainty as there are many variable factors and unknowns. The deployment modelling can't consider every factor, some of the things that will impact deployment include (i) technological advance and innovation, (ii) supply chains and how they develop and (iii) large scale activity to decarbonise infrastructure at other levels: regional, UK and beyond.

In 2023:	1 Initial adoption →	By 2030:	2 Rate of installations accelerates →	By 2050:
400 heat pumps installed		**6,700** heat pumps installed		**41,000** heat pumps installed
23,500 homes with an EPC D and below		**11,000** homes with insulation measures installed		**26,000** homes with insulation measures installed
260 EV chargepoints[a]		**2,300** EV chargepoints[b]		**23,000** EV chargepoints[b]
3,200 roofs with solar PV[c]		**13,500** roofs with solar PV[c]		**43,000 roofs with PV installed**[c]
40 MW ground-mounted solar capacity[d]		**560 MW** ground-mounted solar capacity		**1,800 MW** ground-mounted solar capacity
0.23 MW onshore wind capacity[d]		**0.3 MW** onshore wind capacity		**4 MW** onshore wind capacity
0 electrolysers capacity		**2 MW** electrolyser capacity		**20 MW** electrolyser capacity

Figure 3.3.6: Monmouthshire's energy system component deployment rates

[a]According to the National Charge Point Registry as of May 2023. Refers to individual charge points,

[b]Assuming 4kWp per charge point. Note that the power rating selected will be dependent on location and use case. E.g. Rapid chargers are more suitable at service stations due to the length of stay of customers.

[c]Assuming 4kWp per roof and per installation

[d]Renewable generation capacity is shown for technologies where current installed capacity is >5MW

3. The future local energy system

Deployment modelling

Impact on GHG emissions

Figure 3.3.7 shows the gap in the GHG emissions between the Do Nothing scenario and the optimised scenarios. Our deployment modelling provides additional evidence on the realism of delivering the changes suggested by the optimisation modelling. It helps us to determine the actions needed in the next five years to set us on the pathway to net zero in 2050. There are also bigger systemic changes that will be needed to achieve the scale of change set out in this plan.

The deployment modelling shows how these pathways contribute to the Welsh Government emissions reduction targets.

For Monmouthshire, the 2023 baseline (440ktCO_2e) is already a 51% reduction on the 1990 levels (895ktCO_2e). As seen in Table 3.3.2, none of the modelled scenarios meet the 2030 target of 63%. However, they all surpass the 2040 target of 89% and come close to the net zero 2050 target.

The plan shows that the system doesn't entirely meet net zero in 2050, with residual emissions of 10ktCO_2e in all scenarios. This primarily comes from some GHG emissions associated with electricity imported from the national grid.

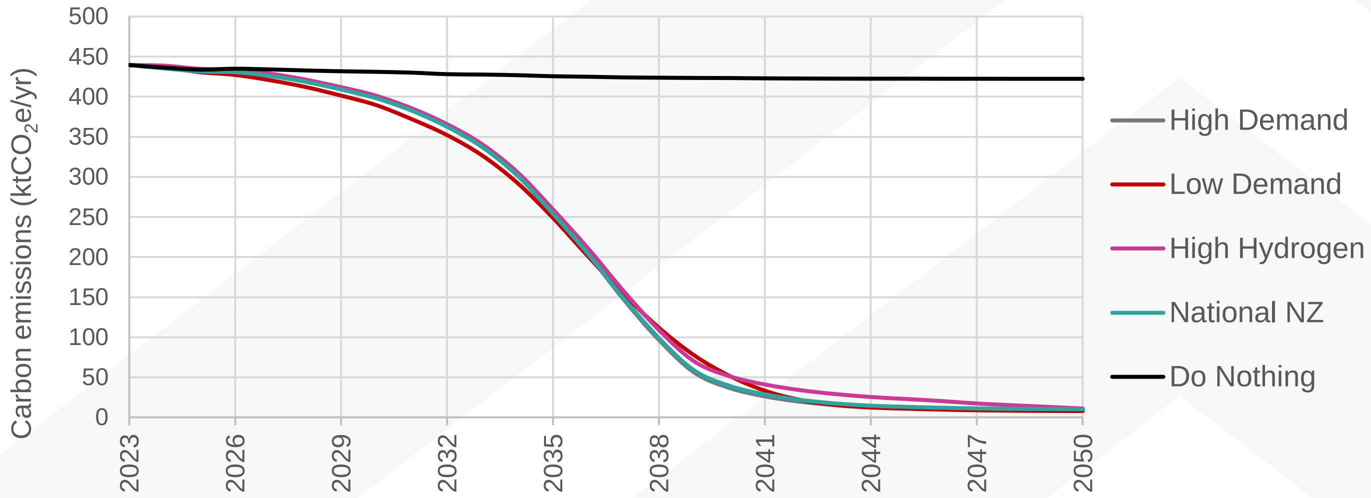


Figure 3.3.7: GHG emissions (ktCO_2e) to 2050 for each modelled scenario compared to the Do Nothing scenario

Scenario	2030	2040	2050
Welsh Gov targets	-63%	-89%	-100%
High Demand	-55%	-96%	-99%
Low Demand	-57%	-94%	-99%
High Hydrogen	-55%	-94%	-99%
National Net Zero	-56%	-96%	-99%
Do Nothing	-52%	-53%	-53%

Table 3.3.2: Decrease in GHG emissions (ktCO_2e) to 2050 for each scenario compared to the 1990 GHG emissions value and the Welsh Government emissions reduction targets

3. The future local energy system

Deployment modelling

Impact on employment

Employment impacts

Investments in local energy systems can be expected to have employment benefits by providing local, skilled jobs. These will include direct jobs from construction and operational phases of the development as well as associated supply chain and multiplier effects[T36].

Method

We conducted a literature review to extract relevant indicators to estimate the employment impacts derived from investment in different decarbonisation measures such as energy efficiency improvements, installing heat pumps in buildings or constructing a solar farm. We have selected indicators that reflect jobs created in the local area to assess the local benefits associated with each scenario, and where possible excluded impacts associated with employment impacts that are likely to be felt beyond the local area. This means that "indirect" employment impacts, or jobs created within the supply chain to support a particular project (e.g. for a wind farm, this could be jobs in the company supplying or manufacturing the blades for wind turbines) are not considered.

Our assessment considers jobs that might be displaced in other parts of the economy owing to an investment in energy efficiency or renewable energy. For example, investment in renewable energy might displace jobs in other parts of the power sector such as those associated with power generation from gas-fired plant. Where possible, indicators from surveys or studies completed for projects in Wales have been used so that the employment impacts reflect the economic conditions in Wales as closely as possible. We compared the employment impacts for each scenario to the employment impacts in the Do Nothing scenario, to help us understand what alternative jobs may have been created if the money were invested in similar ways to what it is today.

Results

The values in Table 3.3.3 are presented in Full-Time Equivalent (FTE) so that employment impacts can be adjusted for the lifetime of the project or plant and duration of the job. For example, a job that lasts 1 year for a project where plant lifetime is 10 years would count at 1 × 1 × 0.1 = 0.1FTEs over the duration of the project.

Metric	Do Nothing	National Net Zero	High Demand	Low Demand	High Hydrogen
Energy reduction (GWh, 2050 relative to 2023)	0	98%	98%	98%	97%
Additional gross local jobs between 2023-2030 (FTE)	No change	530	530	1,100	540
Additional gross local jobs between 2023-2050 (FTE)	No change	3,100	3,200	4,100	3,400

Table 3.3.3: Summary of economic impacts for each scenario: employment impacts. Figures shown relate to the period 2023 – 2050

3. The future local energy system

Deployment modelling

Impact on air quality

Reducing the amount of energy we use and using renewable energy sources for power generation can also impact the quality of the air which in turn impacts: human health, productivity, wellbeing and the environment. For example, for every £1 invested in energy efficiency measures, the NHS can save £0.42 (amounting to annual savings of £1.4 billion in England alone)[T35].

Method

We used the Green Book supplementary guidance for air quality[T50] activity costs from primary fuel use and the transport sector to estimate the air quality cost for each year (2023 to 2050) for each scenario. Activity costs simplify evaluating the effects of air pollution by estimating the value of changes to air quality per unit of fuel consumed. Table 3.3.4 provides a summary of the activity costs used in 2023 for the fuel types included in this analysis. The activity cost for electricity was assumed to vary over time; the costs for all other fuels were assumed to remain constant. Air quality activity costs are presented using 2022 prices and are not discounted.

The Green Book does not include air quality impacts of landfill gas, organic matter, sewage gas, or hydrogen. We assumed that these fuels have the same air quality impact as natural gas.

Fuel	Air quality cost (2022 pence/kWh)
Electricity	0.15
Natural gas	0.16
Landfill gas	0.16
Organic matter	0.16
Sewage gas	0.16
Hydrogen	0.16
Biomass	4.70
Coal	3.74
Oil/LPG	1.25
Diesel	1.33
Petrol	0.17

Table 3.3.4: Air quality activity cost factors

monmouthshire sir fynwy
Sponsors: Llywodraeth Cymru Welsh Government
Delivery partners: ARUP, CARBON TRUST, Prifddinas Ranbarth Caerdydd, Cardiff Capital Region

3. The future local energy system

Deployment modelling

Impact on air quality

Results

Table 3.3.5 presents cumulative economic estimate savings from reduced air pollution in each future energy scenario, compared to the Do Nothing scenario.

Figure 3.3.8 presents an annual economic saving, with activity costs decreasing by approximately £17 million per year by 2050 compared to 2023 for all modelled scenarios. Cumulatively, this equates to a savings of £230-240 million on healthcare services in Monmouthshire.

Overall, lower energy demand and an increase in renewable energy generation uptake equates to less local GHG emissions, resulting in better air quality which creates savings through reduced stress on healthcare services. It also allows better health to Monmouthshire residents.

Metric	Do Nothing	National Net Zero	High Demand	Low Demand	High Hydrogen
Cumulative air quality activity costs between 2023-2050 (2022 prices)	£466 M	£230 M	£220 M	£230 M	£230 M

Table 3.3.5: Summary of economic impacts from air quality for each scenario. Figures shown relate to the period 2023 – 2050. Air quality activity costs are presented using 2022 prices and are not discounted

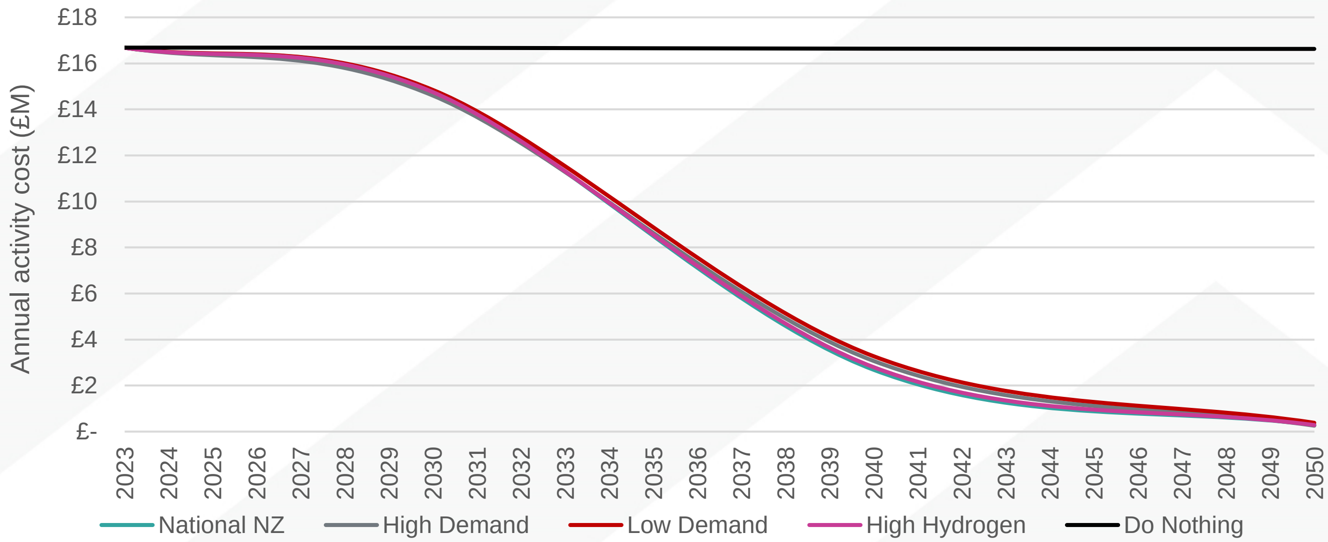


Figure 3.3.8: Annual financial savings stemming from the increase in air quality in each modelled scenario to 2050

3. The future local energy system

Deployment modelling

Investment requirements

High levels of investment will be required to achieve the scale of change required to achieve a net zero energy system. Table 3.3.6 overleaf shows the estimated capital investment (CAPEX) required to build out the critical system components identified in our scenario analysis. Whilst these costs are shown as absolute figures, they should be compared against real-life project examples to determine if additional investment is needed.

Some of these actions will also have additional operational expenditure (OPEX) requirements. For example, heat electrification might result in higher operational costs for consumers. The final capital and operational costs of the energy system are also subject to potential changes in supply, policy, and consumer perception.

We haven't estimated investment requirements where there is a high level of uncertainty in costs:

- Electricity network reinforcement costs will depend on the extent of network upgrades which will be needed across the LV, HV and EHV networks, requiring a more detailed analysis.
- Costs for gas infrastructure have not been included due to the high uncertainty around the scale of the gas network in 2050

Investment throughout the report

Potential future required investment to meet the modelled scenarios and achieve short term aims can be found throughout the report. The key pieces on investment in this report are:

- CAPEX – Indicative CAPEX required for each energy proposition across all scenarios can be found in Table 3.3.6 on page 103 (overleaf).
- Priorities - A breakdown of the suggested priority investment areas to 2030 for Monmouthshire can be found in the plan on a page found on page 109.
- Buildings – Investment costs for the "Improving the energy efficiency of existing buildings" proposition can be found in Table 4.1.2 on page 113.
- Transport – Investment costs for the "Decarbonise transport" proposition can be found in Table 4.1.3 on page 116.
- Renewables – Investment costs for the "Deploy onshore renewables" proposition can be found in Table 4.1.4 on page 120.
- Hydrogen: Investment costs for potential future hydrogen energy components can be found on page 123.

3. The future local energy system

Zoning analysis and deployment modelling

	Indicative CAPEX (£m) (range across scenarios)	Basis for CAPEX estimate	Party responsible for CAPEX	Dependencies on other investments
1. Maximise energy efficiency of buildings	250-3,100	Cost of deep retrofit interventions	Welsh Government, local authority, Registered Social Landlords, building developers, building owners and landlords	
2. Ground-mounted solar PV	760	Build out of ground mounted solar PV	Welsh Government, Building developers, local authority (owned land assets), Registered Social Landlords, building owners and landlords, renewable energy developers	Electricity network
3. Onshore wind	4	Build out of onshore wind		Electricity network
4. Maximise rooftop PV	180	Build out of rooftop PV	Building developers, building owners and landlords, Local authority (owned buildings), Registered Social Landlords, renewable energy developers	Electricity network
5. Decarbonise transport	64-95	Build out of EV chargers and hydrogen refuellers	Charge Point Operators, local authority, building developers, landowners and landlords	Electricity network, hydrogen networks
6. Decarbonise heat	130-210	Heat pump build out costs, heat network decarbonisation cost	Building owners and landlords, local authority, Registered Social Landlords, building developers	Electricity network, energy efficiency of buildings
7. Electricity network intervention	42	Electricity network intervention costs will depend on the extent of network intervention which will be needed across the LV, HV and EHV networks, requiring a more detailed analysis by the DNO.		
8. Roll-out of energy system flexibility	0	Battery, and thermal storage costs	Developers, building owners, energy providers, public, Welsh/ UK Government	Electricity network

Table 3.3.6: Indicative investment requirements by 2050

Monmouthshire LAEP – Technical Report

4. Action planning (stages 6-7)

4. Action planning

Energy propositions

Overview

Figure 4.0.1 shows the process followed to develop the complete LAEP and routemap to transition the local energy system in Monmouthshire.

Energy propositions

Identifying priority focus zones

We discussed what energy system components were common in all scenarios and asked stakeholders what they felt should be prioritised in the near-term. We considered this alongside other technical and social factors (e.g. generation and demand headroom) to prioritise focus zones where they might be deployed.

Creating energy propositions

We took what we learnt from these discussions, and revisited the energy vision and objectives that were agreed with stakeholders. With the strategic vision in mind, we reviewed the results from scenario analysis and deployment modelling to create five energy propositions. These form the strategic foundation for Monmouthshire's LAEP and consolidate the evidence to describe what, how and where to prioritise the deployment of the chosen low-regret energy system components.

Creating the plan

Enabling actions

Using input from stakeholders, highlighted overleaf, we created a routemap and action plan to drive the local energy system transition in Monmouthshire, which includes what needs to happen and what key stakeholders will do to contribute to delivery of the LAEP. This routemap and action plan can be found in the LAEP Main Report.

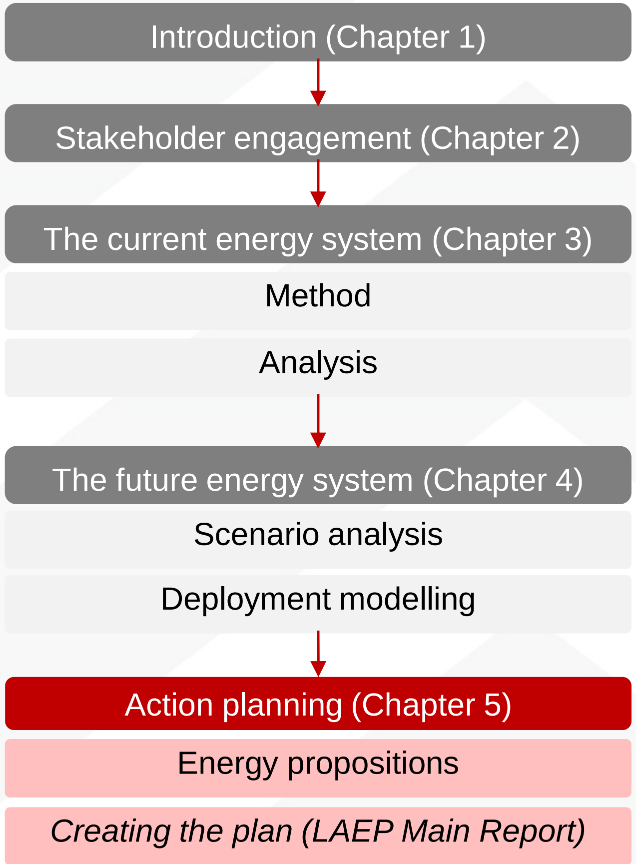


Figure 4.0.1: Flow diagram showing the chapters and sub-chapters in this report (the chapter that follows is highlighted in red)

4. Action planning

Energy propositions

Identifying priority focus zones

Prioritising energy system components

We consulted primary and secondary stakeholders across Monmouthshire and asked:

- Is the energy system component deployed in all scenarios?
- Is this component a strategic priority identified by stakeholders during engagement?
- Does this energy system component align with the wider objectives that have been set for Monmouthshire's?
- Is this energy system component identified as a priority area in Cardiff Capital Region's energy strategy?

We combined this feedback with insights from scenario modelling to develop Monmouthshire's energy propositions, which are the framework for Monmouthshire's LAEP. Monmouthshire's energy propositions focus on areas of the energy system that contribute significantly to the area-wide emissions and have been identified as a priority zone for change in the near term. Energy propositions are a combination of energy system components chosen as a priority to drive change in a particular part of the energy system, that have an indicative timeframe for deployment and magnitude. For example, an energy proposition that includes ground mounted PV as a low-regret energy system component will specify what capacity is needed and by when, as well as indicative investment requirements to achieve it.

Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners:

4. Action planning

Energy propositions

Energy propositions in more detail

1. Improve energy efficiency of existing buildings

Ambition: Enhance the energy efficiency of buildings through retrofitting measures aimed at reducing electricity and heating demand, whilst also transitioning away from fossil fuel-intensive heating systems to more efficient, low-carbon technologies. The following interventions will be considered under this proposals:

- Improving building fabric
- Installing heat pumps and rooftop PV

CAPEX required to deliver: £550 – 3,800 M

2. Deploy onshore renewables

Ambition: Increase renewable energy output by reviewing and updating renewable energy generation targets. Proactively engage with local planners and developers to drive installation of generation assets. The following interventions will be considered under this proposals:

- Deployment of ground-mounted solar PV

CAPEX required to deliver: £760 M

3. Decarbonise transport

Ambition: Reduce transport demand by improving active travel routes and expanding the public transport network. Increase the number of EV chargepoints and explore hydrogen for long-range vehicles. The interventions being considered under this proposition are:

- Installation of EV chargepoints
- Improving active travel routes and the public transport network
- Piloting hydrogen for transport

CAPEX required to deliver: £60 – 77 M

4. Generate green hydrogen for transport and industry

Ambition: Explore options to produce green hydrogen and assess its potential industrial and transport applications. Note that hydrogen for heating homes is not included in this proposition.
The following interventions will be considered under this proposition:

- Investigating the potential for green hydrogen generation

CAPEX required to deliver: £7 – 23 M

5. Reinforce the electricity network

Ambition: Make upgrades to the electricity network that are required to ensure increasing electricity demand can be met. This is key to ensuring the success of propositions (1), (2), (3). The following interventions will be considered under this proposition:

- Upgrading the electricity network

The CAPEX on this page is the amount (£ M) of investment required to meet the 2050 modelled figures. The CAPEX ranges show the minimum and maximum results from each future energy scenario. The CAPEX does not represent the total amount that Monmouthshire County Council needs to spend in order to implement the local actions.

*This CAPEX figure only includes the cost to install EV chargepoints. It does not include investment required to improve active travel routes and public transport networks.
Note: CAPEX has not been calculated for proposition 5 due to the high uncertainty associated with these propositions.

4. Action planning

Energy propositions

Identifying priority focus zones

Our “plan on a page” (overleaf) indicates the location and scale of recommended near-term changes required across Monmouthshire. The map highlights 8 modelling zones identified as priority focus zones for the low-regret energy system components included in Monmouthshire’s energy propositions: heat pumps, EV chargers, rooftop PV, ground-mounted PV, onshore wind, and insulation retrofits. To prioritise where each low-regret energy system component should be deployed, each zone was ranked using the considerations in Table 4.1.1, each weighted by the percentage indicated. A zone was considered for prioritisation if it contributed at least 8% of its primary substation service area[TC06].

- **Off-gas homes** – prioritise zones with higher baseline proportion of off-gas housing, as these are the most likely no-regrets targets for conversion to heat pumps.
- **Socioeconomics** - prioritise zones with higher baseline deprivation (lower WIMD score).
- **Property ownership** - prioritise zones with the most baseline social housing.
- **Substation generation headroom** – prioritise zones with the most baseline generation headroom available.
- **Listed buildings** – prioritise zones with the fewest currently listed buildings.
- **Domestic energy efficiency** – prioritise zones with the highest baseline percentage of homes with an EPC rating of D or below.
- **Built additional substation capacity** - prioritises zones where the least upgrades are required in the high demand scenario, since heat electrification is typically a major contributor to grid upgrade requirements (which may be back-logged by several years).
- **Built EV charging capacity** – prioritise zones with the most EV charging built in the High Demand scenario.
- **Built additional capacity of each local generation technology** (rooftop PV, ground-mounted PV, or onshore wind) – prioritise zones with the largest amount of new modelled capacity built between baseline and 2050 (High Demand).

The summary tables indicate the total scale of change required by 2030, according to the deployment model analysis, and indicate either the total capacity (MW) to be installed or the number of homes requiring retrofit and the associated investment figures.

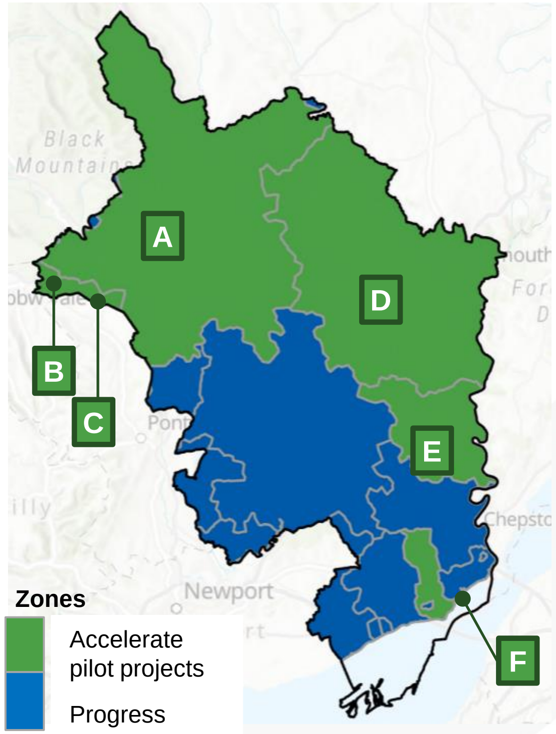
Data	Heat pumps	EV chargers	Local generation	Insulation retrofits
Off-gas homes[T07]	25%	-	-	-
Socioeconomics[T28]	25%	30%	-	20%
Property ownership[T07]	25%	-	-	20%
Substation generation headroom[TC06]	-	-	50%	-
Listed buildings[T04]	-	-	-	5%
Domestic energy efficiency[T07]	-	-	-	35%
Built additional substation capacity	25%	40%	-	20%
Built EV charging capacity	-	30%	-	-
Built additional capacity of each local generation technology	-	-	50%	-

Table 4.1.1: Input data and relative weighting factors used in “plan on a page” calculations

4. Action planning

To support transformation of the energy system, pilot projects may be useful. The map below highlights areas that could provide a useful focus for these pilots

Figure 4.1.1 identifies zones with particularly favourable conditions for specific energy components, making them ideal locations for pilot studies. The summary tables detail key figures for each zone by 2030: (i) pilot ambition, (ii) required investment for each pilot and (iii) total investment for all energy components and electricity network infrastructure interventions. Ranges show the minimum and maximum results from each future energy scenario modelled. Intervention should still be carried out in 'Progress' zones to transition the local area to Net Zero.



Zone		(i)	(ii)	(iii)
Zone A	Abergavenny			
		1,700 – 4,700 homes	£ 17 – 312 M	Total £ 100 – 340 M
		400 – 500 chargers	£ 1.3 – 1.7 M	
		8.9 MW	£ 9.8 M	
		140 MW	£ 59 M	
Zone B	Brynmawr			
		130 – 210 kW	£ 100 – 160 k	Total £ 960 k – 9.8 M
		70 – 120 homes	£ 570 k – 9.4 M	
Zone C	Blaenavon			
		21 – 22 kW	£ 17 – 18 k	Total £ 17– 18 k

Zone		(i)	(ii)	(iii)
Zone D	Monmouth			
		270 kW	£ 55 k	Total £ 84 – 270 M
Zone E	St Arvans			
		540 – 850 kW	£ 400 – 640 k	Total £ 6.5 – 46 M
Zone F	Sudbrook			
		11 MW	£ 8.4 M	Total £ 7.7 – 37 M
		5 MW	£ 2.3 M	

Suggested energy components to pilot in each zone (colour indicates the relevant proposition)

Heat pumps (P1)	EV charger (P3)
Insulation measures (P1)	Onshore wind (P2)
Rooftop PV (P1)	Ground-mounted PV (P2)

Figure 4.1.1: Monmouthshire's spatial representation of opportunities, including 2030 ambition and investment (million £) Zone boundaries are defined by modelling zone

4. Action planning

Improving the energy efficiency of existing buildings

Focus zones for retrofit

National policy indicates a "fabric, worst and low carbon first approach to improve the energy efficiency of the least thermally efficient low-income households in Wales"T38. In Monmouthshire, most homes will need insulation retrofit and heat pumps installed.

Focus zones for insulation retrofit

We used several factors to compare each modelling zone's favourability for near-term insulation retrofits (refer to Table 4.1.1 on page 108). Figure 4.1.2 illustrates the results; the highest-scoring zones are included in Figure 4.1.1 as priority focus areas.

For comparison, Figures 3.2.7 – 3.2.12 (pages 83 – 85) show the quantity of insulation retrofits required in the low demand scenarios, providing an indication to the maximum amount of re

For reference, the focus zones for heat pump installation (discussed further overleaf) are also highlighted in Figure 4.1.3. In the "fabric first" approach, insulation retrofits would precede heat pump retrofits. Care should be taken in these areas to coordinate insulation and heat pump retrofits as needed.

Focus Zones: Brynmawr and Abergavenny

- **Energy efficiency:** Properties had lower levels of energy efficiency in domestic buildings in these zones, with 70% of properties Brynmawr and 53% of properties in Abergavenny had an EPC rating of D or below). This highlights a need for insulation measures and could present an opportunity for a coordinated area- or street-based installation approach.
- **Property tenure:** There is a higher concentration of social housing properties, giving the Council greater influence intervention through engagement with Registered Social Landlords, such as Monmouthshire Housing Association, Melin Homes and Pobl.
- **Likelihood of fuel poverty:** According to the WIMD (2019), an LSOA covering central Abergavenny has a higher level of deprivation compared to most parts of Monmouthshire. Prioritising retrofit in this area could have a significant impact by not only improving energy efficiency and reducing fuel bills but also by directly addressing fuel poverty.

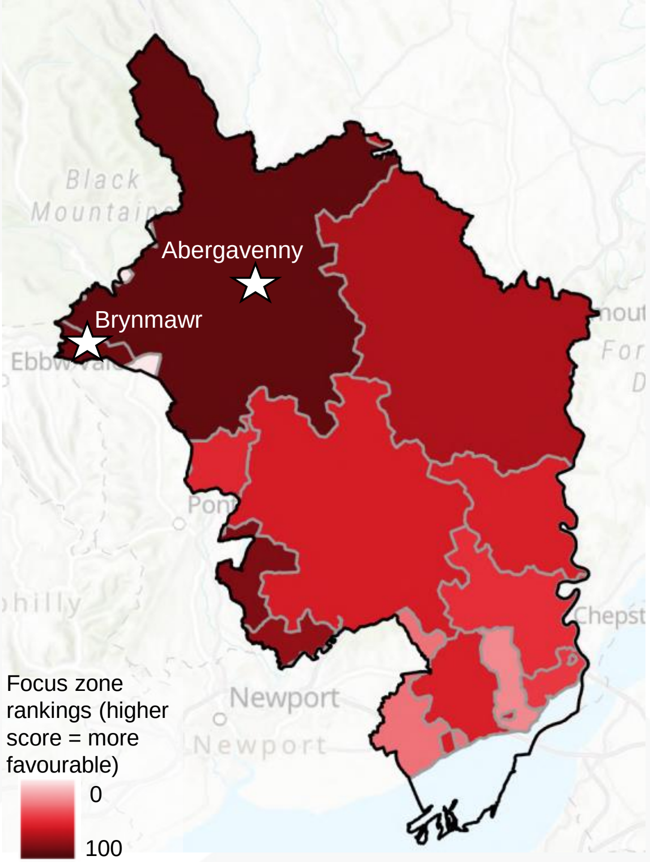


Figure 4.1.2: Priority zones for insulation retrofit

Now: 23,500 homes rated EPC D or below

By 2030: 11,000 homes retrofitted

By 2050: 26,000 homes retrofitted

Connected. Competitive. Resilient.

4. Action planning

Improving the energy efficiency of existing buildings

Focus zones for retrofit

Focus zones for heat pump installation

Electrifying heat in buildings (e.g. via heat pumps) could play a dominant role in decarbonising this sector. We used several factors (refer to Table 3.1.1 in the methodology section) to compare each modelling zone's favourability for near-term heat pump retrofits. Figure 4.1.3 illustrates the results; the highest-scoring zones are included in Figure 4.1.1 as priority focus areas.

For comparison, Figure 2.2.21 on page 53 shows the proportion of homes that are not connected to the gas network. These homes could be low-regrets options for retrofits since they will be the most challenging to serve by low carbon gas networks.

Focus Zones: Brynmawr and St Arvans

- **Substation capacity:** The substations in these zones are less likely to require significant upgrades to meet future energy demands, thereby reducing the likelihood of incurring additional costs for heat pump installations.
- **Off-gas properties:** In Monmouthshire, fewer properties are connected to the gas network compared to other counties in the CCR. The St Arvans zone has an exceptionally high number of off-gas properties, with only around 1% of properties connected to the gas network.
- **Property tenure:** Brynmawr has a higher proportion of social housing relative to other zones, with 22% of properties being social housing. The Council could promote the adoption of heat pumps by engaging with social housing providers. In doing so, it's crucial to emphasise a fabric-first approach, especially for households at risk of fuel poverty. Improving the energy efficiency of properties can help households avoid bill shock when transitioning from gas to heat pumps.

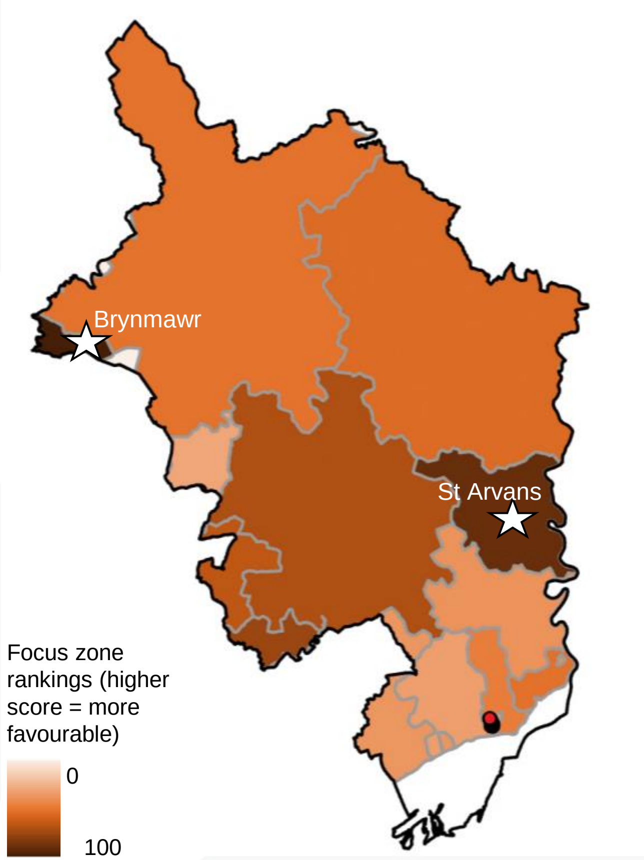


Figure 4.1.3: Priority zones for heat pump installations

Now:	By 2030:	By 2050:
400 heat pumps	**6,700** heat pumps	**41,000** heat pumps

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4. Action planning

Improving the energy efficiency of existing buildings

Focus zones for retrofit

Focus zones for rooftop PV

Across all future energy scenarios, rooftop PV was another prominent technology which featured in Monmouthshire's energy mix. Rooftop PV has been included in this energy proposal because it is commonly integrated into whole-house retrofit projects. Considering rooftop PV with other retrofit measures is beneficial for deployment planning, especially as it is often included in retrofit funding opportunities. The factors that were considered in the prioritisation of zones for rooftop PV installation, are set out in Table 4.1.4. These highest-ranking focus zones are aligned with the priority areas identified in the plan of a page (Figure 4.1.1 on page 109).

Rooftop PV is a more developed, market-ready technology that doesn't require extensive planning permission. We therefore forecast deployment to occur at a relatively consistent rate between now and 2050.

The affordability of rooftop PV systems will have a significant impact on deployment levels, with residential private sector uptake likely slowing if incentives are not provided. Funding schemes, such as grants and green loans, are needed to reduce the upfront costs for consumers and encourage wider adoption.

Focus Zones: Abergavenny and Sudbrook

- **Building density:** The Abergavenny zone covers more densely populated urban areas, where higher building densities provide more rooftop space for PV systems.
- **Deployment of technology:** Our model projects significant rooftop PV installations in Abergavenny, reaching 33 MW by 2050. This is predominantly due to the large amount of roof space identified in the area.
- **Substation capacity:** The Sudbrook zone has higher generation headroom, indicating that the primary substations are more likely to have the spare capacity needed for connecting solar PV systems to the network.

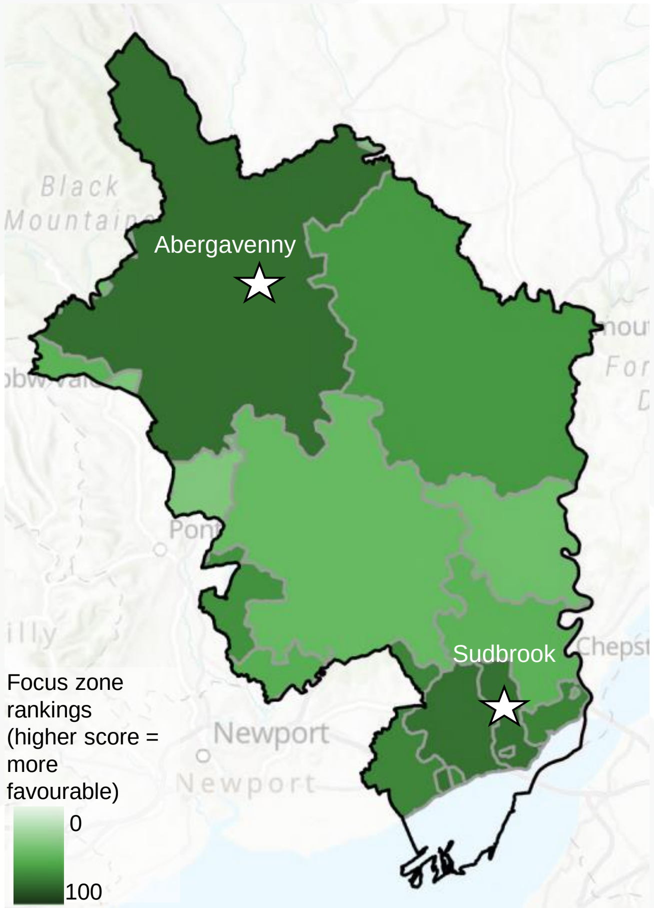

Figure 4.1.4: Priority zones for rooftop PV installations

Now: **400 homes** rated EPC D or below

By 2030: **10,000 homes** retrofitted

By 2050: **41,000 homes** retrofitted

4. Action planning

Improving the energy efficiency of existing buildings

Investment requirements

Investment in retrofit

The upfront investment for retrofit varies depending on the package of measures appropriate for each archetype as well as to what level of performance buildings are retrofitted. In the High Demand scenario, the cost of retrofit can between £8,400 - £25,000 per household and £60,000 – £150,000 per commercial property. In the Low Demand scenario, where the rate of retrofit is significantly higher, the cost is between £39,000 - £150,000 per property and £120,000 - £290,000 per commercial property.

Investment in heat pumps and rooftop PV

The upfront cost for a heat pump and rooftop PV 4 kW system is estimated between £4,500[T42] and £4,400[T52] , respectively. For most homeowners, the cost of equipment is a significant barrier to installation, which has contributed to a slow uptake across the UK[T43].

Note that the modelling process does not account for the feasibility of physically installing heat pumps, which may be more challenging in denser areas with terraced housing due to limited space. Similarly, the modelling does not assess the feasibility of installing rooftop PV systems, as it does not evaluate factors which could impact the ability to install such systems such as, structural integrity of rooftops, shading and asbestos.

Funding opportunities

- Social housing grants
- Private rented properties can be eligible for the GBIS (Great British Insulation Scheme) and landlords are also required to get their properties to EPC C by 2030
- For owner-occupied housing – GBIS is limited, and uptake is low (throughout Great Britain there were only 1,000 installations in November 2023)
- The boiler upgrade scheme (BUS) is also available for eligible properties for up to 45kWth air and ground source heat pumps providing £7.5k of funding per property.
- Bulk purchasing schemes through the council can be attractive to increase uptake of solar PV, insulation and batteries. Many councils have trialled these programmes, so lessons learnt should be available
- Alternative funding such as Retrofit credits via the HACT scheme are available for social housing organisations, these are carbon credits related to the reductions and social value from the retrofit scheme which are sold to provide the investment funding.

Energy system component	Investment required for proposal between 2023 and 2030	Investment required for proposal between 2030 and 2050
Retrofit	£100–1,300 M	£140–1,800 M
Heat pump	£20–31 M	£105–172 M
Rooftop PV	£46 M	£175 M
Resistance heating	£0	£150–570 M

Table 4.1.2: Total investment costs by energy system component

4. Action planning

Decarbonise transport

Focus zones for public transport and EV chargepoints

The transport proposal for Monmouthshire covers active travel, public transport, the deployment of EV's and necessary infrastructure on publicly-owned land. This remit falls within Local Authority's direct sphere of influence. We used the transport hierarchy in our modelling which follows Welsh policy of 13% conversion to active travel.

Predicted EV chargepoint deployment from Wales' EV Charging Strategy[T44] is that by 2030, there could be a total of 32,345 public and privately owned EV chargers in Monmouthshire, of which:

- 95 are rapid
- 2,220 are fast
- 30,030 slow chargers

Note that these from Wales' EV Charging Strategy[T44] are likely to be amended imminently and may differ, reflecting a slower initial rate of deployment. These numbers also differ from Monmouthshire's Cenex report findings.

While the Council intends to install more EV chargepoints on publicly owned land, additional investment will be required to support future deployment across Monmouthshire's privately owned land and to encourage the uptake of EVs.

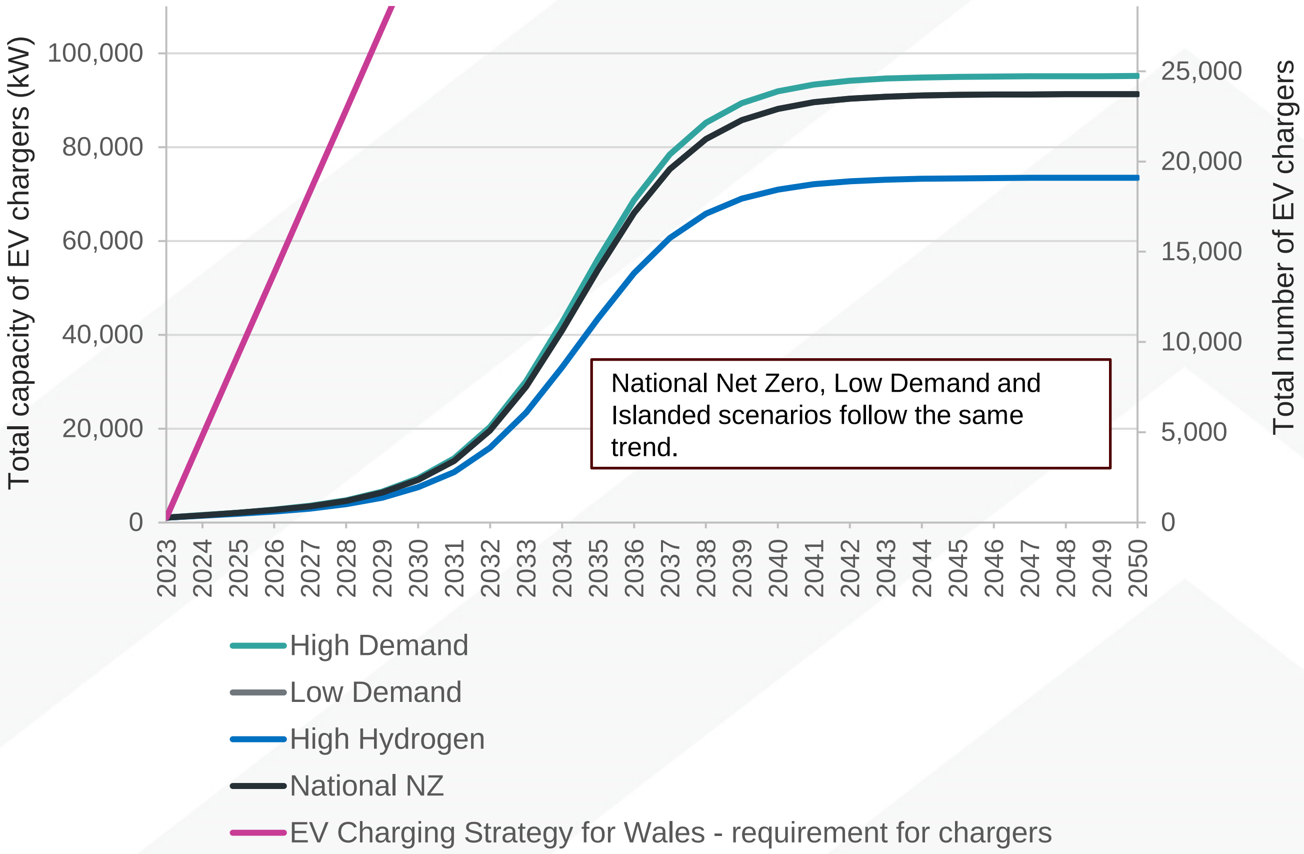

Figure 4.1.5: Capacity and EV chargepoint deployment over time. Note two axes have been provided to translate the total capacity into the total number of EV chargers

4. Action planning

Decarbonise transport

Focus zones for EV chargepoints

Electric vehicle ownership is expected to increase based on national policy and legislation that requires a phase-out of new combustion engine vehicle sales by 2035 under the zero emissions vehicles mandate[T48].

We used several factors (refer to Table 3.1.5 in the methodology section) to compare each modelling zone's favourability for near-term installation of EV chargers. Figure 4.1.6 illustrates the results; the highest-scoring zones are included in as priority focus areas.

To support the development of an efficient, cost-effective EV charging network, further analysis of off-street parking availability, transport patterns and locations of 'destinations' for destination public charging would be required to refine the strategic placement of EV chargers. For example, considering charging hubs in areas with limited off-street parking, or at locations regularly visited by residents such as supermarket car parks.

Focus Zones: Blaenavon and Abergavenny

- **Substation capacity:** Blaenavon has substation capacity spare for meeting new demand.
- **Deployment of technology:** Our model forecasts significant growth in EV chargepoints within the Abergavenny zone, projecting a combined capacity of 24 MW. Road mileage in this zone is particularly high, which likely due to it covering more built-up areas within Monmouthshire. Installing additional EV chargepoints will support the decarbonisation of this demand by enhancing the accessibility of charging infrastructure. The Council should explore the deployment of different types of charging infrastructure, particularly in densely populated areas where roadside parking is more common.

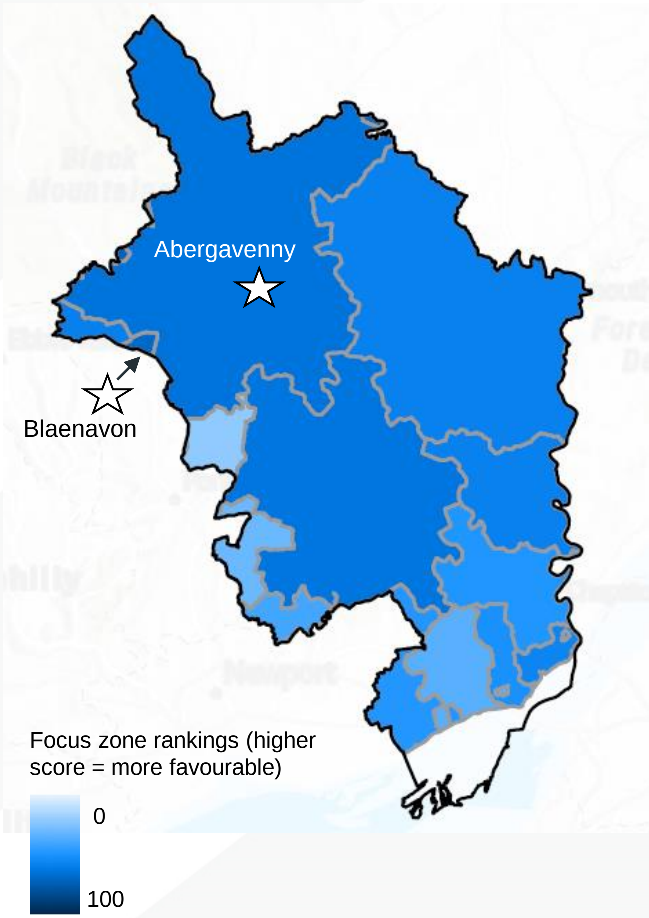

Figure 4.1.6: Priority focus zones for EV chargepoints by substation

Now: **260** EV charge points

By 2030: **2,300** EV charge points

By 2050: **23,000** EV charge points

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4. Action planning

Decarbonise transport

Investment requirements

Investment in EV chargers

The cost to install EV chargepoints will largely depend on the type of charger being installed, as different chargers have varying power outputs and installation requirements. We have calculated the CAPEX assuming the cost per kW is £817. The ratio of EV chargers in Monmouthshire was taken from the EV Charging Strategy for Wales[T44], which forecasts the following distribution:

- Slow (3kW) – 94% of chargers
- Fast (14.5kW) – 5.7% of chargers
- Rapid (43kW) – 0.4% of chargers.

The average power rating per charger is 3.8kW, resulting in an estimated cost per charger of approximately £3,100. In reality, this cost would vary depending on the specific model of the charger and the type of installation (e.g., on-street or off-street).

Investment in active travel and public transport

Our modelling does not account for the investment needed to enhance public transport services and active travel routes. The Council will continue their ongoing efforts to improve these services, as demonstrated in the actions outlined in the 'Decarbonise Transport' energy proposal.

Funding opportunities

- Electric Vehicle Infrastructure Grant for Small and Medium-Sized Businesses provides financial support to small and medium-sized businesses by offering a discount on the installation costs of electric vehicle (EV) chargepoints and associated infrastructure.
- Electric Vehicle Chargepoint and Infrastructure Grant for Landlords offers landlords financial assistance for the installation of EV chargepoints and related infrastructure in rental and leasehold properties, covering a portion of the associated costs.
- Workplace Charging Scheme covers up to 75% of the installation costs for EV chargepoints at workplaces. Note that this scheme is only open until March 2025 and offers minimal funding compared to commercial fleet chargepoint installation.
- Electric Vehicle Chargepoint Grant for Households with On-Street Parking provides homeowners or renters with 75% off the cost of purchasing and installing an EV chargepoint, specifically for properties with on-street parking.

Energy system component	Investment required for proposal between 2023 and 2030	Investment required for proposal between 2030 and 2050
EV chargers	£ 5.3 – 6.9 M	£ 70 – 54 M

Table 4.1.3: Total investment costs by energy system component

4. Action planning

Deploy onshore renewables

Focus zones for local electricity generation

All scenarios show a shift to electrified heating and transport, which could increase the need to harness renewable electricity sources to meet increasing electricity demand. Figure 4.1.7 shows the range of possible deployment of ground-mounted solar and onshore wind across the scenarios in Monmouthshire.

Monmouthshire's Renewable Energy Assessment (REA) was used to determine the amount of land suitable for solar PV and onshore wind, providing the theoretical potential for each renewable technology. The nature of the REA accounts for the protection of good quality agricultural land (grades 1,2 and 3) and environmental and historic designations.

The future energy scenarios indicated that by 2050, an additional 1.7 GW of ground-mounted solar PV was modelled to meet future energy demand (including export from Monmouthshire). The modelling also suggests that an additional 3.7 MW of onshore wind would be required by 2050.

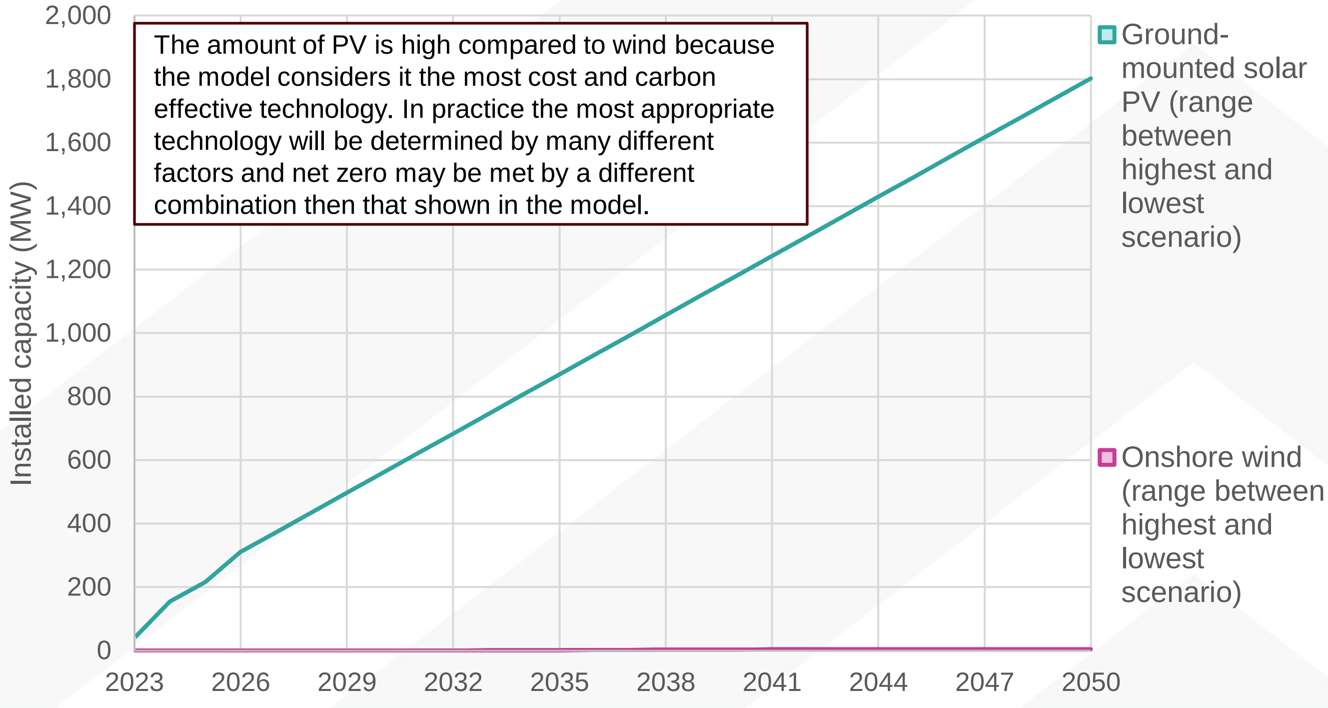

Figure 4.1.7: Summary of scale of renewables deployment across scenarios

Now:	By 2030:	By 2050:
40 MW ground solar PV capacity	**560 MW** ground solar PV capacity	**1,800 MW** ground solar PV capacity
0.23 MW onshore wind capacity	**0.3 kW** onshore wind capacity	**4 MW** onshore wind capacity

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4. Action planning

Deploy onshore renewables

Focus zones for local electricity generation

In the initial stages of the modelling process, the 2020 Renewable and Low Carbon Energy Assessment (RLCEA) was used to identify land suitable for onshore wind and ground-mounted PV. The assessment revealed that Monmouthshire has the potential to generate 9 GW of renewable energy. However, feedback received on the initial future energy system modelling results indicated that this level of renewable energy generation was unrealistic. Since the RLCEA was published, Welsh Government updated their planning policies to protect agricultural land classified as 'the best and most versatile.' In response to this feedback and changes in policy, we revised the land suitable for renewable deployment, excluding land grades 1 to 3a. As a result, the maximum theoretical capacity for ground-mounted solar PV decreased from 7.7 GW to 1.8 GW. The maximum theoretical capacity for onshore wind remained unchanged at 6 MW.

To support Monmouthshire in getting to net zero, ground-mounted capacity is shown in the scenario analysis to reach 1.8 GW. Onshore wind capacity is deployed to reach 66% of its maximum theoretical capacity at 4 MW. Whilst we recognise this scale of build out to be ambitious, we suggest that the shaded orange areas on the map would be priority locations for the development of solar PV infrastructure.

Focus Zones: Abergavenny, Monmouth and Sudbrook

1. **The Sudbrook zone's** primary substation has the most capacity available for the connection of renewable generators.
2. **The Abergavenny zone** has a large amount of suitable land for ground-mounted solar PV deployment. However, the primary substation has more limited headroom comparison to the Sudbrook zone.
3. **The Monmouth zone** has land suitable for both onshore wind and ground-mounted solar PV deployment. The lack of primary substation headroom indicates the area may require reinforcement.

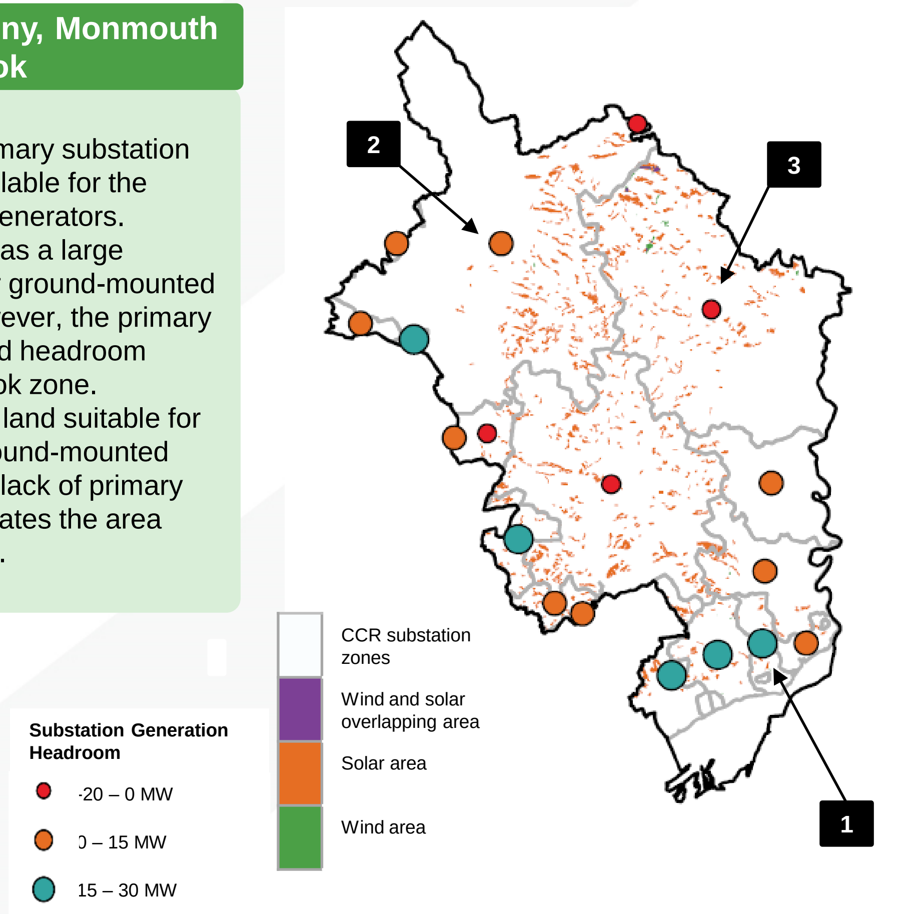

Figure 4.1.8: Areas suitable for wind and ground-mounted solar PV development in Monmouthshire and substation generation headroom (MW)

4. Action planning

Deploy onshore renewables

Focus zones for local electricity generation

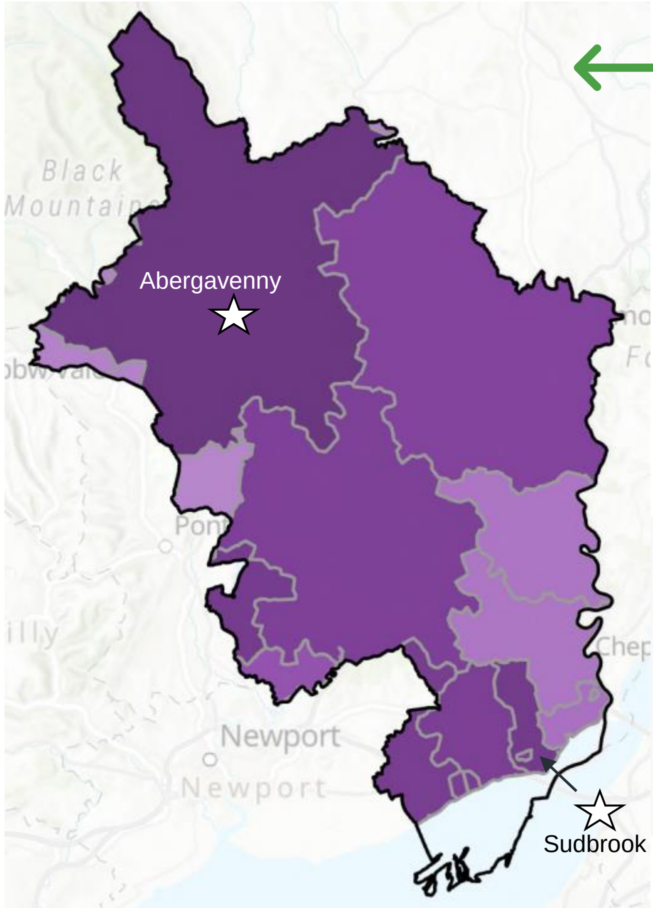

Figure 4.1.9: Focus zone rankings for ground-mounted solar PV by modelling zone

Focus Zones: Abergavenny and Sudbrook

Focus Zones: Monmouth and Sudbrook

- **Suitability of land:** These zones have a large amount of land identified as suitable for ground mounted solar PV and onshore wind deployment.
- **Deployment of ground-mounted PV:** Our model forecasts large deployment in the Abergavenny zone at 430 MW.
- **Deployment of onshore wind:** Our model forecasts the largest deployment of onshore wind in the Monmouth zone at 3 MW.
- **Substation capacity:** The Sudbrook zone has the highest generation headroom so is less likely to require reinforcement for the connection of renewables.

Note: Where substation capacity is limited, alternative delivery models could be explored. For example, if a generator has a private wire connection, it will bypass the need for additional substation capacity and thereby reduce headroom constraints.

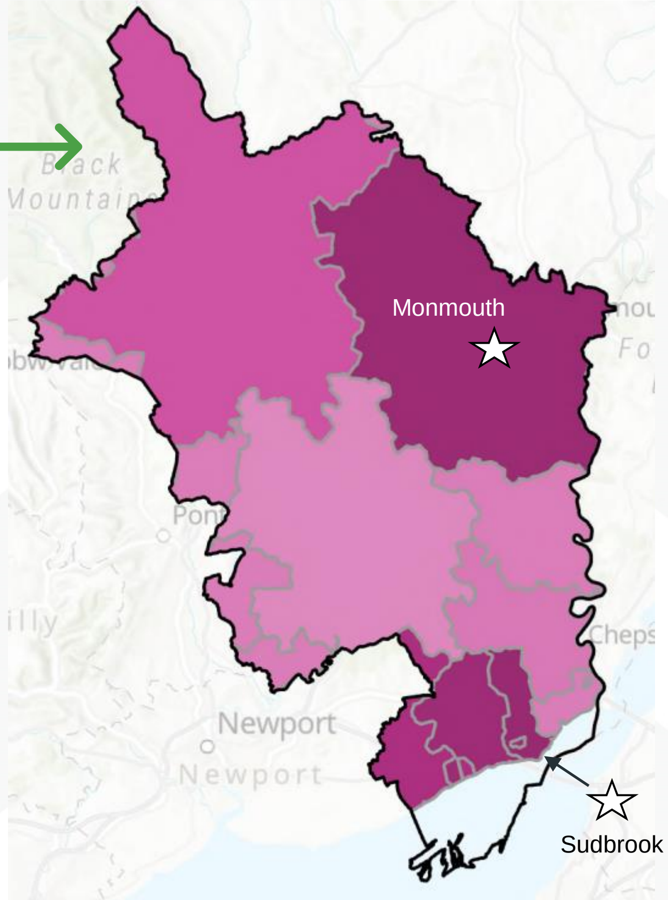

Figure 4.1.10: Focus zone rankings for onshore wind by modelling zone

4. Action planning

Deploy onshore renewables

Investment requirements

The deployment model estimates the capital investment required for ground-mounted PV and onshore wind technologies, which are provided in Table 4.1.4.

Funding opportunities

Funding for solar and wind is most likely to come from private investment as currently, there are no government incentives for onshore renewables.

Community energy groups can support renewable deployment by:

- Encouraging public buy-in for renewable energy projects
- Retaining value in the local area
- Presenting an educational opportunity that cuts across the whole energy system by giving people a sense of ownership and understanding of the energy they use

Funding models could consider how communities can support energy schemes, such as community-ownership schemes through share-offers or other ownership models.

Energy system compone nt(s)	Investment required for proposal between 2023 and 2030	Investment required for proposal between 2030 and 2050
Ground-mounted PV	£220 M	£ 540 M
Onshore wind	£60 k	£4 M

Table 4.1.4: Investment costs by energy system component

4. Action planning

Reinforce the electricity network

How networks operate at the moment

To achieve a net zero energy system, there are major changes needed to both the electricity and gas networks. NGED (electricity distribution network operator in the Cardiff Capital Region and WWU (gas distribution network operator in Wales) are regulated utilities, and their operation is controlled by business planning cycles. They submit business plans in cycles:

- For electricity networks: RIIO-ED2 runs from 2023-2028, and ED3 will commence in 2028; the exact time period hasn't been announced yet.
- For gas networks: GD2 runs from 2021 to 2026. It was considered whether to extend GD2 to align the two networks. However, it's been announced that GD3 will start in 2026 for a "medium term ex-ante" period. Consideration is being given to the length of GD3.

Outside of these cycles, a strategic reopener can be submitted to Ofgem to determine if there is sufficient evidence to make a case for additional investments beyond the business plans.

NGED undertakes an annual modelling, planning and reporting process called Distribution Future Energy Scenarios (DFES) to support business planning, shown in Figure 4.1.11. WWU similarly uses historical data and modelling tools such as Pathfinder to forecast expected demands, resilience and storage needs, and general system operation. While these forecasting tools each incorporate some amount of input from the other network type (for example, DFES considers different options for heat pumps vs hydrogen for heating), they don't typically actively interlink and cross-communicate throughout the analysis processes. Therefore, the whole systems modelling undertaken within the LAEP process can be used as evidence to make strategic changes to the networks.

It is clear from the stakeholder engagement undertaken throughout the project, that one of the barriers currently is that the costs and timeframes of getting grid connections for renewable schemes and new development can make projects unviable.

The gas network provides natural gas to 75% of homes in Monmouthshire. Policy context for hydrogen shifted on 14th December 2023 with a decision to allow blending of 20% hydrogen into the network which will reduce the carbon emissions from the gas network by 7%, however this isn't a zero-carbon solution.

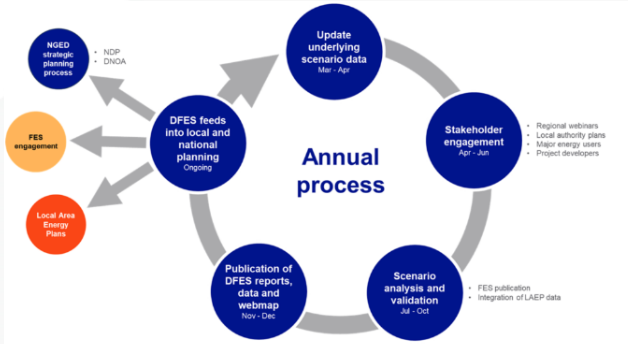

Figure 4.1.11: NGED's annual DFES process (credit: NGED)

4. Action planning

Reinforce the electricity network

Network transition planning

Our modelling shows that the electricity network needs upgrades and reinforcement to get ahead of the pace of change in renewables, heat pumps, EV charging and electrolysis.

For the electricity network to serve the growing demand shown in Figure 4.1.12, our modelling indicates that 10 primary substations will need upgrading between now and 2050. This equates to 255 MW of extra capacity being unlocked through reinforcement. Furthermore, the network may require additional upgrades following comprehensive contingency analysis.

In the High Demand scenario, the estimated cost of reinforcement between now and 2050 is £42 million, equating to approximately £950 per home. However, it is important to emphasise that there is a degree of uncertainty associated with these costs. The type of upgrade required depends on the specific substation and is determined by design-level decisions. Consequently, the extent of substation reinforcement and the associated costs are challenging to predict accurately.

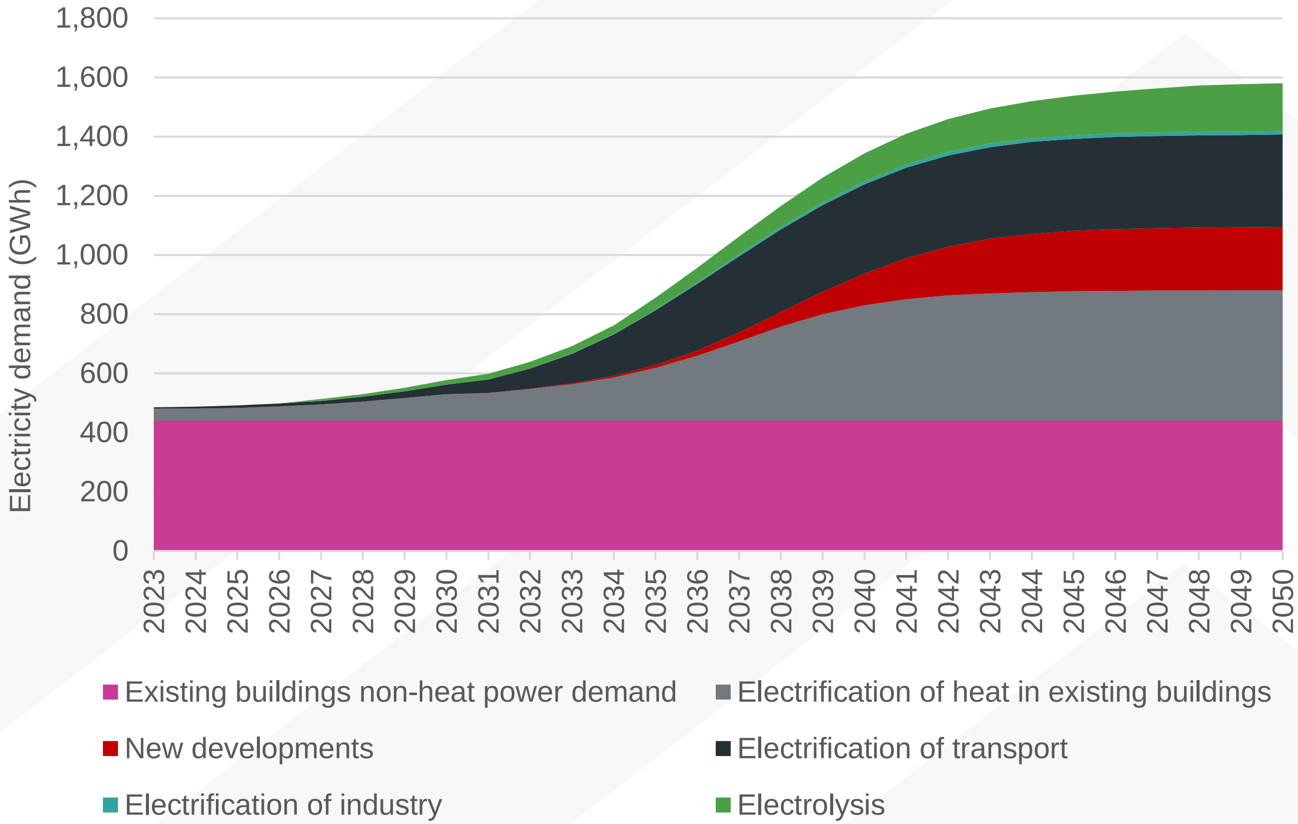

Figure 4.1.12: Projected power demand increase overtime in the High Demand scenario

4. Action planning

Reinforce and transition energy networks

Network transitions

Hydrogen networks

There is more uncertainty around the changes needed for the gas network to enable the transition to net zero. There is a need to understand the role of the gas network in 2050, by continuing to explore the transition to hydrogen and alternatives such as biomethane for specific locations. It's important to continue to explore this, and to make sure that changes made in the energy system do not negatively impact the gas network transition. Our modelling excludes the cost of decommissioning the gas network, which is expected to be significant.

The gas network is undergoing a significant REPEX programme to make the gas networks more suitable for hydrogen by replacing iron mains within 30 meters of a property. The programme is mandated by UK Health and Safety Executive and funded by OfGem. Across Wales, WWU is currently 22 years into the 30-year programme, with a projected end date in 2032.

In the High Hydrogen scenario, the projected annual hydrogen demand for industry is 12 GWh, and for transport is 70 GWh by 2050. However, these values require further verification with key industry stakeholders in Monmouthshire.

To test the sensitivity of hydrogen, we undertook optimisation model runs to incorporate hydrogen for heating. In these model runs we see an additional amount of peak capacity for hydrogen heating. However, our HeatNet modelling did not show any focus zones for hydrogen heating. The optimisation model chooses hydrogen boilers for peak capacity only, which is a very unlikely domestic set up since it would be expensive per household. Therefore, we believe the future of hydrogen for home heating is still uncertain and has therefore been from this short-term roadmap and proposals.

By 2050, the model shows the hydrogen required for industry and transportation is produced via electrolysers with a combined capacity of 12 to 14 MW. Hydrogen is currently localised in the model, which means it is used at the point of production or imported into the system from a national asset.

To achieve the deployment rate outlined in the model, an investment of £900,000 to £2,000,000 in hydrogen will be needed in Monmouthshire by 2030. Additionally, WWU's project HyLine Cymru has the potential to distribute low-carbon hydrogen and thus support the transition across South Wales.

4. Action planning

Reinforce and transition energy networks

Network transitions

WWU are actively involved in a range of innovation projects. Some examples specific to WWU's network in Wales:

Regional decarbonisation pathways – Completed in 2022, these pathways provide a strategic plan to decarbonise Wales (and Southwest England), outlining future gas network requirements to achieve the optimal energy system for the WWU network. Most of the projects described below have been designed to progress these findings and the resulting roadmap.

Hyline Cymru – plans for a new dedicated hydrogen pipeline across south Wales, linking hydrogen production with industrial demand.

Industrial Fuel Switching – Feasibility of fuel switching two sites in North Wales.

For more information on WWU's active projects, visit Network Innovation Allowance - Annual Report 22-23

Storage

Short term and seasonal storage also needs consideration. While our modelling does not show a lot of electrical storage, the majority of scenarios use the electricity grid as storage, choosing to export when there is excess renewable energy in the system and to import when there is a deficit of renewable energy in the system. This means that there is a need for some national asset level storage. Especially since neighbouring local authorities which opt for weather-dependent renewables (e.g. PV and wind) are likely to be generating (and thus exporting) renewable energy at similar times, there is a need for national asset level storage to provide flexibility and resilience in the energy system. This could come in many forms, including batteries, hydrogen storage with CCGT and CCUS, nuclear, or more innovative alternatives. Especially where these storage solutions incorporate multiple energy vectors (for example, hydrogen storage) the relevant network operators will require close collaboration to ensure the storage solution effectively meets the needs of the regional or national energy system.

Our model uses wholesale electricity costs; based on a cost of 6.3p/kWh for the 4,470GWh/year of electricity imported in the high demand scenario, this equates to £281million/year.

4. Action planning

Reinforce and transition energy networks

Network transitions

Smart Local Energy Systems (SLES):
SLES use different energy assets and infrastructure (known as Distributed Energy Resources (DERs)) to enable an area-level optimised demand and supply balance. SLES minimises unnecessary transition between vectors and can lead to benefits in terms of costs and carbon emissions. They are particularly beneficial where there is strong interplay between demand energy vectors (heating, cooling, electricity, and hydrogen).
SLES technologies can provide flexibility services to the national or local power networks, by shifting electricity demand in response to pricing or carbon signals. Technologies can interact directly with the DNO, or they may be aggregated by a central SLES market / control platform which enables the different technologies to interact with one another, and even enable peer to peer trading of energy generation, demand and storage.

Smart local energy systems

We have undertaken model runs at hourly, 3 hour and 24-hour intervals. These show that as the interval shortens, the annual electricity use (i.e. the GWh shown in the Sankey diagram) increases which is due to the peaks in the demand. When the demand is smoothed out over 24 hours, the annual electricity use is smaller. If there were mechanisms to manage local supply vs demand, the annual electricity use could be decreased.

Areas to focus on would be those which need substation interventions shown in Figure 3.2.16 (page 89). DNOs could collaborate with Local Authorities to identify areas suitable for SLES pilot studies.

Investment in SLES can reduce the cost of upgrades needed in the electricity network and expediate the time that it takes to get a grid connection. Applying SLES as a means to avoid reinforcing the electricity network (thus reducing the cost of network upgrades) has nuanced impacts on the reliability and safety of the network which should be carefully considered by each community before implementing this approach.

Regulations need to make it easier for local communities to benefit from renewables installed behind the substation (as opposed to behind the meter). Local communities should be able to respond to signals about their demand to use their localised electricity. Electricity suppliers are rolling this out on a national basis (for instance Octopus saver sessions), and localised trials have been happening, however this is not easy to put in place currently.

Monmouthshire LAEP – Technical Report

Appendices

Section A

monmouthshire sir fynwy

Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners: ARUP, CARBON TRUST, Prifddinas Ranbarth Caerdydd | Cardiff Capital Region

Appendices

Section A

Sponsors: Delivery partners:

Appendix A1

Deployment modelling – National, regional and local policies applied

National (UK or Wales) proposed and committed policies	Source
No more fossil vehicles from 2035	UK Gov – Decarbonising Transport – A Better, Greener Britain. Available at: https://www.gov.uk/government/publications/transport-decarbonisation-plan
No new gas boilers from 2035	UK Gov – Net Zero Strategy: Build Back Greener. Available at: https://www.gov.uk/government/publications/net-zero-strategy
Phase out unabated coal by 2024	
Gov committed to deploying CCUS at scale in 2030s	
Gov committed to 10GW H_2 production by 2030	
New homes low carbon heating ready by 2025	Rigorous new targets for green building revolution. Available at: https://www.gov.uk/government/news/rigorous-new-targets-for-green-building-revolution
UK Gov projects 600,000 heat pumps a year by 2028 (UK), up from 35,000 in 2021	Energy Security Bill factsheet: Low-carbon heat scheme. Available at: https://www.gov.uk/government/publications/energy-security-bill-factsheets/energy-security-bill-factsheet-low-carbon-heat-scheme
700,000 building retrofits by 2025, and all buildings by 2050 (UK)	UK Gov – Energy efficiency: what you need to know. Available at: https://www.gov.uk/government/news/energy-efficiency-what-you-need-to-know
Private rented homes EPC C by 2030, and EPC B for commercial units	UK Gov – Heat and Buildings Strategy (2021). Available at: https://www.gov.uk/government/publications/heat-and-buildings-strategy/heat-and-building-strategy-accessible-webpage
Only 4 low carbon industrial clusters by 2030, and one net zero cluster by 2050 (UK)	UK Gov – Industrial Decarbonisation Strategy. Available at: https://www.gov.uk/government/publications/industrial-decarbonisation-strategy
Quicker and more proportionate consenting regime for energy storage - all planning applications have been delegated to Welsh Local Planning Authorities	Welsh Gov Developments of national significance (DNS). Available at: https://www.gov.wales/developments-national-significance-dns-guidance
Welsh Gov requirement to explore heat networks within Future Wales	Heat strategy for Wales. Available at: https://www.gov.wales/heat-strategy-wales

Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners: ARUP, Carbon Trust, Cardiff Capital Region

Appendix A1

Deployment modelling – National, regional and local policies applied

Local proposed and committed policies	Source
2025- EVs projected on the road for MCC area (235 sockets): 8,450	MCC EVCI Strategy
2030- EVs projected on the road for MCC area (608 sockets): 29,100	MCC EVCI Strategy
2040- EVs projected on the road for MCC area (1100 sockets): 64,300	MCC EVCI Strategy
Total EV charging points in construction/ already built: 39	MCC EVCI Strategy
Planned building of 10,000 new homes in Caldicott over long term redevelopment plan (2050)	RCLEA MCC Non Technical Summary
Renewable and low carbon energy generation (heat and electrical) in Monmouthshire: 97MW	RCLEA MCC Non Technical Summary
Assessment identifies potential for 9GW renewable capacity within Monmouthshire	RCLEA MCC Non Technical Summary
Monmouthshire council construction of small scale solar farm: 5MW	Renewable and Low Carbon Energy Assesment for Monmouthshire
Monmouthshire council installed solar on 39 council buildings	Renewable and Low Carbon Energy Assesment for Monmouthshire
Projected energy consumption 2033 (-4% from 2017 baseline): 2441GWh	Renewable and Low Carbon Energy Assesment for Monmouthshire
Current energy consumption: 2541GWh	Renewable and Low Carbon Energy Assesment for Monmouthshire
Projected electricity consumption 2033 (+11% from 2017 baseline): 413GWh	Renewable and Low Carbon Energy Assesment for Monmouthshire
Current electricity consumption: 371GWh	Renewable and Low Carbon Energy Assesment for Monmouthshire
Estimated annual energy generation from renewable sources: 189,266MWh	Renewable and Low Carbon Energy Assesment for Monmouthshire
Total estimated heat generation: 29MW	Renewable and Low Carbon Energy Assesment for Monmouthshire
Three new sites proposed totaling 12.6 MW or 11,039 MWh p.a.	Renewable and Low Carbon Energy Assesment for Monmouthshire
Existing low carbon energy generation equates to 11% current consumption	Renewable and Low Carbon Energy Assesment for Monmouthshire
Existing low carbon energy generation equates to 16% projected demand 2033	Renewable and Low Carbon Energy Assesment for Monmouthshire
Current renewable electricity generation equals 51% of current demand	Renewable and Low Carbon Energy Assesment for Monmouthshire

Appendix A1

Deployment modelling – National, regional and local policies applied

Local proposed and committed policies	Source
Current renewable electricity generation equals 50% of projected demand	Renewable and Low Carbon Energy Assesment for Monmouthshire
Planning for 10MW ground mounted solar	WGES Screening Report Penarth Site Farm
Planning for 10MW ground mounted solar	WGES Screen Report Bridge View Farm
Electricity grid demand 2020 in Caldicot: 39,339MWh	An Energy Revolution for the Market Town of Caldicot
Projected grid demand 2030 in Calidicot: 61,967MWh	An Energy Revolution for the Market Town of Caldicot
Total Co2 emissions Caldicot (tonnes): 19,273CO2e	An Energy Revolution for the Market Town of Caldicot
Projected total Co2 emissions Caldicot (tonnes) (2030): 37,586CO2e	An Energy Revolution for the Market Town of Caldicot
Jigsaw, Ringland site approved for 200 dwellings	The Vale of Usk Heat Mapping and Masterplanning Report
Llanwern village development sites, 110 dwellings and a primary school	The Vale of Usk Heat Mapping and Masterplanning Report
Provision for approximately 5940 new homes over planning period (2033)	MCC RLDP- Prefered Strategy
Plan includes 1580 affordable homes (2033)	MCC RLDP- Prefered Strategy
Monmouthshire has an estimated population of 92,961	MCC RLDP- Prefered Strategy
New jobs by 2040: 25,000	MCC RLDP- Prefered Strategy
10.9% population growth from 2018 to 2033: 9,480	MCC RLDP- Prefered Strategy

Appendix A2

Glossary of terms

Term	Definition or meaning
Action	The process of doing something – a specific action assigned to a responsible person preferably with a date to be completed.
Anaerobic digestion	Processes biomass (plant material) into biogas (methane) that can be used for heating and generating electricity.
Baseline	The baseline is the data showing the current energy system, containing the 2019 data sets provided by the LA and publicly available data.
Batteries	Devices that store electrical energy to be used at a later time.
Biomass boiler	A boiler which burns wood-based fuel (e.g. logs, pellets, chippings) to generate heat and electricity.
Carbon capture and storage (CCS)	The process of capturing and then storing carbon emissions before they enter the atmosphere.
Carbon neutral	Check preference with LA and note down in the table in Glossary of terms.docx .
Cardiff Capital Region	Cardiff Capital Region is a regional body (also known as a Corporate Joint Committee) made up of the 10 councils across South East Wales; Blaenau Gwent; Bridgend; Caerphilly County Borough; Cardiff; Merthyr Tydfil; Monmouthshire, Newport; Rhondda Cynon Taf; Torfaen; Vale of Glamorgan.
Certainties	A fact that is definitely true or an event that is definitely going to take place. In terms of a local energy system, certainties include funded projects, etc.
Demand	Local energy demand that the local energy system needs to meet.
Demand headroom	The difference between the electrical capacity of a substation, and the electricity demand at the substation at the time of peak demand.

Appendix A2

Glossary of terms

Term	Definition or meaning
Deployment modelling	A model investigating rates by which to deploy specific technologies between the baseline year and 2050 to achieve the end state developed by the optimisation model for each scenario. The model considers broader plan objectives and local, regional, and national strategic priorities, policies, and targets to help us to define a suitable level of ambition and inform an action plan.
Dispatchable energy generation	Energy generation that can turn on and off (i.e. isn't controlled by the weather) – this is likely to be gas turbines of some sort.
Distribution network	Takes energy from transmission network and delivers it to users via pipes or wires at low pressure / voltages.
Electricity network	Interconnected infrastructure which consists of power stations, electrical substations, distribution lines and transmission lines. The network delivers electricity from the producers to consumers.
Electrolyser	A piece of equipment that uses electricity to split water into hydrogen and oxygen.
Energy proposition	A proposition is an energy component with a scale and a timescale. For instance, X MW of wind turbine to be built in 5 years, 10,000 buildings to retrofit with XX by 2030, or a pilot project such as hydrogen storage innovation. These are typically near term, low regrets energy components that are needed in future energy systems (it is likely that these appear in all scenarios).
Energy system component	A term used to describe [illegible] ave a direct impact on energy [illegible] way energy is supplied. E.g. installi[illegible] s can reduce overall heating d[illegible] solar PV capacity can change the suppl[illegible] that the energy system operat[illegible]
Focus zone	A modelling zone which has been identified as an area in which to target near-term installation, upgrade, retrofit, or other activities related to a specific energy system component.

Appendix A2

Glossary of terms

Term	Definition or meaning
Generation	Local generation – size below 100MW.
Generation headroom	Generation headroom in a local authority's electricity distribution network refers to the remaining primary substation capacity at the time of peak generation, crucial for maintaining a stable and reliable power supply to meet the community's needs
Grid electricity	Electricity that is supplied by the electricity network.
Grid substation	The physical equipment comprising a substation with a 132kV-33kV transformer(s) connecting the grid-level, extra high voltage electricity lines to the primary-level, high voltage electricity lines. The grid substation facilitates connection with the national grid.
Heat network	A distribution system of insulated pipes that takes heat from a central source and delivers it to a number of domestic or non-domestic buildings.
Heat pump	A piece of equipment that uses a heat exchange system to take heat from air, ground or water and increases the temperature to heat buildings.
Hydrogen	A flammable gas that can be burned, like natural gas, to generate heat or power vehicles. The by-product is water only, no carbon.
Infrastructure	Local energy distribution infrastructure, includes storage assets if these are at grid level.
Landfill gas	Gases such as methane that are produced by micro-organisms in a landfill site that can be used as a source of energy.
Lever	We use the term policy levers to refer to the 'governing instruments'[T57] which the state has at its disposal to direct, manage and shape change in public services.

Appendix A2

Glossary of terms

Term	Definition or meaning
Local energy system	The distribution level energy system, excludes the transmission and national assets.
Longer-term options	The likely outcome of these is less certain and dependent upon actions and decisions being made that are not under our control, e.g. a national policy or the capability / availability of a technology.
Major industrial load	The power demand of industrial sites in the 2019 NAEI Point Sources data are large enough to be classified as major industrial loads. Sites that aren’t included in this database are likely too small to have a significant impact on the energy system singlehandedly.
Methane reformation	Process of producing hydrogen by heating methane from natural gas and steam, usually with a catalyst. Produces carbon dioxide as a by product.
Microgeneration	Small-scale generation of heat and electricity by individuals, households, communities or small businesses for their own use.
Modelling zone	A specified area in our modelling which is the smallest level of granularity for analysis. The zones are used through energy modelling, deployment modelling, and mapping. Zones were created by intersecting the Local Authority boundary with the primary substation service area boundary, as described in the "Methodology - electricity and gas network infrastructure" section of the Technical Report. *May also be called "zone" or "substation zone" in the reports.*
National asset	National infrastructure (can be supply or demand and the accompanying transmission / distribution infrastructure) – defined as over 100MW, unless it produces heat which can only be used locally this is generally excluded from LAEP particularly the modelling.
National Grid	A generic term [illegible] referring to the electricity net[illegible], including both the transmission and distrib[illegible] facilitating the flow of electricit[illegible] during areas or regions. *May also be called* [illegible] *the reports.*

Appendix A2

Glossary of terms

Term	Definition or meaning
National Net Zero	The National Net Zero modelled in the LAEP. Details of assumptions are in the methodology section.
Natural Heritage	This includes features which are of ecological, geological, geomorphological, hydrological or visual amenity importance within the landscape, and which form an essential part of the functioning of the natural environment and natural assets of Vale of Glamorgan.
Net zero	Check preference with LA and note down in the table in Glossary of terms.docx . Net zero when used in this LAEP is the energy net zero as it does not include all emissions, only energy emissions.
No regrets/ low regrets	Options which are common to all scenarios, cost-effective, provide relatively large benefits, and are very likely to be important parts of the future energy system, regardless of future uncertainty.
Optimisation modelling	Modelling to create the most cost and carbon optimal system.
Option	A term used to describe ways that a particular objective can be achieved. In the context of this LAEP, an option could be deploying a particular energy system component
Outward code	The first part of a postcode i.e. BS1.
Pathway	A pathway is how we get from the current energy system, to the most likely net zero end point. The pathway will consider what is needed from across the scenarios, the supply chain, number of installers etc. The propositions will make up the more certain part of the pathway, whereas the longer-term energy components will need further definition in the future.
Power factor	The ratio between useful power (kW) and apparent power (kVA) consumed or transformed by electrical equipment.

Appendix A2

Glossary of terms

Term	Definition or meaning
Power purchase agreement (PPA)	A contract between two parties where one produces and sells electricity and the other purchases electricity.
Primary substation	The physical equipment comprising a substation with a 33kV-11kV transformer(s) connecting the primary-level, high voltage electricity lines to the consumer-level, low voltage electricity lines.
Primary substation service area	The area bounding the buildings or other electricity demands which are served by a primary substation (or, in ANW, a group of primary substations acting together to serve one area).
Programme	A series of projects, usually with a theme, that is run collectively.
Project	Strategic scale projects being implemented or planned for implementation in the local energy system that will significantly affect local demand or local supply.
Quick win projects	Very short-term actions, certain as no major blockers.
Renewable Energy Guarantees of Origin (REGO) Agreement	A scheme that tells consumers what proportion of their electricity comes from renewable sources.
Resistance heating/ heater	Generate heat by passing electrical currents through wires.
RIIO-ED2/3 & RIIO-GD2/3	RIIO stands for Revenue = Incentives + Innovation + Outputs, a regulatory framework used by the UK energy regulator, Ofgem. RIIO-ED2 is a price control covering the electricity distribution sector for the next five years from April 2023 to March 2028. RIIO-ED3 covers the price control period following ED2. RIIO-GD3 is a price control covering the gas distribution network, with GD2 covering April 2021- March 2026.

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Appendix A2

Glossary of terms

Term	Definition or meaning
Scenario	A scenario is a set of assumptions for a particular end point (usually 2050) which are modelled in our optimisation model. We modelled 5 different scenarios to see what was common across the scenarios and therefore is a “no regrets” measure, and what changed between the modelled scenarios.
Solar PV	Convert solar radiation into electricity using photovoltaic (PV) cells.
Strategic objective	Strategic objectives are purpose statements that help create an overall vision and set goals and measurable steps to achieve the desired outcome. A strategic objective is most effective when it is quantifiable either by statistical results or observable data. Strategic objectives further the vision, align goals and drive decisions that impact change.
Sensitivities	Sensitivities of a specific scenario can be tested – for instance to test the impact of increasing electricity/hydrogen prices on the scenario. Testing a sensitivity is when you change one thing multiple times to assess the impact on the cost/carbon.
Sewage gas	A mixture of gases generated in sewer systems, used in a reciprocating gas engine to produce heat and electricity.
Strategic options	Strategic options are longer-term changes to demand, generation and infrastructure that will lead onto decarbonisation of the local energy system - and the key variables that determine scenarios.
Substation upgrades	Interventions at an existing primary substation designed to increase the capacity of the substation, such as upgrading an existing primary substation or installing a new primary substation. *May also be called ‘substation interventions’ in the reports.*
Supply	Energy supply options – this is how energy is delivered from the point of source – so a supply option would be solar PV.

Appendix A2

Glossary of terms

Term	Definition or meaning
Supply/generation headroom	The difference between the electrical capacity of a substation, and the power being supplied to the substation at a given time.
TfW zone	An area used by the Transport for Wales (TfW) as a point of origin or departure for vehicle trips. M*ay also be called "transport zone" within the reports.*
Transmission network	Move energy via pipes or wires for long distances around the country at high pressure/ voltages.
Uncertainties	Uncertainty results from lack of information or from disagreement about what is known or even knowable.
We	The range of consultants that have been commissioned by Welsh Government to support each Local Authority to develop this LAEP.
Wind power	Harnessing the kinetic energy of wind to turn a turbine to generate electricity.

Appendix A3

Units of measure

Unit	Definition or meaning
°C	Degree(s) Celsius – a unit of temperature on the Celsius scale.
GWh	Gigawatt hour(s) – a unit of energy representing 1 billion watt-hours.
kgCO_2e	Kilogram(s) of carbon dioxide equivalents – a unit of measurement for greenhouse gas warming potential, expressing the equivalent weight of carbon dioxide with the same global warming potential.
ktCO_2e	Kilotonne(s) of carbon dioxide equivalents - a unit of measurement for greenhouse gas warming potential, expressing the equivalent weight of carbon dioxide with the same global warming potential. Represents 1 million kgCO2e.
kV	Kilovolt(s) – a unit of potential energy of a unit charge in a point of a circuit relative to a reference (ground) representing 1000 volts.
kW	Kilowatt(s) – a metric unit of power measuring rate of energy consumption or production representing 1000 watts.
kWh	Kilowatt hour(s) - a unit of energy representing 1000 watt-hours.
kWp	Peak kilowatt(s) – the maximum power rating possible produced by an energy generation source (i.e., amount of power produced in ideal generation conditions).
MVA	Mega volt amp(s) – a metric unit of apparent power measuring rate of energy consumption or production and considering the efficiency by which electrical power is converted into useful output. It is related to MW by the power factor of the system or equipment.
MW	Megawatt(s) – a metric unit of power measuring rate of energy consumption or production representing 1 million watts.
MWe	Megawatt(s) electric – a unit of electric power output from a generation source representing 1 million watts electric.

Appendix A3

Units of measure

Unit	Definition or meaning
MWth	Megawatt(s) thermal – a unit of thermal power output from a generation source representing 1 million watts thermal.
MWh	Megawatt hour(s) - a unit of energy representing 1 million watt-hours.
tCO_2 per capita	Tonne(s) of carbon dioxide per capita – a unit of mass of carbon dioxide emitted per member of a population per year. Represents 1000 $kgCO_2$ per capita.

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Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners: ARUP CARBON TRUST Prifddinas Ranbarth Caerdydd Cardiff Capital Region

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Appendix A5

Additional context

The energy transition across Wales

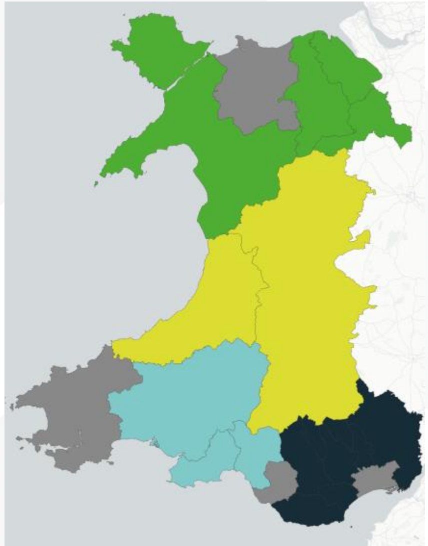
The Welsh Government's "Net Zero Wales" plan[T02] establishes an increased level of ambition on decarbonisation, with a legally binding target to reach net zero emissions by 2050. It is the first national government to fund the roll-out of LAEP to all its local authorities. The programme is being co-ordinated through a regional approach, where LAEPs are being developed for local authorities in Mid Wales, South West Wales, North Wales and the Cardiff Capital Region. Several suppliers have been selected to produce the LAEPs for each region, as detailed in the map.

To contribute to the Welsh Government's commitment of producing a "National Energy Plan" in 2024, upon completion of the LAEP programme Energy Systems Catapult[T03] will aggregate the LAEPs into a national view. To support this task, they are working with the Welsh Government to create and import standardised LAEP outputs for aggregation into the DataMapWales platform[T04]. The Catapult is also providing technical advisory support to the Welsh Government throughout the programme.

The LAEPs will also form the basis of the 'National Energy Plan' Welsh Government have committed to produce in 2024.

Monmouthshire's Local Area Energy Plan (LAEP) provides an evidence-based plan of action that identifies the most effective route to a net zero local energy system for an area. This LAEP has been developed by bringing local organisations and groups together to discuss the evidence created as part of the development process and collectively agree on the best way forward to achieve this objective.

Applying this approach, a LAEP puts local needs and views at the centre of the planning process, and helps creates a co-ordinated, place-based plan that avoids the duplication of efforts, aims to save money, and realises additional social benefits that might otherwise have been over-looked.



Appendix A6

Stakeholder engagement

Stakeholder identification process

This section provides a detailed overview of the stakeholder identification and prioritisation process. It describes the methodology and definitions used to understand and identify the stakeholders relevant to Monmouthshire.

Stakeholder definitions and roles

Specific definitions and roles are included in the introduction (overleaf). Our approach was guided by the imperative to involve a broad cohort of secondary stakeholders with specific local knowledge, experience and / or influence over the local energy system. As the LAEP methodology adopts a whole systems approach at the local authority level, we needed individuals from a broad range of stakeholder organisations. To avoid stakeholder fatigue and to ensure we addressed regional synergies we created the additional regional secondary stakeholder group described in the introduction.

Stakeholder identification and mapping

A pre-developed stakeholder mapping tool was provided to each local authority. This was used to collect stakeholder data, both for organisations and appropriate target individuals. These were reviewed by the LAEP programme teams so that their wider knowledge of the local energy system and potential stakeholders could be used to jointly iterate and continuously improve the final stakeholder map. The mapping tool was then used to allocate identified stakeholders to either a primary or secondary stakeholder role based on a scoring schema that reflected their respective knowledge and influence of the local energy system.

Stakeholder engagement planning

During the development of the LAEP, we consistently updated our stakeholder list to ensure the appropriate representatives involved at each relevant stage. For example, through our analysis of the current energy system, we identified any key organisations that were absent from our initial list, including them to provide local insight in future engagement sessions.

Limitations and mitigation

Some limitations applied to our stakeholder mapping, and we undertook mitigations to address them as far as possible:

1. Knowing which stakeholders had high levels of local knowledge and / or local influence over the local energy system. This risk was mitigated through iterative reviews of the stakeholder mapping and inclusion of the wider programme team's knowledge and experience of stakeholders across all relevant sectors in each local authority.
2. Our ability to identify appropriate individuals at relevant stakeholder organisations relied on having access to sufficient data and information. To mitigate this constraint, we networked with participants, continuously improved our knowledge and connections, and promoted LAEPs locally.

Appendix A6

Stakeholder engagement

Stakeholder identification process

Stakeholder group	Organisations	Role in LAEP development	Method of engagement
Primary stakeholders	Local Authority officers, council member(s), energy network operators i.e. Distribution Network Operators, (DNOs) and Gas Distribution Networks (GDNs).	Responsible for the creation of the LAEP, as well as having executive decision-making powers. Contribute existing and future policies and programmes relevant to the LAEP.	Steering groups, workshops, bi-weekly meetings, emails, 121 interviews
Secondary local stakeholders	Other local government organisations, major energy users, organisations with influence over and / or local knowledge of specific energy system components (e.g. developers, housing associations), community energy organisations, local organisations active in net zero and decarbonisation, transport sector organisations	Responsible for shaping the direction and actions collectively agreed in the LAEP. Contribute advice and guidance to the LAEP programme given influence over and / or local knowledge of specific element(s) of the local energy system, e.g. share details of existing programmes and projects.	Interactive workshops
General public and other businesses	Members of the public and organisations not considered as secondary stakeholders.	Providing insights into public acceptance for different interventions to help shape the actions in the LAEP. (CCR)	Survey
Secondary regional stakeholders	Transmission network operators, transport providers, housing associations, growth deal organisations, landowners, national parks, further education, public bodies or national organisations (e.g. TfW) with a regional influence, trade organisations.	Responsible for shaping the actions and considering opportunities to deliver at scale across local authority boundaries by providing advice and guidance given regional influence and / or knowledge of specific elements of the regional energy system.	Interactive workshops
Technical advisors for LAEP	Energy Systems Catapult (ESC).	Ensuring a consistent approach is taken to the development of LAEPs in Wales.	Monthly meetings and invited to attend all workshops

Overview of engagement activity for identified stakeholder groups

Appendix A6

Stakeholder engagement

Overview of the stakeholder engagement plan

This section describes the stakeholder engagement completed throughout the development of this LAEP.

Contract meetings

As part of the overarching programme, a national forum brought together representatives from the local authorities, regional leads, Welsh Government and ESC to share learnings, ensuring a consistent approach to LAEP development was being taken across Wales. The suppliers and regional leads also met on regular basis to share assumptions and challenges.

We held regional steering groups for the Cardiff Capital Region, attended by the regional and local authority leads, as well as bi-weekly meetings with the local authority leads.

Online workshops

Online workshops were held virtually via Microsoft Teams, to engage with both primary and secondary stakeholders. These workshops were interactive, allowing participants to share their thoughts and views through different communication channels, such as verbal discussions, responses in the Teams chat and annotations on an online whiteboard platform called Miro.

Approach to workshops

Workshops were conducted at specific points to help us gather the local knowledge and insight necessary to advance through each of the seven LAEP stages. The agenda and content of the workshops were tailored to ensure we could meet the objectives outlined in Table 2.1.2.

Workshop data collection, analysis and synthesis

For Monmouthshire's LAEP workshops, participant responses were recorded through:

- Meeting minutes
- Workshop exercises using Miro boards
- Post-workshop emails
- Follow-up meetings

We collated stakeholder's contributions and used them to inform our energy systems analysis. For instance, when we presented Monmouthshire's future energy scenario outputs, stakeholders offered valuable insight into upcoming renewable energy technologies that are currently in the pipeline. This feedback guided us in refining our energy modelling to more accurately depict the mix of technologies expected to be integrated into Monmouthshire's future energy system.

Limitation and mitigation

We undertook an exercise to identify limitations in our stakeholder engagement approach, allowing us to establish strategies to mitigate them as much as possible. Below are two key limitations and their associated measures:

- The lack of structure in data collection posed a potential risk due to the open discursive nature of workshops. To address this, we held clear briefings, pre-defined the workshop purposes, agendas, and effective facilitation to ensure participants had various opportunities to contribute and engage in group discussions.
- Participants may not have felt confident or comfortable speaking openly during discussions, potentially leading to a lack of representation of stakeholder views. To mitigate this, we encouraged the use of the Teams chat and provided the opportunity for extended contributions via email after the workshop.

Sponsors: Delivery partners:

Appendix A6

Stakeholder engagement

Overview of stakeholder engagement plan

LAEP stages>>	1	2	3	4	5	6	7
Objectives / purposes Regional Local	Governance set-up. Identify relevant regional policy and strategic drivers for work and create objectives Review stakeholder mapping	Review constituents of the local energy system Review the local energy system baseline. Review potential scenarios	Agree regional scenarios to be used in the LAEP modelling Identify local scenarios for each LA Review regionally consistent assumptions for LAEP modelling	Review potential futures for the local energy system Determine 'low regrets' near-term propositions Understand local barriers and enablers	Review near-term, low regrets propositions Share deployment pathways to net zero. Identify local and regional actions and responsibilities	Identify opportunities for regional collaboration and focus from local discussions.	Launch of LAEP report
Key outputs	Objectives for the LAEP Stakeholder mapping refined	Set local strategic energy objectives, local policy drivers .	Agree four future energ y scenarios, as well as a reference “do-nothing” scenario.	Identify low-regrets, near term energy proposi tions.	Agree collective action to address barriers to delivering energy propositions locally	Agree regional actions and responsibilities to support the delivery of the local propositions	Final comments
Technical advisor							
Primary							
Regional							
Secondary							
General public							

Groups of stakeholders engaged at each stage of the LAEP process

Sponsors: Llywodraeth Cymru Welsh Government

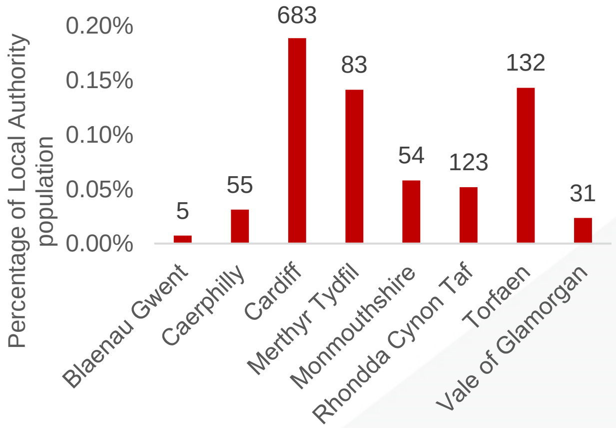
Delivery partners:

Appendix A6

Stakeholder engagement

Overview of the public engagement plan and results

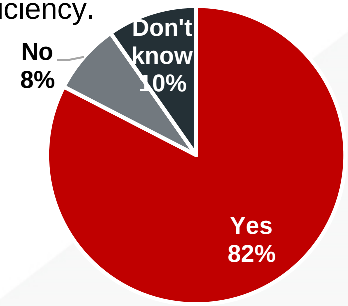
As part of the stakeholder engagement scope for the CCR LAEPs, a public survey was released between 14th November and 31st December 2023 to understand attitudes towards energy measures and to provide opportunity for public input. The survey was targeted at people living or working within eight CCR Local Authorities, with response rates as displayed.



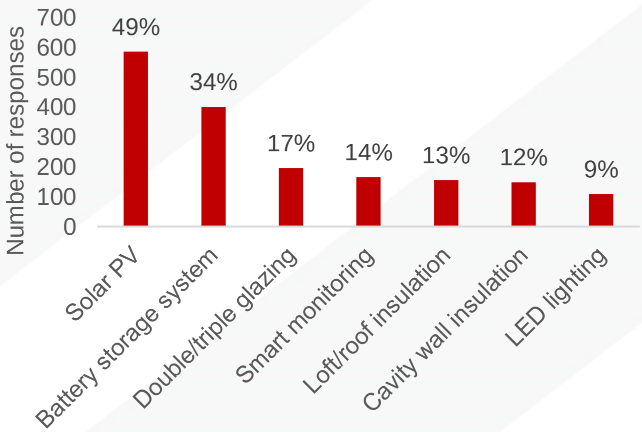
Response rate by individuals across the eight Local Authorities targeted by percentage of population

Explanations were given for each type of technology included within the survey. Across the CCR, there were 1,187 individual responses.

The results displayed a positive attitude towards improving home energy efficiency, with 82% of respondents wanting to improve their home energy efficiency.



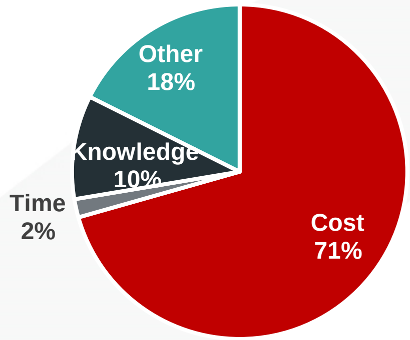
Response to "Would you like to improve the energy efficiency of your home?"



Response to "Which energy measures would you like to install in your home?"

The primary energy measure that people wanted to install was solar PV panels (49%).

Cost was the main barrier preventing respondents from installing energy efficiency measures in their homes (71%).



Response to "What is the main barrier that might prevent you from installing energy efficiency measures in your home?"

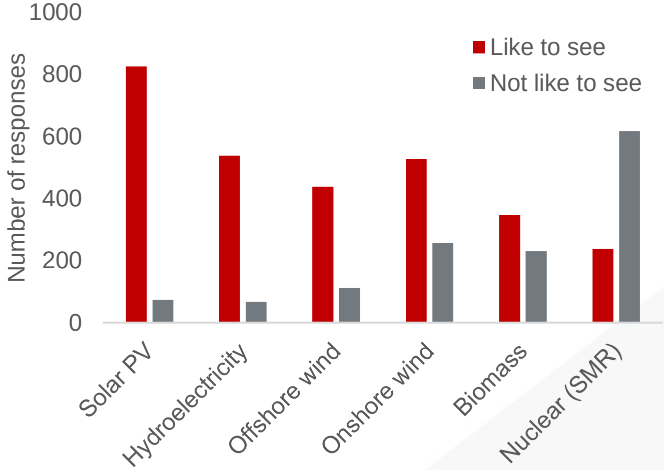
In terms of heating, 87% of respondents currently have a gas boiler in their home. 38% of respondents would consider air source and 26% would consider ground source heat pumps to heat their homes in the future - alongside solar thermal panels (29%), electric boilers (15%) and communal heat networks (13%).

Appendix A6

Stakeholder engagement

Overview of the public engagement plan and results

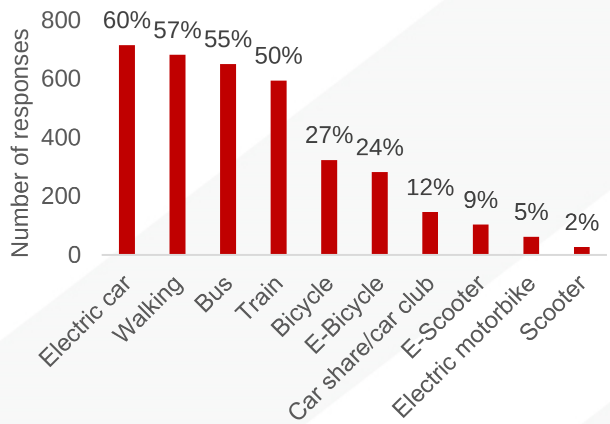
In terms of renewables, solar PV (70%) was the most popular technology respondents wanted to see in their local area, alongside hydroelectricity (45%) and offshore wind (37%). The least popular technologies for local deployment were nuclear SMR (52%) and biomass (19%).



Renewable technologies respondents would "like to see" and "not like to see" in their local area

For transport, 68% of respondents stated they use a petrol or diesel car as their primary source of transport, followed by the bus (8%), walking (8%), electric car (7%), bicycle (6%) and train (1%).

When asked which low-carbon transport options they would consider, respondents primarily chose EVs (60%), walking (57%) and buses (55%).



Responses to "Which low-carbon transport options would you consider?"

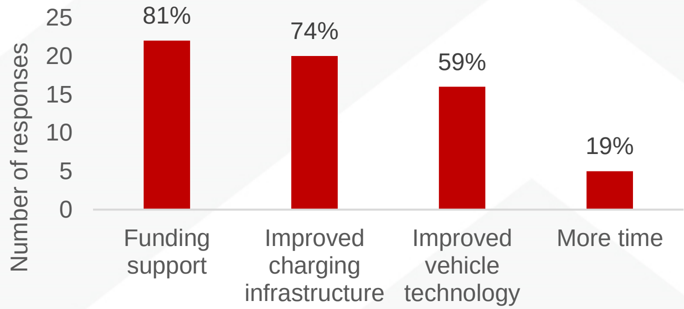
When asked what might influence their decision to use low-carbon transport options, 56% of respondents stated funding support and 44% stated access to EV charging at home.

63 organisations across the eight CCR Local Authorities targeted also responded to the survey. Like the results of the individuals, 92% said their organisation wanted to improve its buildings energy efficiency, with rooftop solar PV the most popular energy measure wanted (65%).

Cost was again identified as the primary barrier for installing energy efficiency measures (80%).

For transport within organisations, 28% of organisations claimed to use fleet within their operations, 16% used freight and 56% did not use transport in day-to-day operations.

Of those that regularly use vehicles, cars/vans are the most used (85%), followed by HGVs (37%) and factory vehicles (30%). 44% used electric vehicles, and 33% had EV charging infrastructure at their site.



Responses to "What would influence your organisation to use low-carbon transport options?"

It is worth noting that the number of responses received in Monmouthshire was low, relative to the population size (0.055% of population responded).

Monmouthshire LAEP – Technical Report

Appendices

Section B

Appendices

Section B

Appendix B1

Emissions sources in scope

LAEP emissions source	Inclusion	Comment
Domestic		
Electricity	✓	
Gas	✓	
'Other fuels'	✓	Oil, biomass, coal, LPG
Road transport		
'A' roads	✓	
Minor roads	✓	
Other (off-road, machinery)		
Commercial and public sector		
Electricity	✓	
Gas	✓	
'Other fuels'	✓	
Industry		
Electricity	✓	
Gas	✓	
'Other fuels'	✓	
Large installations	✓	Partial inclusion
Agriculture		Emissions from agricultural processes not included but emissions from energy use is included.
Other fuels demand		
Domestic	✓	
Commercial	✓	
Industrial	✓	
Transport	✓	

Appendix B1

Emissions sources in scope

LAEP emissions source	Inclusion	Comment
Gas network infrastructure		
Network coverage	✓	
Transport infrastructure		
EV charging infrastructure	✓	
Supply		
Non-renewable energy	✓	Includes: fossil (gas) and fossil (oil, LPG)
Renewable energy	✓	Includes: Ground- and roof-mounted solar PV, onshore wind, anaerobic digestion, biomass, energy from waste
Heat networks	✓	Undertaken for all LAs, only presented where appropriate
Generation		
Traditional electricity	✓	
Electricity demand		
Domestic	✓	
Commercial	✓	
Industrial	✓	
Transport	✓	

Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners: ARUP, Carbon Trust, Prifddinas Ranbarth Caerdydd Cardiff Capital Region

Appendix B1

Emissions sources in scope

LAEP emissions source		Comment
Gas demand		
Domestic	✓	
Commercial	✓	
Industrial	✓	
Electricity network infrastructure		
Primary substation headroom	✓	
Other		
Domestic and international shipping	X	Reserved as national priority
Domestic and international aviation	X	Reserved as national priority
Military transport	X	Reserved as national priority
Exports	X	Reserved as national priority
Waste	X	Emissions from waste treatment without energy recovery not included.
Storage		
Electrical	X	
Thermal	X	
Other	X	
Land use, land use change and forestry	X	LAEP focused on energy system and associated emissions, rather than all sources of territorial emissions.

Appendix B2

Emission factors

Technology	Value	Units	Reference
Biomass	0.0119	kgCO2e/kWh	Department for Energy Security and Net Zero (2023) Government conversion factors for company reporting of greenhouse gas emissions. Available at: https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting (Average of 4 biomass fuels: wood logs, wood chips, wood pellets, grass/straw)
Sewage gas	0.0002	kgCO2e/kWh	DESNZ, 2023 (Biogas - Biogas)
Organic matter	0.0002	kgCO2e/kWh	DESNZ, 2023 (Biogas - Biogas)
Natural gas	0.1843	kgCO2e/kWh	DESNZ, 2023 (Gaseous fuels - natural gas, Gross CV)
Oil/LPG	0.2413	kgCO2e/kWh	DESNZ, 2023 (Average of LPG and Fuel Oil, Gross CV)
Diesel	0.2391	kgCO2e/kWh	DESNZ, 2023 (Liquid fuels - Diesel (average biofuel blend), Gross CV)
Petrol	0.2217	kgCO2e/kWh	DESNZ, 2023 (Liquid fuels - Petrol (average biofuel blend), Gross CV)
Landfill gas	0.0002	kgCO2e/kWh	DESNZ, 2023 (Biogas - Landfill gas)
Waste incineration	0.0380	kgCO2e/kWh	Tolvik (2021) Annual report from Waste sector. Available at: https://www.tolvik.com/published-reports/view/uk-energy-from-waste-statistics-2021
Coal	0.3226	kgCO2e/kWh	DESNZ, 2023 (Coal - Industrial, Gross CV)

Grid electricity carbon factor source	National Grid ESO Future Energy Scenarios (FES) 2023 (averaged scenarios). Available at: https://www.nationalgrideso.com/future-energy/future-energy-scenarios-fes

Note: The reference in the first row is abbreviated to "DESNZ, 2023 in subsequent rows.

Appendix B3

Buildings - assumptions

No.	Assumption Description
1	[BASELINE] EPC and AddressBase records are up to date from April 2023
2	[BASELINE] Properties without an EPC record were assigned most likely property attributes based on neighbouring buildings of the same age and archetype with EPC records. For example, a 1900s Victorian property (AddressBase) without an EPC will be assigned the most common house type and mean insulation levels for similarly aged properties in the same LSOA area. For flats in the same block (i.e. same building number/name), the same extrapolation method was used using flats in the same block in the first instance, instead of LSOA. Where there was insufficient data within an LSOA, the local authority average was used instead.
3	[BASELINE] Each non-domestic archetype is assigned a single energy benchmark value per unit floor area
4	[FUTURE ENERGY SYSTEM] The energy efficiency cost data is Carbon Trust proprietary data, incorporating a combination of inputs including Spon's Architects' and builders' price book 2021, in-house market research and published construction market data. The Spon's Architects' and builders' price book data was converted into a usable format using EPC building dimensions for the cost optimisation
5	[FUTURE ENERGY SYSTEM] The following assumptions were made to inform the application of the cost data to specific property types: • Pitched loft insulation happens at the joists (270mm) • Insulation on suspended floors is assumed to be "easy access" • Filled cavities are assumed to be fully insulated • Unfilled or partially filled cavities receive cavity wall insulation • Pre-1930s solid walls receive 100mm internal wall insulation • Post-1930s solid walls receive 200mm external wall insulation, with a higher rate for flats.
6	[FUTURE ENERGY SYSTEM] Pitched roofs include properties with roof rooms which account for a small percentage (<10%) of pitched roofs. Roof rooms are more challenging to insulate as it is more disruptive for the occupant – additional costs have not been considered in this analysis
7	[FUTURE ENERGY SYSTEM] The heat demand profile used in the analysis is based on 2018 weather conditions. Three individual profiles representing an intermediate day, a winter day, and an extreme winter day (Beast from the East) were applied across the whole year to generate annual energy consumption profiles.
8	[FUTURE ENERGY SYSTEM] The average lifetime of the packages of energy efficiency measures being installed is assumed to be 30 years.
9	[FUTURE ENERGY SYSTEM] Dwellings classed as EPC A will not make any additional fabric improvements

Appendix B3

Buildings – domestic archetypes

- For each domestic and non-domestic archetype, a property with median thermal attributes is selected to perform the energy efficiency analysis

Archetype	Description	Av. floor area (sqm)	Wall	Roof	Floor	Window	HTC* (W/K)
1	Detached - after 1930 - medium/high efficiency	121.9	Insulated cavity wall	Insulated pitched roof	Uninsulated solid floor	Double glazing	379.8
2	Detached - low efficiency	170.9	Uninsulated solid wall	Insulated pitched roof	Uninsulated solid floor	Double glazing	1192.1
3	Terrace - medium efficiency	77.1	Insulated cavity wall	Insulated pitched roof	Uninsulated solid floor	Double glazing	153.6
4	Terrace - before 1930 - low efficiency	89.5	Uninsulated solid wall	Uninsulated pitched roof	Uninsulated solid floor	Double glazing	422.5
5	Semi-detached - after 1930 - low efficiency	79.5	Uninsulated cavity wall	Partially insulated pitched roof	Uninsulated solid floor	Double glazing	288.6
6	Semi-detached - after 1930 - high efficiency	79.5	Insulated cavity wall	Insulated pitched roof	Uninsulated solid floor	Double glazing	231.7
7	Semi-detached - before 1930 - low efficiency	105.3	Uninsulated solid wall	Uninsulated pitched roof	Uninsulated solid floor	Double glazing	741.2
8	Semi-detached - before 1930 - high efficiency	102.4	Insulated cavity wall	Insulated pitched roof	Uninsulated solid floor	Double glazing	495.5
9	Flat - high efficiency	54.2	Insulated cavity wall	Insulated pitched roof	Other premises below	Double glazing	85.5
10	Top floor flat - low efficiency	64.6	Uninsulated solid wall	Uninsulated pitched roof	Other premises below	Double glazing	332.0
11	Bottom floor flat - low efficiency	61.7	Uninsulated solid wall	Other premises above	Uninsulated solid floor	Double glazing	231.8

** Heat Transfer Coefficient (HTC) is a measure of thermal efficiency and is proportional to heat demand.*
To calculate HTC, the heat flow rate is divided by the ideal indoor and lowest outdoor temperature difference

Sponsors: Llywodraeth Cymru Welsh Government

Delivery partners: ARUP, Carbon Trust, Prifddinas Ranbarth Caerdydd / Cardiff Capital Region

Appendix B3

Buildings – non-domestic archetypes

Archetype	Description	Age	Wall	Roof	Floor	Window	Heat demand (kWh/m²)	Electricity demand (kWh/m²)	Cooling demand (kWh/m²)
12	Office unit	Pre-1930	Uninsulated solid wall	Other premises above	Uninsulated solid floor	Double glazing	73.8	95.1	28.0
13	Retail	After 1930	Insulated cavity wall	Other premises above	Uninsulated suspended floor	Double glazing	95.1	117.0	28.0
14	Hotel / hostel	After 1930	Insulated cavity wall	Insulated flat roof	Uninsulated suspended floor	Double glazing	120.9	117.6	30.0
15	Leisure/sports facility	After 1930	Insulated cavity wall	Insulated flat roof	Uninsulated suspended floor	Double glazing	181.3	72.4	40.0
16	Schools, nurseries and seasonal public buildings	Pre-1930	Uninsulated solid wall	Uninsulated pitched roof	Uninsulated suspended floor	Double glazing	127.7	41.0	0.0
17	Museums / gallery / library / theatre	Pre-1930	Uninsulated solid wall	Part insulated pitched roof	Uninsulated suspended floor	Double glazing	107.3	59.7	0.0
18	Health centre/clinic	After 1930	Uninsulated cavity wall	Part insulated pitched roof	Uninsulated solid floor	Double glazing	141.0	55.7	0.0
19	Care home	Pre-1930	Uninsulated solid wall	Insulated pitched roof	Uninsulated suspended floor	Double glazing	113.3	64.6	30.0
20	Emergency services, local Gov services, law, military	After 1930	Insulated cavity wall	Insulated pitched roof	Uninsulated solid floor	Double glazing	177.8	94.5	0.0
21	Hospital	After 1930	Insulated cavity wall	Uninsulated flat roof	Uninsulated solid floor	Double glazing	162.6	86.4	45.0

Sponsors: Delivery partners:

Appendix B3

Buildings – non-domestic archetypes

Archetype	Description	Age	Wall	Roof	Floor	Window	Heat demand (kWh/m²)	Electricity demand (kWh/m²)	Cooling demand (kWh/m²)
22	Warehouse						24.8	24.2	0.0
23	Restaurant / bar / café						67.1	245.8	0.0
24	Religious building						33.0	12.8	0.0
25	Transport hub/station						71.3	32.5	0.0
26	University campus						105.8	35.3	0.0
27	Other non-domestic	-	-	-	-	-	61.0	56.8	0.0

For non-domestic archetypes 22-27, no retrofit options were modelled due to the increased difficulty in improving the thermal efficiency of these property types

Appendix B3

High demand retrofit options – domestic

Archetype	Original HTC (W/K)	Cavity wall insulation	Internal wall insulation (complex interior)	External wall insulation	External wall insulation (complex façade)	Loft insulation (Joists) 100 - 270mm	Loft insulation (Joists) 0 - 150mm	Insulate solid floor	high performance triple glazing	New-build standard thermal bridging	Enerphit airtightness (1 n50)	AECB airtightness (1.5 n50)	New double panel double convector radiators	New distribution pipework and triple panel radiators	Hot water cylinder and associated pipework	MVHR (de-centralised)	MEV	New HTC (W/K)	Cost £
1	379.8									■			■		■			357.1	£2,755
2	1192.1							■						■	■			1059.5	£9,115
3	153.6											■			■			148.6	£1,250
4	422.5						■						■		■			367.1	£3,404
5	288.6	■					■								■			231.7	£4,562
6	231.7														■			229.5	£1,250
7	741.2						■			■			■		■			678.9	£4,242
8	495.5									■					■			487.5	£1,250
9	85.5														■			85.3	£1,250
10	332.0						■								■			246.8	£2,810
11	231.8							■					■		■			176.1	£10,071

Appendix B3

High demand retrofit options – non-domestic

Archetype	Original heat demand (kWh/m²)	Cavity wall insulation	Internal wall insulation (complex interior)	External wall insulation (complex façade)	Loft insulation (Joists) 0 - 270mm	New roof with insulation (complex)	Insulate flat roof	Insulate solid floor	Insulate suspended floor (difficult access)	high performance triple glazing	New-build standard thermal bridging	Building regs airtightness (5 n50)	AECB airtightness (1.5 n50)	New double panel double convector radiators	New triple panel triple convector radiators	Hot water cylinder and associated pipework	New distribution pipework to radiators	Communal thermal store	MEV	New heat demand (kWh/m²)	Cost £
12	73.8									■						■				66.5	£1,517 +£82/m^2
13	95.8										■	■				■				94.8	£1,250 +£0/m^2
14	120.9										■							■		118.5	£11,250 +£0/m^2
15	72.4										■							■		70.9	£26,000 +£0/m^2
16	127.7				■							■			■					110.0	£27,295 +£32/m^2
17	107.3					■									■		■			88.5	£49,620 +£45/m^2
18	141.0	■												■		■				132.7	£5,120 +£10/m^2
19	113.3								■									■		108.4	£11,250 +£22/m^2
20	177.8											■		■		■				173.7	£5,120 +£0/m^2
21	162.6						■								■			■		157.8	£83,076 +£69/m^2

22-27 not modelled, Industry modelled separately

Appendix B3

Low demand retrofit options – domestic

Archetype	Original HTC (W/K)	Cavity wall insulation	Internal wall insulation (complex interior)	External wall insulation	External wall insulation (complex façade)	Loft insulation (Joists) 100 - 270mm	Loft insulation (Joists) 0 - 150mm	Insulate solid floor	high performance triple glazing	New-build standard thermal bridging	Enerphit airtightness (1 n50)	AECB airtightness (1.5 n50)	New double panel double convector radiators	New distribution pipework and triple panel radiators	Hot water cylinder and associated pipework	MVHR (decentralised)	MEV	New HTC (W/K)	Cost £
1	379.8					■		■	■	■	■					■		302.4	£90,680
2	1192.1		■					■	■	■		■			■	■		710.5	£130,151
3	153.6							■	■	■		■			■			122.4	£18,186
4	422.5				■		■	■	■	■		■	■		■			226.5	£42,371
5	288.6	■					■	■	■	■		■				■		189.2	£30,945
6	231.7				■	■		■	■	■		■			■	■		189.2	£29,826
7	741.2			■			■	■	■	■		■				■		409.8	£76,134
8	495.5				■			■	■	■		■				■		393.2	£39,410
9	85.5								■		■				■		■	76.3	£10,255
10	332.0		■				■		■	■		■			■	■		166.6	£28,362
11	231.8																	111.6	£29,406

Appendix B3

Low demand retrofit options – non-domestic

Archetype	Original heat demand (kWh/m²)	Cavity wall insulation	Internal wall insulation (complex interior)	External wall insulation (complex façade)	Loft insulation (Joists) 0 - 270mm	New roof with insulation (complex)	Insulate flat roof	Insulate solid floor	Insulate suspended floor (difficult access)	high performance triple glazing	New-build standard thermal bridging	Building regs airtightness (5 n50)	AECB airtightness (1.5 n50)	New double panel double convector radiators	New triple panel triple convector radiators	Hot water cylinder and associated pipework	New distribution pipework to radiators	Communal thermal store	MEV	New heat demand (kWh/m²)	Cost £
12	73.8		■							■	■					■			■	52.6	£1,517 +£150/m²
13	95.8								■	■	■		■			■			■	56.6	£1,250 +£172/m²
14	120.9								■	■	■							■		112.8	£11,250 +£116/m²
15	72.4									■	■	■						■		69.2	£26,000 +£73/m²
16	127.7			■	■				■	■	■	■			■					44.9	£9,805 +£393/m²
17	107.3			■	■				■	■	■	■			■		■			43.2	£36,105 +£340/m²
18	141.0	■			■			■		■	■	■		■		■				86.3	£5,120 +£198/m²
19	113.3			■					■	■	■	■						■		72.9	£11,250 +£271/m²
20	177.8				■			■		■	■		■			■				127.9	£1,250 +£185/m²
21	162.6			■			■			■	■	■			■			■		133.2	£83,076 +£115/m²

Appendix B4

Transport - assumptions

No.	Assumption Description
1	[BASELINE] Typical 24-hour period for demand tables represented average day in a year.
2	[BASELINE] Rail supplied by transmission network so excluded.
3	[BASELINE] Trip distances = distance between zone centroids multiplied by route indirectness factor
4	[BASELINE] Total mileage of trips per vehicle type taken from zone A to zone B: Mileage_{AB}= distance_{AB} * number of trips_{AB}
5	[BASELINE] Mileage summed and assigned to outbound zone (zone A)
6	[BASELINE] Multiply mileage by vehicle fuel consumption factors to estimate annual kWh.
7	[BASELINE] Fuel consumption factors for combustion vehicles: Car: 0.94 kWh/mile Van: 0.89 kWh/mile HGV: 6.21 kWh/mile Bus: 8.43 kWh/mile
8	[FUTURE] Car dependency factors (1 :national average, <1: less car dependent, >1: more car dependent) based on average number of cars per household Cardiff: 0.85 Merthyr Tydfil: 0.89 Blaenau Gwent: 0.92 Rhondda Cynon Taf: 0.93 Caerphilly: 0.97 Torfaen: 0.98 Vale of Glamorgan: 1.02 Monmouthshire: 1.14

Appendix B5

Renewable generation - assumptions

No.	Assumption Description
1	[BASELINE] For renewable generators identified in the REPD database, only those marked as “Operational” were captured, using 2019 as a baseline year.
2	[BASELINE] For renewable generators identified in NGED and SPEN registers (ECR), only those marked as “Connected” were captured, using 2019 as a baseline year.
3	[BASELINE] Generation (MWh) was calculated using LA-specific, hourly time-step profiles for wind and solar from PVGIS and Renewables.ninja. For other technologies, standard capacity factors from BEIS/DESNZ were used.
4	[PIPELINE] For REPD entries, only those marked as “Planning Application Granted – Awaiting Construction” and “Under Construction” were captured.
5	[PIPELINE] For ECR entries, only those marked as “Accepted to connect” were captured.
6	[FUTURE ENERGY SYSTEM] The solar and wind capacity factors (MW/km^2) used to calculate maximum available capacity (MW) at substation granularity were calculated using an average of the 4 factors from the renewable energy assessment (REA) undertaken by the Carbon Trust between 2020-2021. The REA factors used were for Blaenau Gwent, Caerphilly, Monmouthshire and Torfaen, all of which had values in the range of 50-60 MW/km^2 for solar PV, which agrees with literature. The final values used to estimate solar and wind resource were 53.4 MW/km^2 and 8.1 MW/km^2, respectively.
7	[FUTURE ENERGY SYSTEM] Overlap between areas suitable for both wind and solar were calculated to ensure that capacity was not double-counted.
8	[FUTURE ENERGY SYSTEM] Maximum roof-mounted PV capacity was estimated using roof-area coverage at the LA- and substation-level. It was assumed that 50% of roofs would be north-facing and therefore unsuitable and assumed a further 50% would be unsuitable due to further technical or planning constraints (e.g.: unsuitable roof type, extensive shading, listed buildings…). As both residential and commercial roofs were considered, a factor of 7.2 m^2/kW was used to estimate maximum available capacity.
9	[FUTURE ENERGY SYSTEM] Areas suitable for wind and solar developments were mapped using a variety of sources provided by the individual LAs. In instances where no shapefiles were provided, areas were traced manually using publicly-available information (REA, LDP or similar). The additional areas identified in the Welsh-wide study (Arup, 2019) were included for LAs where data was either outdated or missing detail, see adjacent table.
10	[FUTURE ENERGY SYSTEM] It was assumed that of the areas identified in the Welsh-wide study (which primarily considered planning constraints and not technical constraints), 10% of the land could be developed on for solar and/or wind.

Local Authority	Welsh-wide Arup renewable study (2019)
Blaenau Gwent	No
Caerphilly	No
Cardiff	Yes
Merthyr Tydfil	Yes
Monmouthshire	No
Torfaen	No
Rhondda Cynon Taf	No
Vale of Glamorgan	No
Denbighshire	Yes
Flintshire	Yes
Isle of Anglesey	Yes
Gwynedd	Yes
Wrexham	Yes

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Appendix B6

Heat networks – assumptions

- Counterfactual techno-economic assumptions - For developing a LCoH value for decentralised ASHPs

Assumptions log – 1/2

Item	Value	Units	Source/notes	Item	Value	Units	Source/notes
ASHP plant capex cost	700	£/kWth	Taken from calliope inputs – average of now and 2050 costs	Elec boiler plant capex cost	150	£/kWth	Taken from calliope inputs
ASHP lifetime	18	Years	Taken from calliope inputs	Elec boiler lifetime	20	Years	Typical technology assumption
ASHP O&M costs	0.01	£ p.a./kWhth	Used in the NCA study – calliope input looks like it has an error	Elec boiler O&M costs	0	£ p.a./kWhth	Taken from calliope inputs
ASHP peak capacity	50	% of peak building heat	Assumption based on typical load duration curves	Elec boiler peak capacity	50	% of peak building heat	Electric boilers are assumed to provide peaking role
ASHP annual supply	80	% of annual building heat	Assumed to be lower than the 90% heat network figure due to less thermal storage at building level	Elec boiler annual supply	20	% of annual buildin g heat	Assumed to be higher than 10% heat network figure due to less thermal storage at building level
Ambient air temperature	5	ºC	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Elec boiler efficiency	100	%	Taken from calliope inputs
ASHP carnot cycle effi ciency	50	%	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Electricity unit cost	0.1304	£/kWhe	HMT Green Book central commercial/public sector price
ASHP source ΔT	10	ºC	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Electricity supply connection cost	200	£/kWe	Based on average of DNO connection offers in urban areas
ASHP supply ΔT	5	ºC	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Building supply temperature	65	ºC	Typical building supply temperature – inputs give equivalent COP to calliope

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Heat networks – assumptions

- Counterfactual techno-economic assumptions - For developing a LCoH value for decentralised ASHPs

Assumptions log – 2/2

Item	Value	Units	Source/notes
Discount rate	3.5	%	HMT Green Book for public sector projects
Project lifetime	60	Years	DESNZ assumption
Testing & commissioning costs	2	% of Capex	High level assumption used in Arup HNDU feasibility studies
Builders work costs	3	% of Capex	High level assumption used in Arup HNDU feasibility studies
Preliminaries costs	10	% of Capex	High level assumption used in Arup HNDU feasibility studies
Overheads & profits costs	5	% of Capex	High level assumption used in Arup HNDU feasibility studies
Design & professional fees	12	% of Capex	High level assumption used in Arup HNDU feasibility studies
Optimism bias	15	% of Capex	High level assumption used in Arup HNDU feasibility studies

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Appendix B6

Heat networks – assumptions

- For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log – 1/3

Item	Value	Units	Source/notes	Item	Value	Units	Source/notes
ASHP plant capex cost	420	£/kWth	Assumes large plant is 60% price of decentralised plant based on work on other Arup projects	Elec boiler plant capex cost	90	£/kWth	Assumes large plant is 60% price of decentralised plant based on work on other Arup projects
ASHP lifetime	18	Years	Taken from calliope inputs	Elec boiler lifetime	20	Years	Typical technology assumption
ASHP O&M costs	0.01	£ p.a./kWh th	Used in the NCA study – error in calliope input	Elec boiler O&M costs	0.0075	£ p.a./kWh th	Used in Arup HNDU feasibility studies; based on DECC report
ASHP peak capacity	50	% of EC peak heat	Assumption based on typical load duration curves	Elec boiler peak capacity	50	% of EC peak heat	Electric boilers are assumed to provide peaking role
ASHP annual supply	90	% of EC annual heat	Assumption based on typical load duration curves	Elec boiler annual supply	10	% of EC annual heat	Assumption based on typical load duration curves
Ambient air temperature	5	ºC	Typical ambient temperature during heating hours – same as counterfactual	Elec boiler efficiency	100	%	Taken from calliope inputs
ASHP carnot cycle efficiency	60	%	Applied to ideal carnot cycle COP; typical technology assumption; higher than for smaller equipment	Electricity unit cost	0.1304	£/kWhe	HMT Green Book central commercial/public sector price
ASHP source ΔT	10	ºC	Typical technology assumption – same as counterfactual	Electricity supply connection cost	200	£/kWe	Based on average of DNO connection offers in urban areas
ASHP supply ΔT	5	ºC	Typical technology assumption– same as counterfactual	Heat network supply temperature	65	ºC	Consistency in supply temperature

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Appendix B6

Heat networks – assumptions

- For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log – 2/3

Item	Value	Units	Source/notes	Item	Value	Units	Source/notes
Waste-heat heat pump plant capex cost	420	£/kWth	Assumes large plant is 60% price of decentralised plant based on work on other Arup projects	Waste heat capture plant capex cost	*See note*	£/kWth	See waste heat assumptions; depends on source
Waste-heat heat pump lifetime	20	Years	Typical technology assumption	Waste-heat capture plant O&M costs	*See note*	£/kWhth	See waste heat assumptions; depends on source
Waste-heat heat pump O&M costs	0.01	£ p.a./kWhth	Used in the NCA study	Thermal storage capex cost	24	£/kWhth	Supplier quotes; used in Arup HNDU feasibility studies
Waste-heat heat pump peak capacity	50	% of EC peak heat	Assumption based on typical load duration curves	Thermal storage sizing	4	Hours of EC peak	High-level assumption
Waste-heat heat pump annual supply	90	% of EC annual heat	Assumption based on typical load duration curves	Network pipework cost	2000	£/m	DESNZ assumption
Waste-heat source temperature	*See note*	ºC	See waste heat assumptions; depends on source	Network losses	20	%	DESNZ assumption and limit of acceptable losses in CIBSE CP1
Waste-heat heat pump carnot cycle efficiency	60	%	Typical technology assumption; higher than for smaller equipment	Network O&M costs	0.5	£/m pipework	Based on data from Arup projects
Waste-heat heat pump source ΔT	5	ºC	Typical technology assumption; lower ΔT than for air	Energy centre ancillaries costs	20	£/kWth	Based on supplier quotes; used in Arup EfW heat network opportunities study
Waste-heat heat pump supply ΔT	5	ºC	Typical technology assumption	Ancillary electricity usage (e.g., for pumps)	3	% of EC annual heat	Used in Arup HNDU feasibility studies

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Heat networks – assumptions

- For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log – 3/3

Item	Value	Units	Source/notes	Item	Value	Units	Source/notes
Energy centre building cost	100	£/kWth	Used in the NCA study	Discount rate	3.5	%	HMT Green Book for public sector projects
Hydrogen boiler capex cost	90	£/kW	Takes calliope input and assumes large plant is 60% price of decentralised plant based on work on other Arup projects	Testing & Commissioning costs	2	% of Capex	High level assumption used in Arup HNDU feasibility studies
Hydrogen boiler lifetime	15	Years	Calliope inputs	Builders work costs	3	% of Capex	High level assumption used in Arup HNDU feasibility studies
Hydrogen boiler efficiency	84	%	Calliope inputs	Preliminaries costs	10	% of Capex	High level assumption used in Arup HNDU feasibility studies
Hydrogen boiler O&M	0.005	£ p.a./kWhth	O&M costs half that of heat pumps – based on calliope inputs	Overheads & profits costs	5	% of Capex	High level assumption used in Arup HNDU feasibility studies
Hydrogen fuel cost	0.07	£/kWh	Calliope inputs	Design & professional fees	12	% of Capex	High level assumption used in Arup HNDU feasibility studies
Hydrogen boiler backup capacity	100	% of EC peak heat	Assumed that backup boilers able to meet full peak will be available	Optimism bias	15	% of Capex	High level assumption used in Arup HNDU feasibility studies
Project lifetime	60	Years	DESNZ assumption				

Appendix B6

Heat networks – assumptions

- Waste heat capture techno-economic assumptions - For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log: Substations

Item	Value	Units	Source/notes
Substation capturable heat (kW)	1.82	kWth/MVA	LSBU waste heat research
Substation capturable heat (kWh)	15,910	kWhth/MVA	LSBU waste heat research
Source temperature	45	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	850	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

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Heat networks – assumptions

- Waste heat capture techno-economic assumptions - For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log: WWTW

Item	Value	Units	Source/notes
Waste production rate	32.5	Kg dried solids p.a./person	Sludge Treatment - Huber Technology UK - Rotamat Ltd.
WWTW capturable heat (kW)	0.035	kWth/PE	LSBU waste heat research
WWTW capturable heat (kWh)	302	kWhth/PE	LSBU waste heat research
Source temperature	17.5	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	180	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

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Heat networks – assumptions

- Waste heat capture techno-economic assumptions - For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log: Minewater treatment plants

Item	Value	Units	Source/notes
Capturable heat per plant	2000	kW/plant	LSBU waste heat research
Operational hours	7884	hours	Assumes constant operation with 90% availability
Source temperature	20	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	180	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

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Heat networks – assumptions

- Waste heat capture techno-economic assumptions - For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log: Data centres

Item	Value	Units	Source/notes
DC power density	1	kW IT/m^2	Estimate based on data from other Arup projects
Utilisation factor	80%	% of IT capacity utilised	Estimate based on data from other Arup projects
Capturable heat rate	35%	% of DC heat produced	Estimate based on data from other Arup projects
Source temperature	32.5	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	180	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

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Heat networks – assumptions

- Waste heat capture techno-economic assumptions - For using in HeatNet’s TEM to estimate the LCoH of networks

Assumptions log: EfW plants

Item	Value	Units	Source/notes
EfW capturable heat rate	33%	% of MWe capacity	Based on 10 MWth heat available from 30 MWe Cardiff facility
Plant operational hours	7884	hours	Assumes constant operation with 90% availability
Source temperature	>65	ºC	Assumes high grade heat; no heat pump boosting required
Capture plant capex rate	350	GBP/kWth	Estimate based on data from other Arup projects
Wholesale electricity cost	0.06	GBP/kWhe	Taken from calliope inputs
Z factor	10		https://assets.publishing.service.gov.uk/media/605b862ed3bf7f2f0b5830ec/draft-sap-10-2-appendix-c.pdf
Capture plant Opex rate	0.010	GBP/kWhth	Estimate based on data from other Arup projects plus lost electricity production costs

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Heat networks – assumptions

- Waste heat capture techno-economic assumptions - For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log: Cold stores

Item	Value	Units	Source/notes
EfW capturable heat rate	33%	% of MWe capacity	Based on 10 MWth heat available from 30 MWe Cardiff facility
Plant operational hours	7884	hours	Assumes constant operation with 90% availability
Source temperature	>65	ºC	Assumes high grade heat; no heat pump boosting required
Capture plant capex rate	350	GBP/kWth	Estimate based on data from other Arup projects
Wholesale electricity cost	0.06	GBP/kWhe	Taken from calliope inputs
Z factor	10		https://assets.publishing.service.gov.uk/media/605b862ed3bf7f2f0b5830ec/draft-sap-10-2-appendix-c.pdf
Capture plant Opex rate	0.010	GBP/kWhth	Estimate based on data from other Arup projects plus lost electricity production costs

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- Waste heat capture techno-economic assumptions - For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log: Industry – water-based capture

Item	Value	Units	Source/notes
EfW capturable heat rate	33%	% of MWe capacity	Based on 10 MWth heat available from 30 MWe Cardiff facility
Plant operational hours	7884	hours	Assumes constant operation with 90% availability
Source temperature	>65	ºC	Assumes high grade heat; no heat pump boosting required
Capture plant capex rate	350	GBP/kWth	Estimate based on data from other Arup projects
Wholesale electricity cost	0.06	GBP/kWhe	Taken from calliope inputs
Z factor	10		https://assets.publishing.service.gov.uk/media/605b862ed3bf7f2f0b5830ec/draft-sap-10-2-appendix-c.pdf
Capture plant Opex rate	0.010	GBP/kWhth	Estimate based on data from other Arup projects plus lost electricity production costs

Appendix B6

Heat networks – assumptions

- Waste heat capture techno-economic assumptions - For using in HeatNet's TEM to estimate the LCoH of networks

Assumptions log: Industry – flue gas-based heat capture

Item	Value	Units	Source/notes
Heat capture rate	20%	% of kWh fuel use	Estimate based on data from other Arup projects
Plant operational hours	7884	Hours	Assumes constant operation with 90% availability
Source temperature	>65	ºC	Assumes high grade heat; no heat pump boosting required
Capture plant capex rate – large sites	650	GBP/kWth	Estimate based on data from other Arup projects – for sites >3 MWth
Capture plant capex rate – small sites	350	GBP/kWth	Estimate based on data from other Arup projects - for sites <3 MWth
Wholesale electricity cost	0.06	GBP/kWhe	Taken from calliope inputs
Z factor for power producers	10		Assumes same Z factor as EfW plants
Capture plant Opex rate – non-power producers	0.004	GBP/kWhth	Estimate based on data from other Arup projects
Capture plant Opex rate – power producers	0.010	GBP/kWhth	Uplifts rate to account for lost electricity sale revenue

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Appendix B7

Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Anaerobic digestion	*Energy CAPEX*	*4,760.00*	*£ / kW*	*BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020*	*CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price. No change across years*
Anaerobic digestion	*Energy efficiency*	*0.32*	*fraction*	*BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020*	*From the BEIS electricity generation costs 2020. This is the load factor multiplied by the plant efficiency to account for the fact that the plant cannot operate at full load throughout the year.*
Anaerobic digestion	*Lifetime*	*20.00*	*years*	*BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020*	
Anaerobic digestion	*Operational cost of production*	*0.07*	*£ / kWh generated*	*BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020*	*OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh). No change across years*
Anaerobic digestion	*Operational fuel consumption cost*	*0.00*	*kgCO_2e / kWh fuel in*	*BEIS (2020). Greenhouse gas reporting: conversion factors 2020. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2020*	*Biogas scope 1 emissions factor used*

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Hydrogen import	Lifetime	1	years	n/a	Selected to have no effect
Hydrogen import	Operational fuel consumption cost	0.0203	kgCO2e / kWh	BEIS Hydrogen Production Costs 2021 report and annex. Availabe at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	Carbon capture rate for SMR + CCUS of 90% (annex) combined with hydrogen production emission factor 0.20297kgCO2$_e$/kWh (report emission assumptions).
Hydrogen import	Operational cost of production	0.051	£ / kWh	BEIS Hydrogen Production Costs 2021 Annex, average of all the methane reformation technologies for the wholesale price (central) in 2050. Availabe at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	Average of all the methane reformation technologies for the wholesale price (central) in 2050.
Biomass import	Energy efficiency	1	fraction	n/a	Default
Biomass import	Lifetime	1	years	n/a	Default
Biomass import	Operational cost of production	0.04	£ / kWh generated	Heat roadmap EU (2017) EU28 fuel prices for 2015, 2030 and 2050. Available at: https://heatroadmap.eu/wp-content/uploads/2020/01/HRE4_D6.1-Future-fuel-price-review.pdf (Accessed 2023).	Price for wood pellet - medium labour share + fuel handling charges medium scenario. Converted from Euros using 0.91 exchange rate.
Biomass import	Operational fuel consumption cost	0.01053	kgCO2e / kWh	BEIS (2022). Greenhouse gas reporting: conversion factors 2022. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-20202	
Electrolyser	Annual investment fraction	0.02	(fraction) of capex	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	50:50 SEM and Alkaline electrolyser from 2050.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Electrolyser	Energy CAPEX	750	£ / kW	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	50:50 SEM and Alkaline electrolyser from 2050.
Electrolyser	Energy CAPEX	535.5	£ / kW	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	50:50 SEM and Alkaline electrolyser from 2050.
Electrolyser	Energy efficiency	0.65	fraction	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	50:50 SEM and Alkaline electrolyser from 2050.
Electrolyser	Energy efficiency	0.82	fraction	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011506/Hydrogen_Production_Costs_2021.pdf (Accessed 2023).	Medium scenario for both Alkaline and PEM electrolysers.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Electrolyser	Lifetime	30	years	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011506/Hydrogen_Production_Costs_2021.pdf (Accessed 2023).	Medium scenario for both Alkaline and PEM electrolysers.
Ground PV	Energy CAPEX	431.25	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Large-scale Solar. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000).
Ground PV	Energy CAPEX	531.25	£ / kW	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Ground PV	Lifetime	35	years	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Ground PV	Operational cost of production	7.3	£ / kW /year	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh)
Hydrogen CCGT	Energy CAPEX	623.42	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	CCGT H Class. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000).
Hydrogen CCGT	Energy efficiency	0.53	fraction	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	From the BEIS electricity generation costs 2020. This is the average fuel efficiency.
Hydrogen CCGT	Lifetime	25	years	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Hydrogen CCGT	Operational cost of production	0.004	£ / kWh generated	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh)

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Hydrogen CCGT	Opex	18.8	£/kW/year	BEIS (2020) Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Includes fixed O&M, insurance, connection and use of system charges for CCGT H Class.
Hydrogen CHP	Annual operational cost	14.2	£/kW/year	Battelle Memorial Institute (2016) Manufacturing Cost Analysis of 100 and 250 kW Fuel Cell Systems for Primary Power and Combined Heat and Power Applications. Available at: https://www.energy.gov/eere/fuelcells/articles/manufacturing-cost-analysis-100-and-250-kw-fuel-cell-systems-primary-power (Accessed 2023).	Converted using 0.71 USD to GBP.
Hydrogen CHP	Energy CAPEX	2094	£ / kW	Battelle Memorial Institute (2016) Manufacturing Cost Analysis of 100 and 250 kW Fuel Cell Systems for Primary Power and Combined Heat and Power Applications. Available at: https://www.energy.gov/eere/fuelcells/articles/manufacturing-cost-analysis-100-and-250-kw-fuel-cell-systems-primary-power (Accessed 2023).	
Hydrogen CHP	Energy efficiency	0.42	fraction	2G Energy Ltd (2024) Leading Combined Heat and Power Technology. Available at: https://www.2-g.com/en/hydrogen-chp/ (Accessed 2023).	Heating efficiency

Sponsors: Delivery partners:

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Hydrogen CHP	Lifetime	15	Years	Alan Beech, Clarke Energy (2024) CHP - here to stay. Available at: https://www.energymanagermagazine.co.uk/chp-here-to-stay/#:~:text=INNIO%20Jenbacher%20gas%20engines%20can,into%20the%20net%20zero%20world. (Accessed 2023).	
Hydrogen refueller	Energy CAPEX	1076	£ / kW	Mariya Koleva and Marc Melaina (2020)Hydrogen Fuelling Stations Cost. Available at: https://www.hydrogen.energy.gov/pdfs/21002-hydrogen-fueling-station-cost.pdf (Accessed 2023).	Assuming a 24hr flat usage profile and an exchange rate of 0.74£/$.
Hydrogen refueller	Energy efficiency	0.65	fraction	G. Sdanghi, G. Maranzana, A. Celzard, and V. Fierro (2019), Review of the current technologies and performances of hydrogen compression for stationary and automotive applications. Available at: https://www.sciencedirect.com/science/article/abs/pii/S1364032118307822 (Accessed 2023).	Efficiency accounting for compression losses.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Hydrogen refueller	Lifetime	18	years	NREL (2014) Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs. Available at: https://www.nrel.gov/docs/fy14osti/58564.pdf (Accessed 2023).	
Hydrogen storage tank	Lifetime	30	years	NREL (2014) Hydrogen Station Compression, Storage, and Dispensing Technical Status and Costs. Available at: https://www.nrel.gov/docs/fy14osti/58564.pdf (Accessed 2023).	
Hydrogen storage tank	Energy efficiency	0.94	fraction	Department of Mechanical Engineering, The University of Hong Kong (2006) An Overview of Hydrogen Storage Technologies. Available at: https://journals.sagepub.com/doi/pdf/10.1260/014459806779367455 (Accessed 2023).	
Hydrogen storage tank	Operational cost of production	0.34	£ / kWh	HM Government (2021) Defining and organising functional documentation to meet functional standards. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760479/H2_supply_chain_evidence_-_publication_version.pdf (Accessed 2023).	Medium pressure tank - Unlikely to decrease over time.

Sponsors: Llywodraeth Cymru Welsh Government
Delivery partners: ARUP, Carbon Trust, Prifddinas Ranbarth Caerdydd Cardiff Capital Region

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Hydrogen storage tank	Storage CAPEX	11.45	£ / kWh	HM Government (2021) Defining and organising functional documentation to meet functional standards. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760479/H2_supply_chain_evidence_-_publication_version.pdf (Accessed 2023).	Medium pressure tank - Unlikely to decrease over time.
Onshore wind	Energy CAPEX	1088.63	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price
Onshore wind	Lifetime	25	years	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Onshore wind	Opex	30	£/kW/year	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Onshore wind	Operational cost of production	0.006	£ / kWh generated	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	OPEX includes fixed O+M, Variable O+M, fuel costs, decommissioning & waste, Steam revenue, and additional costs. Costs are assumed constant between 2040 and 2050. No change across years

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Technology	Setting	Value	Units	Reference	Notes
Onshore wind	Operational cost of production	0	kgCO2e / kWh fuel in	Default value	Renewable energy, assume operational emissions are zero.
Hydrogen distribution	Energy CAPEX per energy capacity per distance	1.2	£/kW/km	Arup (2023) Future of Great Britain's Gas Networks. Available at: Future of UK Gas Networks, https://nic.org.uk/app/uploads/Arup-Future-of-UK-Gas-Networks-18-October-2023.pdf (Accessed 2023).	This is equivalent to the value for the LTS backbone as stated in the source document. Transformed from a capex and distance, to a capex/distance.This is then divided by 1m kW which is a typical capacity in the system to give 1.2 £/kW/km If the additional services were also transitioned the total cost per m would be 4.8£/kW/km.
Hydrogen distribution	Energy efficiency	1	fraction	To account for in demands	
Hydrogen distribution	Lifetime	40	years	NG2050 - from WWU	
Hydrogen export	Lifetime	1	years	n/a	Selected to have no effect
Hydrogen export	Operational cost of production	-0.051	£ / kWh	BEIS Hydrogen Production Costs 2021 Annex, average of all the steam reformation technologies	
Hydrogen export	Operational fuel consumption cost	0	kgCO2e / kWh	n/a	Hydrogen for export only produced via electrolysis so assumed zero emissions

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Rooftop PV	Energy CAPEX	1100	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Solar PV 4-10 kW, assume 10 kW. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Rooftop PV costs do not change
Rooftop PV	Lifetime	30	years	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Rooftop PV	Annual operational cost	7	£/kW/year	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Rooftop PV	Operational cost of production	0	kgCO2e / kWh	Default value	Renewable energy, assume operational emissions are zero.
Hydroelectricity	Energy CAPEX	3000	£ / kW	BEIS (2020) Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	No new ones being built.
Hydroelectricity	Energy efficiency	1	fraction	DESNZ, Environmental Agency and BEIS (2013) Harnessing hydroelectric power. Available at: https://www.gov.uk/guidance/harnessing-hydroelectric-power#:~:text=Hydroelectric%20energy%20uses%20proven%20and, factor%20of%2035%20to%2040%25. (Accessed 2023).	Assumed to be equal to 1, with the capacity factor dictating the amount of electricity produced.

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Technology	Setting	Value	Units	Reference	Notes
Hydroelectricity	Capacity factor	0.3605	fraction	DUKES (2023) Load factors for renewable electricity generation (6.3). Available at: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes. Accessed 2023.	Hydro load factor for 2019.
Hydroelectricity	Lifetime	41	years	BEIS (2020) Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	
Hydroelectricity	Operational cost of production	0	kgCO2e / kWh fuel in	Default value	Renewable energy, assume operational emissions are zero.
Hydroelectricity	Operational cost of production	0.006	£ / kWh generated	BEIS (2020) Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	OPEX only variable O+M
Hydroelectricity	Opex	48.1	£/kW/year	BEIS (2020)Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Fixed O&M
Tidal	Energy efficiency	1	fraction	n/a	Default
Tidal	Capacity factor	0.2	fraction	North Wales Tidal Energy (2024) Electricity consumption keeps rising. Available at: https://www.northwalestidalenergy.com/energy-generation (Accessed 2023).	Assumption that 4TWh per year of electricity could be generated from 2-2.5GW. This translates to a capacity factor of 0.182 - 0.228.

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Technology	Setting	Value	Units	Reference	Notes
Tidal	Lifetime	120	years	Tidal Lagoon Swansea Bay plc (2014) Environmental Statement Volume 3 Appendix 5.1 Sustainability: Carbon Balance. Available at: http://www.tidallagoonpower.com/wp-content/uploads/2018/02/App-5.1-Sustainability-%E2%80%93-Carbon-Balance.pdf (Accessed 2023).	
Tidal	Energy CAPEX	3331	£ / kW	Arup experience. Available at: http://www.poyry.co.uk/sites/www.poyry.co.uk/files/tidallagoonpower_levelisedcoststudy_v7_0.pdf (Accessed 2023).	
Tidal	Opex	0.02	£ / kW	n/a	Arup experience
Anaerobic digestion	Energy CAPEX	4760	£ / kW	BEIS (2020)Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price. No change across years
Anaerobic digestion	Energy efficiency	0.4	fraction	BEIS (2020)Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	From the BEIS electricity generation costs 2020. This is the load factor multiplied by the plant efficiency to account for the fact that the plant cannot operate at full load throughout the year.

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Technology	Setting	Value	Units	Reference	Notes
Anaerobic digestion	Lifetime	20	years	BEIS (2020)Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	
Anaerobic digestion	Operational cost of production	0.07	£ / kWh generated	BEIS (2020)Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh). No change across years
Anaerobic digestion	Operational fuel consumption cost	0.00022	kgCO2e / kWh fuel in	BEIS (2022). Greenhouse gas reporting: conversion factors. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022 (Accessed 2023).	Biogas scope 1 emissions factor used
Sewage gas	Energy CAPEX	5906.67	£ / kW	BEIS (2020)Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Assumed price in 2020 is equivalent to projected 2025 price. No change across years
Sewage gas	Energy efficiency	0.46	fraction	BEIS (2020)Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	From the BEIS electricity generation costs 2020. This is the load factor, which can be used as an efficiency to ensure the plant does not operate at full capacity all year.

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Delivery partners: ARUP, CARBON TRUST, Prifddinas Ranbarth Caerdydd Cardiff Capital Region

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Technology	Setting	Value	Units	Reference	Notes
Sewage gas	Lifetime	20	years	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Sewage gas	Operational cost of production	0.014	£ / kWh generated	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Sewage gas	Opex	105	£/kW/year	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Sewage gas	Operational cost of production	0.00022	kgCO2e / kWh fuel in	BEIS (2022). Greenhouse gas reporting: conversion factors 2022. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022 (Accessed 18/03/2024).	Biogas scope 1 emissions factor used
Biogas import	Operational cost of production	0.017	£ / kWh	IEA (2020) Outlook for biogas and biomethane: propsects for organic growth. Available at: https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/sustainable-supply-potential-and-costs (Accessed 2023).	

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Technology	Setting	Value	Units	Reference	Notes
Biogas boiler	Annual operational cost	6	£/kW/year	Climate Change Committee (2018) Analysis of alternative UK heat decarbonisation pathways (Imperial). Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways/ (Accessed 2023).	Assumed same maintenance cost as hydrogen boiler.
Biogas boiler	Energy CAPEX	150	£ / kW	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	Assumed same cost as hydrogen boiler.
Biogas boiler	Energy efficiency	0.84	fraction	HM Government (2013) Part L Domestic Building Services Compliance Guide. Available at: https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document-l. (Accessed 2024).	Assuming same efficiency as a gas boiler.
Biogas boiler	Lifetime	15	years	Currie & Brown and AECOM for CCC (2019) The costs and benefits of tighter standards for new buildings. Available at: https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/. (Accessed 2024).	Assuming same lifetime as a gas boiler.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Biogas CHP	Energy efficiency	0.42	fraction	2G Energy Ltd (2024) Leading Combined Heat and Power Technology. Available at: https://www.2-g.com/en/hydrogen-chp/ (Accessed 2023).	Assume same as hydrogen CHP. Heating efficiency.
Biogas CHP	Lifetime	15	years	2G Energy Ltd (2024) Leading Combined Heat and Power Technology. Available at: https://www.2-g.com/en/hydrogen-chp/ (Accessed 2023).	Assume same as hydrogen CHP.
Biomass boiler to heat	Energy CAPEX	750	£ / kW	Biomass boilers: SPONS mechanical and electrical services	
Biomass boiler to heat	Energy efficiency	0.7	fraction	BEIS (2019) Measurement of the in-situ performance of solid biomass boilers. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831083/Full_technical_report.pdf (Accessed 2023).	Mean gross %
Biomass boiler to heat	Lifetime	20	years	BEIS (2019) Measurement of the in-situ performance of solid biomass boilers. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831083/Full_technical_report.pdf	
Biomass boiler to heat	Operational cost of production	0.004	£ / kWh generated	IRENA (2012) Biomass for Power Generation. Available at: Available at: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2012/RE_Technologies_Cost_Analysis-BIOMASS.pdf (Accessed 2023).	Variable OPEX from the report is stated as 0.005 USD/kWh. Adjusted for 2012 exchange rate (0.7271 GBP) and inflation from 2012 to 2022 (33%), shown to one significant figure.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Biomass boiler to electricity	Energy CAPEX	3141.74	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000).
Biomass boiler to electricity	Energy efficiency	0.29	fraction	BEIS (2020) Electricity Generation Costs.	
Biomass boiler to electricity	Lifetime	25	years	BEIS (2020) Electricity Generation Costs.	
Biomass boiler to electricity	Operational cost of production	0.009	£ / kWh generated	BEIS (2020) Electricity Generation Costs.	OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh)
Biomass boiler to electricity	Opex	96	£ / kW / year	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Operational cost of production	0.013	£ / kWh	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Energy CAPEX	5551.4	£ / kW	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Lifetime	24	years	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Annual operational cost	307	£ / kW / year	BEIS (2020) Electricity Generation Costs.	
Biomass CHP to heat	Energy efficiency	0.43	fraction	Digest of UK Energy Statistics (DUKES) (2023) combined heat and power. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2023 (Accessed 2023).	Heat efficiency calculated using heat output and total CHP fuel use in 2022.

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Technology	Setting	Value	Units	Reference	Notes
Biomass CHP to electricity	Carrier output ratio	0.57	fraction	Digest of UK Energy Statistics (DUKES) (2023) combined heat and power. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2023 (Accessed 2023).	The carrier output ratio indicates that 0.57 units of electricity are produced for every unit of heat produced. Calculated using the ratio of electricity generation efficiency to heat generation efficiency.
Ground PV	Operational cost of production	0	kgCO2e / kWh fuel in	Default value	Renewable energy, assume operational emissions are zero.
Heat pump	Energy CAPEX	750	£ / kW	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	Average of ASHP and GSHP. For ASHP: Annual maintenance costs for medium business +industry ASHP £2966.04 Divided by the reference size (150kW) does not change between years. For GSHP - https://core.ac.uk/download/pdf/141667173.pdf
Heat pump	Energy CAPEX	650	£ / kW	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	Average of ASHP and GSHP. For ASHP: Annual maintenance costs for medium business +industry ASHP £2966.04 Divided by the reference size (150kW) does not change between years. For GSHP - https://core.ac.uk/download/pdf/141667173.pdf
Heat pump	Energy efficiency	2.5	fraction	HM Government (2021) Defining and organising functional documentation to meet functional standards. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/606818/DECC_RHPP_161214_Final_Report_v1-13.pdf (Accessed 2023).	

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Technology	Setting	Value	Units	Reference	Notes
Heat pump	Lifetime	18	years	Currie & Brown and AECOM for CCC (2019) The costs and benefits of tighter standards for new buildings. Available at: https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/ (Accessed 2023).	
Heat pump	Annual operational cost	11.18	£ / kW / year	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	Average of ASHP and GSHP. For ASHP: Annual maintenance costs for medium business +industry ASHP £2966.04 Divided by the reference size (150kW) does not change between years. For GSHP - https://core.ac.uk/download/pdf/141667173.pdf
Hydrogen boiler to heat	Annual operational cost	6	£/kW/year	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	Annual maintenance costs for residential hydrogen boiler 120. Divided by the reference size (20kw) does not change between years
Hydrogen boiler to heat	Energy CAPEX	150	£ / kW	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	CAPEX includes unit and installation costs. Values used for residential. Does not change through the years.

Sponsors: Delivery partners:

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Technology	Setting	Value	Units	Reference	Notes
Hydrogen boiler to heat	Energy efficiency	0.84	fraction	HM Government (2013) Part L Domestic Building Services Compliance Guide. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/697525/DBSCG_secure.pdf	
Hydrogen boiler to heat	Lifetime	15	years	Currie & Brown and AECOM for CCC (2019) The costs and benefits of tighter standards for new buildings. Available at: https://www.theccc.org.uk/publication/the-costs-and-benefits-of-tighter-standards-for-new-buildings-currie-brown-and-aecom/	
Hydrogen OCGT	Energy CAPEX	345.65	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	OCGT 600MW 500hr. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000).
Hydrogen OCGT	Energy efficiency	0.34	fraction	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Hydrogen OCGT	Lifetime	25	years	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Hydrogen OCGT	Operational cost of production	0.004	£ / kWh generated	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Assuming 300MW OCGT. Variable O&M.

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Delivery partners: ARUP, Carbon Trust, Prifddinas Ranbarth Caerdydd, Cardiff Capital Region

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Technology	Setting	Value	Units	Reference	Notes
Hydrogen OCGT	Opex	11	£/kW/year	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Assuming 300MW OCGT. OPEX includes fixed O&M, insurance, connection and use of system charges.
Methane reformation	Variable opex, annual operational cost of production	0.041	£ / kWh generated	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	Levelised Cost Estimates (£/MWh H2 (HHV)) for Projects Commissioning in 2050; Wholesale Price (Central); average of total cost (not including capex and fixed opex)for all SMR and ATR technologies.
Methane reformation	Fixed opex, annual operational cost of production	0.003	£ / kWh generated	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	Levelised Cost Estimates (£/MWh H2 (HHV)) for Projects Commissioning in 2050; Wholesale Price (Central); average of the fixed opex of all SMR and ATR technologies.
Methane reformation	Energy CAPEX	500	£ / kW	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	From the "technical and cost assumptions" data, average capex (medium scenario) for all SMR and ATR technologies, £/kW H2 HHV.
Methane reformation	Lifetime	40	years	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	Operating lifetime of SMR and ATR technologies.
Methane reformation	Operational cost of production	0.0203	kgCO2e / kWh	Available at: https://www.sciencedirect.com/topics/engineering/methane-steam-reforming	We assume in 2020 no CCS

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Methane reformation	Operational cost of production	0.01	kgCO2e / kWh	Timmerberg, Kaltschmitt, and Finkbeiner (2020)Hydrogen and hydrogen-derived fuels through methane decomposition of natural gas – GHG emissions and costs. Available at: https://doi.org/10.1016/j.ecmx.2020.100043 (Accessed 2023).	Assuming that our methane reformation technology is SMR with CCS. After converting units, the value to 3 significant figures is 0.013kgCO2e/kWh.
Resistance heating	Annual operational cost	0	£/kW/year	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	Annual maintenance costs for resistance heaters zero. Does not change between years
Resistance heating	Energy CAPEX	150	£ / kW	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	CAPEX includes unit and installation costs. Values used for Residential. Does not change through the years.
Resistance heating	Energy efficiency	1	fraction	National Renewable Energy Laboratory (1997). Available at: Saving Energy with Electric Resistance Heating. https://www.nrel.gov/docs/legosti/fy97/6987.pdf	All incoming electricity is converted to heat by resistance heaters.
Resistance heating	Lifetime	20	years	Indeeco (2017) Heater life expectancy. Available at https://indeeco.com/news/2017/06/20/heater-life-expectancy/. (Accessed 2024)	Assuming that the life expectancy of a resistance heater is dictated by the lifetime of the heating element.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
National grid import	Lifetime	1	years	n/a	Set to have no impact.
National grid import	Operational cost of production	0.063	£ / kWh	BEIS (2020) Updated energy and emissions projections 2019, Annex M. Available at: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019 (Accessed 2023).	Annex M
National grid import	Operational fuel consumption cost	0	kgCO2e / kWh	Assume 0 emissions in 2050 as Welsh government has committed to net zero by 2050.	
National grid export	Lifetime	1	years	n/a	Selected to have no effect.
National grid export	Operational cost of production	-0.063	£ / kWh	BEIS (2020) Updated energy and emissions projections 2019, Annex M. Available at: https://www.gov.uk/government/publications/updated-energy-and-emissions-projections-2019 (Accessed 2023).	Annex M
National grid export	Operational fuel consumption cost	0	kgCO2e / kWh	n/a	Export set to zero carbon because export is when there are excess renewables.
Electricity distribution lines (grid level)	Energy CAPEX	625.54	£/kW	NGED charging statements - CDCM model for South Wales (2021).	Assuming grid level electricity distribution lines correspond to 132kW network level assets, which have a cost of 13.9 £/kW/year. Multiplying by the asset lifetime of 45 years gives an energy CAPEX of 625.54.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Electricity distribution lines (primary substation level)	Energy CAPEX	0	£/kW	n/a	Assuming that the cost of the distribution lines are free, as they have already been built. The costs of new lines to be built in the future will be associated with substation upgrades.
Primary substation upgrades	Energy CAPEX	165.15	£ / kW	NGED charging statements - CDCM model for South Wales (2022) Available at: https://www.nationalgrid.co.uk/our-network/use-of-system-charges/charging-statements-and-methodology (Accessed 2023).	The cost of 132kV/HV network level assets in 2022 was 3.68 £/kW/year. Multiplying by the asset lifetime of 45 years gives an energy CAPEX for primary substation upgrades of 165.15 £/kW.
Battery	Annual operational cost	3	£ / kW/ year	Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery	
Battery	Storage CAPEX	186.42	£ / kWh	Cole, Wesley and Akash Karmakar.(2023) Cost Projections for Utility-Scale Battery Storage: 2023 Update. Golden, CO: National Renewable Energy Laboratory. Available at: NREL/TP-6A40-85332 https://www.nrel.gov/docs/fy23osti/85332.pdf (Accessed 2023).	Converted from USD to GBP 01.03.22

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Battery	Energy efficiency	0.92	fraction	Cole, Wesley and Akash Karmakar.(2023) Cost Projections for Utility-Scale Battery Storage: 2023 Update. Golden, CO: National Renewable Energy Laboratory. Available at: NREL/TP-6A40-85332 https://www.nrel.gov/docs/fy23osti/85332.pdf (Accessed 2023).	Changed energy efficiency to 0.92 this means a round trip efficiency of 0.85
Battery	Lifetime	15	years	Cole, Wesley and Akash Karmakar. 2023. Cost Projections for Utility-Scale Battery Storage: 2023 Update. Golden, CO: National Renewable Energy Laboratory. Available at: NREL/TP-6A40-85332 https://www.nrel.gov/docs/fy23osti/85332.pdf	
EV chargers	Energy CAPEX	817	£ / kW	Michael Nicholas (2019) Estimating electric vehicle charging infrastructure costs across major U.S.metropolitan areas. Available at: https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf (Accessed 2023). Calculations: https://arup.sharepoint.com/:x:/t/prj-28041700/EZof4JF_CH5HngEuZKZWJ5gBSDd8irdD4zCUWBIbznK54A?e=vjQttT	Networked 50 kW Rapid DC charger - Capex includes hardware, labour and materials (3-5 chargers per location)
EV chargers	Energy efficiency	1	fraction	n/a	Selected to have no effect

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
EV chargers	Lifetime	12	years	Deloitte (2019) UK EV charging infrastructure update (part 2): Show me the money. Available at: https://www2.deloitte.com/uk/en/pages/energy-and-resources/articles/uk-ev-charging-infrastructure-update-show-me-the-money.html (Accessed 2023).	
Landfill gas	Energy CAPEX	2740	£ / kW	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Landfill gas	Variable OPEX	0.01	£/kWh	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Landfill gas	Fixed OPEX	95	£/kW/year	BEIS (2020) BEIS Electricity Generation Costs (2020). https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Landfill gas	Carbon OPEX	0.18387	kgCO2e/kWh	BEIS (2020). Greenhouse gas reporting: conversion factors 2020. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022 (Accessed 2024).	Assumed same as natural gas
Landfill gas	Energy efficiency	0.58	fraction	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	
Landfill gas	Lifetime	28	years	BEIS (2020) BEIS Electricity Generation Costs (2020). Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020	

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Energy from Waste	Energy efficiency	0.28	fraction	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (accessed 2023).	
Energy from Waste	Lifetime	35	years	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (accessed 2023).	
Energy from Waste	Energy CAPEX	8806.666667	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (accessed 2023).`	CAPEX includes pre-development cost (medium scenario) in Â£/kW, construction cost (medium scenario) in Â£/kW and infrastructure cost. Infrastructure cost (Â£'000) is converted to Â£/kW by dividing by reference plant size (MW*1000).
Energy from Waste	Carbon OPEX	0.038	kgCO2e / kWh	DESNZ (2023) Greenhouse gas reporting: conversion factors 2023, and Tolvik (2021) UK Energy from Waste Statistics. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023 and https://www.tolvik.com/published-reports/view/uk-energy-from-waste-statistics-2021/ (accessed 2024).	The DESNZ data provides a refuse combustion conversion factor of 21.280kgCO2e/tonne. Average energy from waste export electricity per tonne fuel input averaged over 2017-2021 is found at 558.4kWh/tonne (Tolvik, Figure 10). This results in a carbon OPEX of 21.280/558.4 = 0.0381kgCO2e/kWh.

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Heat storage	Energy efficiency	0.95	fraction	Arup expertise	
Heat storage	Storage loss	0.018164	fraction	Arup expertise	
Heat storage	Storage CAPEX	29	£ / kW	Arup expertise	
Heat storage	Lifetime	30	years	Arup expertise	
Canopy PV	Energy CAPEX	1100	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Solar PV 4-10 kW, assume 10 kW. CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000). Rooftop PV costs do not change.
Canopy PV	Annual operational cost	7	£/kW/year	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	
Canopy PV	Lifetime	30	years	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	

Sponsors: Delivery partners:

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Pumped storage	Lifetime	41	years	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	Assumed Lifetime of pumped storage the same as hydropower.
Pumped storage	Energy efficiency	0.75	fraction	Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf 50MW Frequency Management battery (Accessed 2023).	Round Trip Efficiency value used.
Pumped storage	Energy CAPEX	1362.9	£ / kW	Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW (Accessed 2023).	CAPEX includes infrastructure costs, design costs, capital costs and installation costs. Medium value.
Pumped storage	Annual operational cost	17.8	£/kW/year	Mott MacDonald for BEIS (2018) Storage cost and technical assumptions for BEIS. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/910261/storage-costs-technical-assumptions-2018.pdf Connected peak lopping, 200MW (Accessed 2023).	OPEX includes Operation, Inspection, Maintenance, Replenishment / refurbishment of consumables, Insurance, Security. Medium Value.

Appendix B8

Air quality – method, assumptions, and data sources

Calculation Method (all fuels other than electricity)

We used the Green Book supplementary guidance for air quality (AQ) activity costs from primary fuel use and the transport sector [1] to estimate the air quality cost for each year (2030 to 2050) for each scenario per the following calculation method.

For each scenario and fuel (other than electricity), and in each year 2030 – 2050:

$$AQ\ activity\ cost\ (£) = fuel\ (kWh)\ *\ fuel\ AQ\ activity\ cost\ \left(\frac{p}{kWh}\right)\ *\ \frac{1\ £}{100\ p}$$

For electricity only, for each scenario and in each year 2030 – 2050:

$$AQ\ activity\ cost\ (£) = \ annual\ electricity\ (kWh)\ *\ electricity\ AQ\ activity\ cost\ \left(\frac{p}{kWh}\right)\ *\ \frac{1\ £}{100\ p}$$

where

- Fuel (kWh) and annual electricity (kWh) were calculated in the deployment model.
- Fuel AQ activity costs (p/kWh) were from the Green Book guidance [1]. Refer to the remainder of this appendix for further assumptions. Electricity was the only “fuel” where the activity cost was allowed to vary each year between 2023 and 2050, reflecting the changing nature of the electricity grid.

For each scenario and year, the air quality impacts from each fuel then were summed to derive a total impact per year.

Appendix B8

Air quality – method, assumptions, and data sources

Primary Fuel Use

Electricity was the only "fuel" which was allowed to vary each year between 2023 and 2050, reflecting the changing nature of the electricity grid. We used the air quality values from the National Average scenario in Table 15 of the Green Book supplementary guidance [1]. These are documented in Table B9.1 below for reference.

All other primary fuels used the same activity cost for each year in 2023-2050, again reflecting the pattern shown in Table 15 of the Green Book supplementary guidance [1]. We used the activity costs shown in Table B9.2 below, each documented along with any relevant assumptions.

Table B9.1. Air quality activity costs from primary fuel use, 2022 p/kWh – Electricity [1]

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
Electricity	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02

Year	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Electricity	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00

Table B9.2. Air quality activity costs from primary fuel use, 2022 p/kWh – Non-electric primary fuels

Fuel	Air quality cost (2022 p/kWh)	Data source(s) and assumptions
Natural gas	0.16	[1] Data Table 15 *Air quality activity costs from primary fuel use*, National Average (p/kWh) for gas.
Landfill gas	0.16	Assume the air quality impacts are similar to natural gas.
Organic matter	0.16	
Sewage gas	0.16	
Hydrogen	0.16	
Biomass	4.70	[1] Data Table 15 *Air quality activity costs from primary fuel use*, National Average (p/kWh) for biomass
Coal	3.74	[1] Data Table 15 *Air quality activity costs from primary fuel use*, National Average (p/kWh) for coal
Oil/LPG	1.25	[1] Data Table 15 *Air quality activity costs from primary fuel use*, average of the National Average (p/kWh) for burning oil (2.28 p/kWh) and LPG (0.22 p/kWh)

Appendix B8

Air quality – method, assumptions, and data sources

Transport Sector

We calculated activity costs from the transport sector (diesel and petrol) per the following procedure:

1. Estimating the proportion of diesel vs petrol vehicle using licensing data. The figures in Tables B9.3 and B9.4 below reflect 2019 Q4 data in the UK [2].
2. Taking the air quality activity cost (p/litre) for each vehicle type from the Green Book supplementary guidance, Table 14, Transport Average. The values for rigid HGV diesel (6.35 p/litre) and articulated HGV diesel (2.22 p/litre) were averaged to derive the value for HGV diesel in Table B9.3 below.
3. Calculating a weighted average air quality factor (p/litre) for each fuel type, weighted by the proportion of vehicles.
4. Converting this to air quality factors in p/kWh using:
   - The GHG intensity of each fuel by volume [3]
     - Diesel, average biofuel blend: 2.48 kgCO_2e / litre
     - Petrol, average biofuel blend: 2.08 kgCO_2e / litre
   - The GHG emission factor for each fuel (kgCO2e/kWh), documented in the deployment model Appendix B2.

Table B9.3. Air quality activity costs transport (diesel)

Vehicle type	Quantity [2]	Air quality activity cost (p/litre) [1]
Car diesel	687,916	13.02
HGV diesel	22,360	4.29
LGV diesel	214,969	17.15
Air quality factor, weighted average by fuel (p/litre)		13.77
Air quality factor, converted to p/kWh		1.33

Table B9.4. Air quality activity costs transport (petrol)

Vehicle type	Quantity [2]	Air quality activity cost (p/litre) [1]
Car petrol	876,250	1.58
LGV petrol	6,167	1.28
Air quality factor, weight average by fuel (p/litre)		1.57
Air quality factor, converted to p/kWh		0.17

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Air quality – method, assumptions, and data sources

References

[1] Department for Energy Security and Net Zero (2023) Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal. Available at: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[2] Department for Transport and Driver and Vehicle Licensing Agency (2023) vehicle licensing statistics data tables. Available at: https://www.gov.uk/government/statistical-data-sets/vehicle-licensing-statistics-data-tables

[3] Department for Energy Security and Net Zero (2023) Greenhouse gas reporting: conversion factors 2023. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2023.

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Appendix B9

Summary of content in Local Area Energy Plan and Technical Report

	Stage	Included in the Technical Report	Included in the Local Area Energy Plan
Introduction	1	• Overview of LAEP programme • Process of preparing to create LAEP, identifying resources, appointing lead organisation and agreeing roles.	• Overview of LAEP programme
	2	• Summary of stakeholder identification process • Overview of stakeholder engagement plan	• Summary of stakeholder engagement
The current local energy system	3	• Data sources used to inform the energy system baseline • Detailed definition of the system boundary and scope of assessment • Assumptions used to define the energy system baseline • Additional analysis not included in Local Area Energy Plan • Local, regional and national policy review	• Summary of energy system baseline • Summary of local, regional and national policy drivers for LAEP
The future local energy system	4	• Modelling approach for scenario analysis • Assumptions applied: cost, network dependencies • Sensitivity analysis results • Comparing scenarios and defining energy propositions	• Description of scenarios • Summary of key outputs and aspects of scenarios such as cost, emissions savings, energy savings and impact on networks • Defining energy propositions
	5	• Modelling approach for deployment model • Illustration of focus zones for each energy proposition across buildings, industry, transport and renewable generation • Describing deployment rates for different technologies related to each energy proposition across buildings, industry, transport and renewable generation • Opportunities with neighbouring local areas / regional	• Summary of deployment pathways for each scenario and setting level of ambition • Illustration of key focus zones for each energy proposition across buildings, industry, transport and renewable generation, with an indication of deployment from deployment modelling
Action Plan	6 - 7	• Analysis and evidence to support implementation for each energy proposition	• Action plan routemap • Details of near-term actions • Details of enabling actions, such as upskilling, funding