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Cyngor Gwynedd

Local Area Energy Plan (LAEP) Technical Report

Gwynedd

Final Issue

August 2024

Figure 0.1.1: Tanygrisiau, Gwynedd. Image provided by Meilyr Tomos ©

This Local Area Energy Plan was prepared by Arup, Carbon Trust and Afallen on behalf of Cyngor Gwynedd and Ambition North Wales. Energy Systems Catapult is the Technical Advisors for the LAEP Programme in Wales.

The Plan's development was funded by the Welsh Government.

Abbreviations

Acronym	Definition or meaning
ANW	Ambition North Wales.
BEIS	Business, Energy and Industrial Strategy.
CAPEX	Capital Expenditure.
CCGT	Combined Cycle Gas Turbine.
CCUS	Carbon Capture, Utilisation and Storage.
CPO	Charge Point Operator.
COP	Coefficient of Performance.
DESNZ	Department for Energy Security and Net Zero.
DFES	Distribution Future Energy Scenarios.
DfT	Department for Transport.
DNO	Distribution Network Operator.
ECOFLEX	Flexible Eligibility Energy Company Obligation.
ECR	Embedded Capacity Register.
EfW	Energy from Waste.
EGW	Energy Generation in Wales.

Acronym	Definition or meaning
EPC	Energy performance certificate.
ESC	Energy Systems Catapult.
EV	Electric Vehicle.
FES	Future Energy Scenarios.
GDN	Gas Distribution Network.
GHG	Greenhouse Gas.
GIS	Geographic Information System.
HGV	Heavy Goods Vehicles.
LAEP	Local area energy planning or Local area energy plan.
LDP	Local Development Plan.
LGV	Light Goods Vehicles.
LSOA	Lower super output area, a small area classification in the UK designed to have a comparable population.
LULUCF	Land Use, Land Use Change and Forestry.

Abbreviations

Acronym	Definition or meaning
NAEI	National Atmospheric Emissions Inventory.
NGED	National Grid Electricity Distribution.
NZ	Net Zero.
NWTM	North Wales Transport Model.
NZIW	Net Zero Industry Wales.
OPEX	Operational Expenditure.
OS	Ordnance Survey.
PRI	Pressuring Regulating Installation.
RdSAP	Reduced data Standard Assessment Procedure.
REA	Renewable Energy Assessment.
REPD	Renewable Energy Planning Database.
REPEX	Replacement Expenditure.
RFI	Request for Information.
RIIO	Revenue = Incentives + Innovation + Outputs, a regulatory framework used by the UK energy regulator, Ofgem.
RLCEA	Renewable and Low Carbon Energy Assessment.

Acronym	Definition or meaning
RSP	Regional Skills Partnership.
RTP	Regional Transport Plan.
SAP	Standard Assessment Procedure.
SEWBCC	Southeast Wales Business Climate Coalition.
SEWTM	Southeast Wales Transport Model.
SDP	Strategic Development Plan.
SLES	Smart Local Energy System.
SMR	Steam Methane Reformation.
SPEN	SP Energy Networks.
SSE	Scottish and Southern Energy plc.
SWIC	South Wales Industrial Cluster.
TEC	Transmission Embedded Capacity.
TfW	Transport for Wales.
WIMD	Welsh Index of Multiple Deprivation.
WWU	Wales and West Utilities.

Note: full definitions for terms used through the report are provided in the glossary at the end of the document.

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This report's development was funded by the Welsh Government.

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Technical Report

Chapter 1: Introduction (stage 1)

Figure 1.0.1: Cob, Porthmadog. Photo provided by Ambition North Wales ©

1. Introduction

The energy transition across Wales

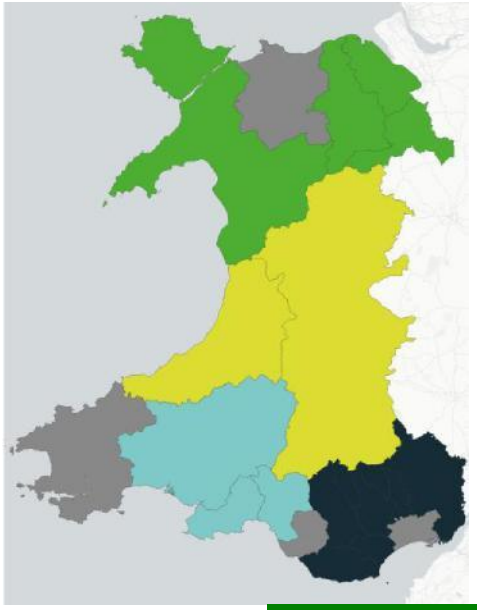
The Welsh Government's "Net Zero Wales" plan[T02] establishes an increased level of ambition on decarbonisation, with a legally binding target to reach net zero emissions by 2050. It is the first national government to fund the roll-out of LAEP to all its local authorities. The programme is being co-ordinated 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] (ESC) 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 has committed to produce in 2024.

Gwynedd'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.



North Wales by Arup, Carbon Trust and Afallen

Mid Wales by Energy Systems Catapult

South West Wales by City Science

Cardiff Capital Region by Arup, Carbon Trust and Afallen

Existing LAEPs

Figure 1.1.1: Progress made in the development of LAEPs across Wales

1. Introduction
LAEP development

Gwynedd's LAEP was prepared by Arup, Carbon Trust and Afallen on behalf of Cyngor Gwynedd and Ambition North Wales. 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 Gwynedd's LAEP in accordance with ESC's LAEP Guidance[T01], which breaks the LAEP development process down into seven stages. (See Figure 1.1.2).

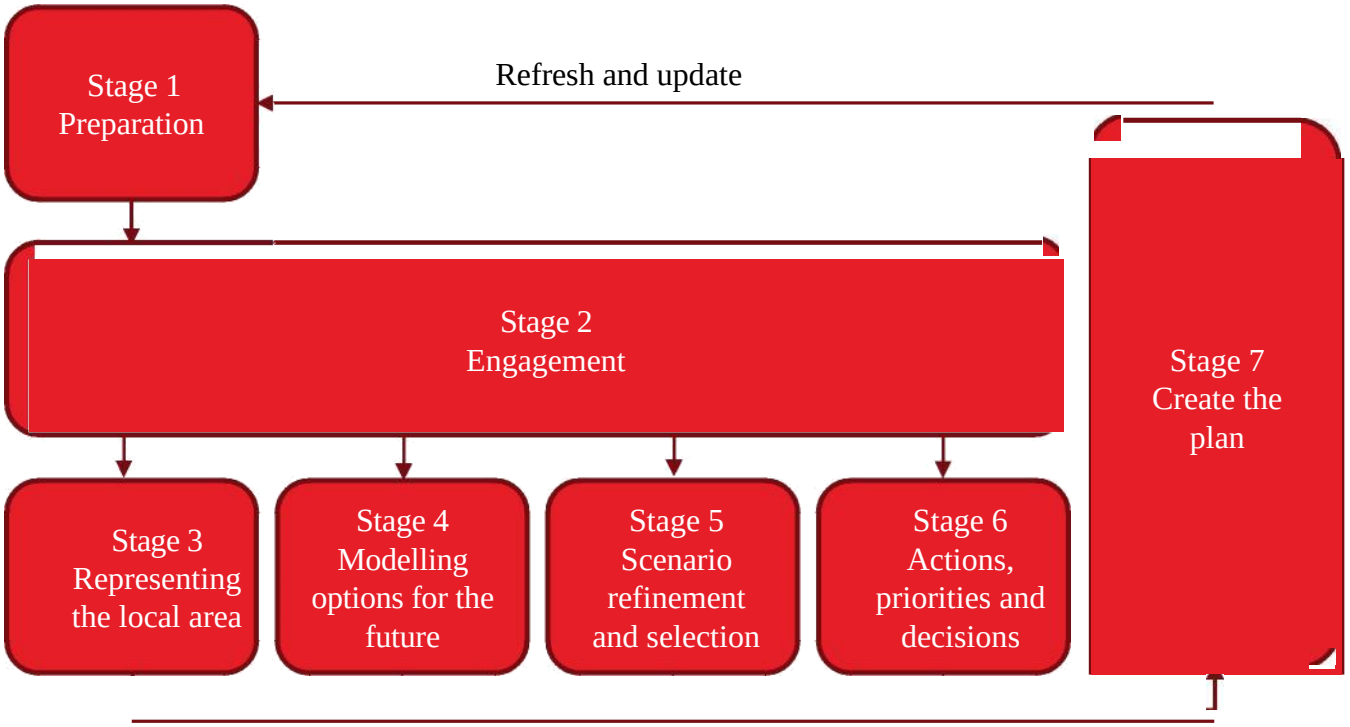


Figure 1.1.2: Seven stages of local area energy planning (LAEP) according to ESC's LAEP Guidance[T01]

1. Introduction

Introduction to Technical Report

The LAEP has been divided into two 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 **Local Area Energy Plan** focuses on Gwynedd's local energy strategy and action plan.

Figure 1.1.4 (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 ESC's LAEP Guidance[T01], please see Appendix A5.

A note on the use of "we" throughout this report:
In this report, the term "we" has been used throughout to refer to the consultants that have been commissioned by Welsh Government to support the development of this LAEP.

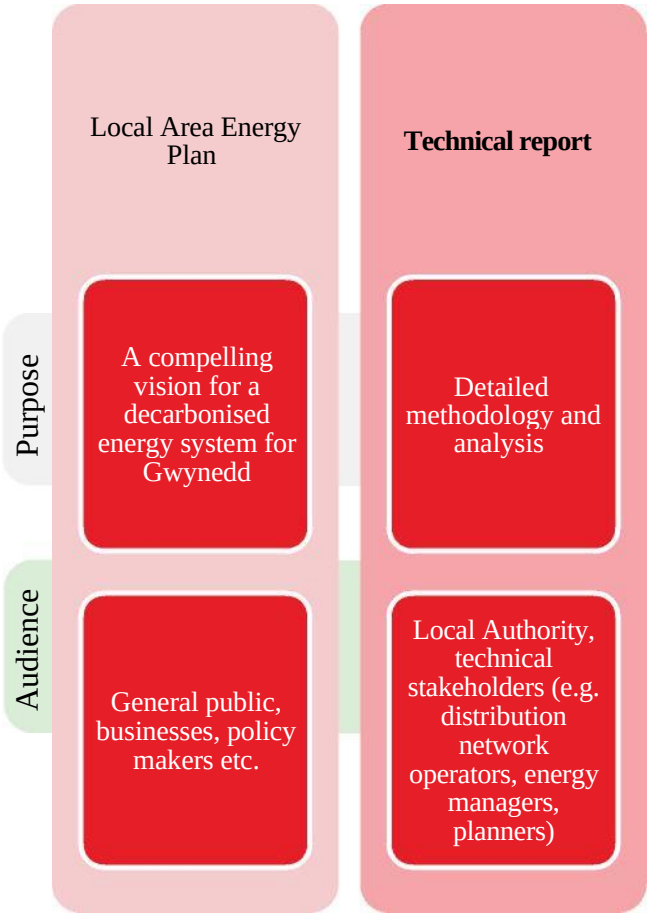
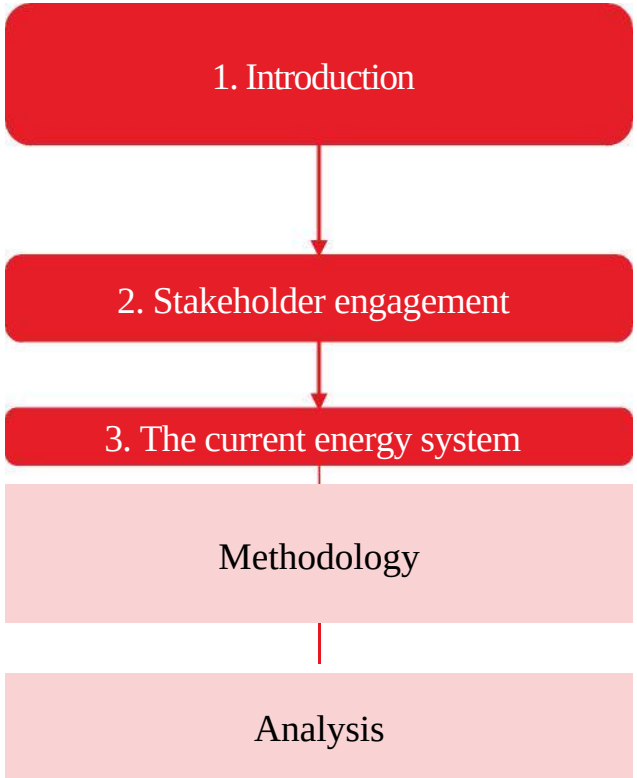


Figure 1.1.3: Summary of LAEP reports' purpose and audience

1. Introduction

Introduction to the Technical Report

Navigating this report



Content

- 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.

- Approach taken to identify, prioritise and engage stakeholders throughout the development of the LAEP.

- Summary of data sources used to inform the energy system baseline.
- Summary of assumptions used to define the energy system baseline.

- Presentation of local socio-economic context.
- Discussion of Gwynedd's baseline energy use from buildings, industry and transport and energy generation.

Figure 1.1.4: Summary of content in Technical Report

1. Introduction

Introduction to the Technical Report

Navigating this report

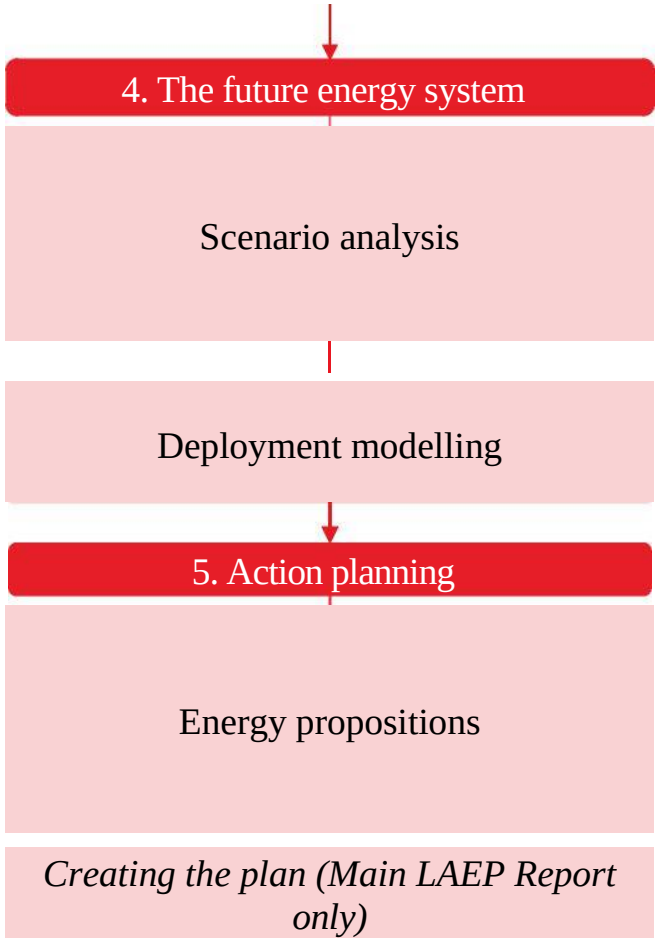


Figure 1.1.5: Summary of content in Technical Report

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

1. Introduction

Boundary and scope

A LAEP considers energy use, supply and generation within the Cyngor Gwynedd's county 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.

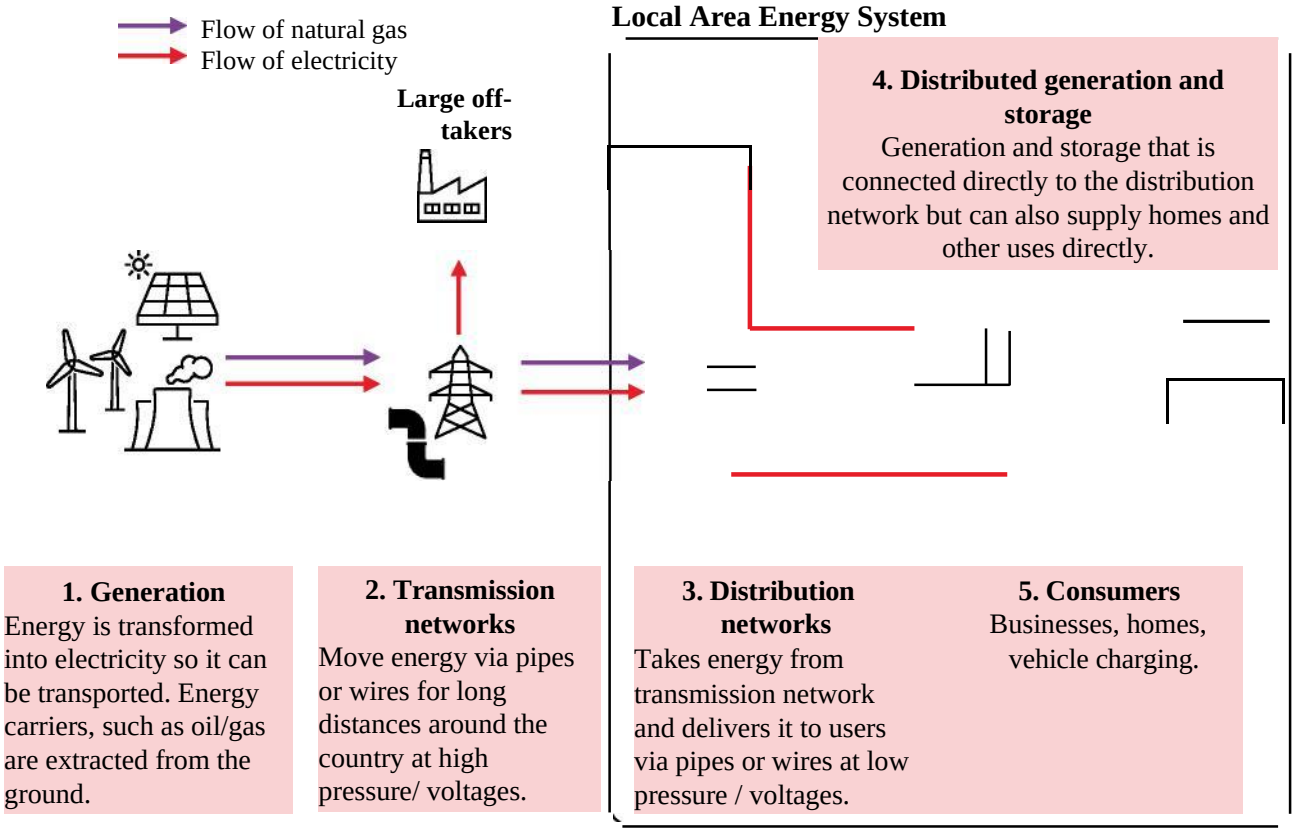


Figure 1.1.6: Illustration of transmission and distribution of gas and electricity from supply to consumer, and what parts of this system are included in the system boundary for LAEP

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, which includes local energy supply, use and supporting infrastructure. We used the geographic boundary for Gwynedd to set the boundary for the LAEP, 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[T03]. The Guidance states that certain energy assets should be considered national rather than local despite being present in the geographic boundary and where the asset serves the wider energy needs of the UK. Considering this, electricity connection at lower voltages (132kV / 33kV / 11kV) was defined as "local" and included in the modelling for the LAEP. Any assets connected at higher voltages (400kV / 275kV) or with capacities > 100MW were considered "national" and excluded from the modelling unless otherwise specified. For example, Gwynt y Môr and Rhyl flats offshore wind farms are considered "national" assets.

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.

Like the above, any demand connected to the transmission network is excluded, as we are focused on the local distribution network.

The scope of the LAEP also excludes energy use in shipping, aviation, exports, military transport, and oil refineries because they are considered national decarbonisation challenges and should be addressed by central Government.

Emissions

Emissions from sources that are not related to the energy system are excluded. This includes emissions from land use, land use change and forestry, industrial processes and waste and wastewater treatment processes. Please refer to Appendix B1 for a summary of emissions in scope.

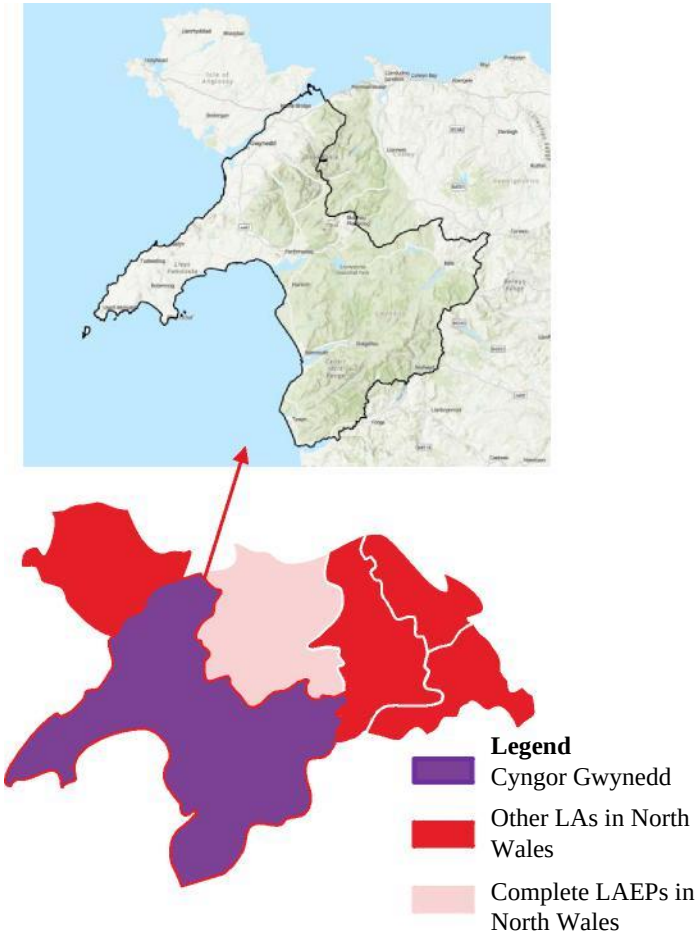


Figure 1.1.7: Location of the North Wales economic region (red) and the LAEP system boundary for Gwynedd (purple)

Technical Report

Chapter 2: Stakeholder engagement (stage 2)

Figure 2.1.1: Harlech Beach, Gwynedd. Image provided by Emma Carter (Arup) ©

2. 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 a local authority.

1. Stakeholder definitions and roles

Specific definitions and roles are included in the introduction (see Table 2.1.1 overleaf). Our approach was particularly 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 within the local authority area. As LAEP is a whole systems approach at the local authority level, so we needed individuals from a broad range of stakeholder organisations with the appropriate level of local expertise and local knowledge. To avoid stakeholder fatigue and to ensure we addressed regional synergies we created the additional regional secondary stakeholder group described in the introduction.

2.Stakeholder identification and mapping

A pre-developed stakeholder mapping tool was provided to each local authority to collect stakeholder data, both for organisations and appropriate target individuals. These were reviewed with the LAEP programme team 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.

3. Stakeholder engagement planning

We reviewed the scored stakeholder lists and a final list of primary and secondary stakeholders confirmed, we ensured that where possible, stakeholders that represented key components of the local energy system were considered. For example, where industry is a key component, stakeholders were identified.

4. Limitations and mitigation

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

1. Knowledge within the local authority team of the local energy system and participants with high levels of local knowledge and / or local influence. Mitigated through iterative reviews of the developing stakeholder mapping and inclusion of the wider programme team's local knowledge and experience of stakeholders across all relevant sectors in each local authority.
2. Sufficient data and information on stakeholder organisations was needed to identify appropriate individuals. This was mitigated by networking with participants, continuous improvement, and promotion of LAEPs locally.

2. Stakeholder engagement

Stakeholder identification process

Stakeholder group	Organisations	Role in LAEP development	Method of engagement
Primary stakeholders	Local Authority officers, council member(s), Welsh Government, Ambition North Wales, 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
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

Table 2.1.1: Overview of engagement activity for identified stakeholder groups

2. Stakeholder engagement

Overview of stakeholder engagement plan

This section describes the methodology used to engage with primary and secondary (local and regional) stakeholders throughout the programme.

1. Contract meetings

As part of the overarching programme, a national forum brought together all suppliers, local authority leads, the regional leads, Welsh Government and the Technical Advisor to share learnings and maintain a consistent approach across Wales. The suppliers and regional leads also had regular catch ups to share assumptions and challenges.

We held regional steering groups for North Wales, attended by the regional and local authority leads, as well as bi-weekly meetings with the local authority leads – also attended by the regional leads.

2. Interactive, online workshops

Interactive online workshops were used as the primary means of engaging with both primary and secondary stakeholders. The benefits of using them included: reduced time commitments for participants ensuring attendance was maximised, the interactivity of workshops allows participants to contribute dynamically, e.g. verbally, chat, Miro boards, enabling a broader data collection via these interactive tools, and the ability to cost effectively deliver multiple workshops. As well as enabling local workshops to be delivered the use of virtual workshops meant regional stakeholder workshops were easier to convene.

0. Approach to workshops

The purpose of each of the interactive workshops were tailored to the objectives of respective stage of the LAEP. Agendas were constructed to deliver the purpose(s), see Table 2.1.2 overleaf. For each agenda item a clear aim was set that supported achievement of one or more of the workshop's purpose. Using the research question(s) and / or outcome needed to achieve the aim presentation material, exercises, facilitation material and appropriate means of data collection were created.

1. Workshop data collection, analysis and synthesis

Appropriate means of data collection were used to ensure a complete and accurate record of participants responses was made. These included:

- Workshop recordings
- Chat transcripts
- Workshop exercises requiring inputs in response key research questions best presented and facilitated visually used Miro boards
- Post-workshop emails and follow-up interviews

Analysis, evaluation and synthesis of data was undertaken to achieve the workshop outcomes. Examples include: identification of comments relating to missing data in material presented, evaluation and synthesis of the data to identify key themes emerging from a synthesis of collected data.

5. Limitations and mitigation

Some limitations applied to our methodology, and we undertook mitigations to address them as much as possible:

Potential risk of a lack of structure to the data collection given the open discursive nature of workshops. Mitigated through clear workshop briefings, purpose(s), agenda and sound facilitation to ensure participants had a range of opportunities to contribute and group discussions remained focussed on the research questions.

Potential risk participants have a personal preference for text based or commercial reason for not contributing comments in an open forum. These were mitigated through the use of chat, and facilitation introducing chat comments on participants behalf, and the opportunity to contribute for an extended period after the workshop by email.

Potential risk that stakeholders did not participate in all workshops. This was mitigated through providing an overview if work to date in each workshop and distributing slides to invitees.

2. Stakeholder engagement

Regional

Local

Overview of stakeholder engagement plan

LAEP stages>>	1	2	3	4	5	6	7
Objectives / Purposes	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.	Presentatio n of draft LAEP results
Key outputs	Objectives for the LAEP Stakeholder mapping refined	Set local strategic energy objectives, local policy drivers.	Agree four future energy 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 actio ns and responsibilities to support the delivery of the local propositions	Final comments
Technical advisor							
Primary							
Regional							
Secondary							

Table 2.1.2: Groups of stakeholders engaged at each stage of the LAEP process

Technical Report

Chapter 3: The current local energy system (stage 3)

Figure 3.0.1: Image provided by Bethan Richardson (Cyngor Gwynedd) ©

3. The current energy system
Overview

This section is structured as follows:

Methodology

This section summarises the data sources and assumptions applied to describe the characteristics of Gwynedd'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.

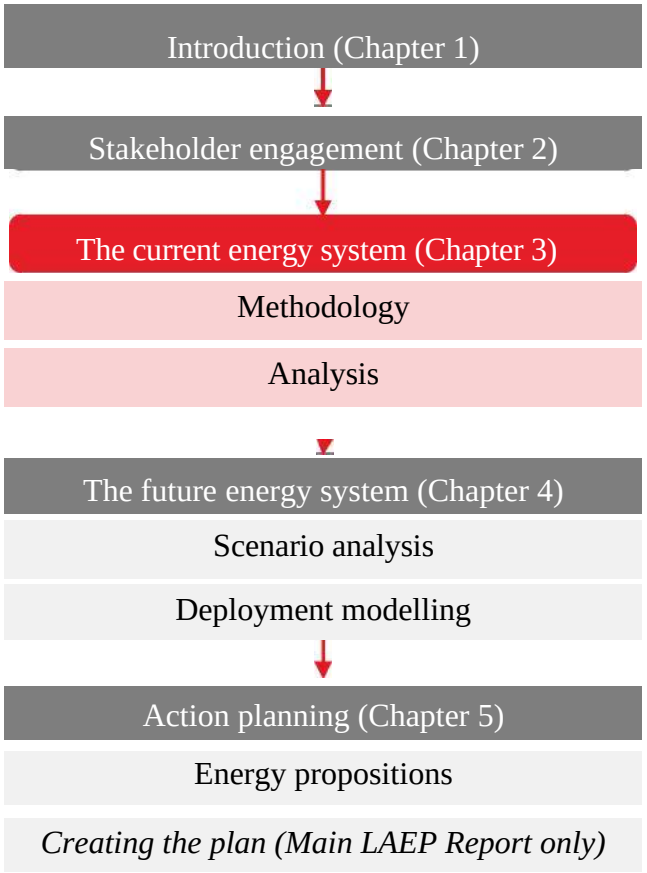


Figure 3.1.1: Flow diagram showing the chapters and sub-chapters in this report (the chapter that follows is highlighted in red)

Technical Report

Chapter 3: The current local energy system (stage 3)

Methodology

Figure 3.0.1: Image provided by Bethan Richardson (Cyngor Gwynedd) ©

3. The current local energy system

Methodology overview

This section provides a detailed overview of the 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

Energy consumption data and the capacities for existing energy generators in Gwynedd were compiled from local and regional sources, prioritising the highest level of granularity possible. A Request for Information (RFI) was circulated to the Local Authority to gather local 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, industry, transport, heat networks, renewable energy, 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 (2019) 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

The calculated results were cross-referenced 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 New 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

Maps were generated to present spatial information related to the current energy system to support analysis.

Context: maps showing socio-economic and energy efficiency data.

Demand: maps showing electricity, heat/gas and transport demand data.

Infrastructure: maps showing primary substation demand headroom, generation headroom and the proportion of properties that are not connected to the gas.

Supply: maps showing energy generators.

3. 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.

For five small areas in the north Wales region, there was no data provided. These areas with data gaps were referred to as modelling zones, with an unlimited capacity for modelling purposes.

Exclusions

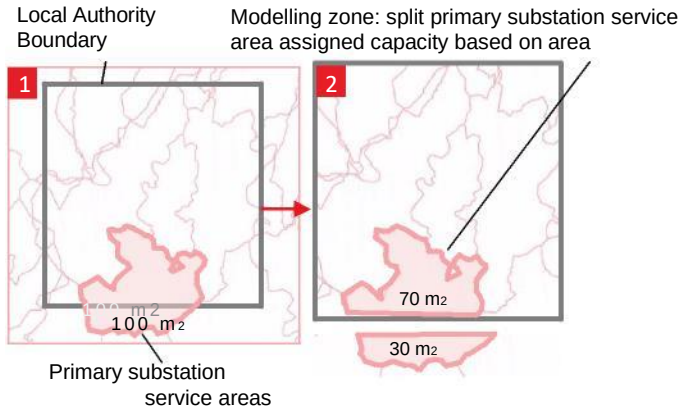
This piece of analysis only considers the distribution network, as the transmission network is considered a national asset and therefore out of scope of the LAEP.

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	SPEN Open Data Portal[T06]	Primary	Five small areas in the north Wales region were not included within any SPEN substation zones.
Off-gas grid homes	EPC data[T07]	Primary	Heating-type data available for ~60% of homes

Table 3.1.1: Electricity network infrastructure – data sources



*Note: areas shown here are theoretical values.

Figure 3.1.2: Process of mapping primary substation service areas to the local authority boundary

3. The current local energy system

Methodology – gas and electricity network infrastructure

Substations are important components of the electricity network that allow electricity to be transmitted safely at different voltages across the network. Owned and operated by the DNO, (SPEN in North Wales) primary substations reduce electricity voltages to ensure safe usage in buildings.

These primary substations serve specific areas, creating boundaries known as substation zones. Torfaen is intersected by a large number of substation zones, as shown in Figure 3.1.3. Note that throughout this report, these substation zones are also referred to as modelling zones.

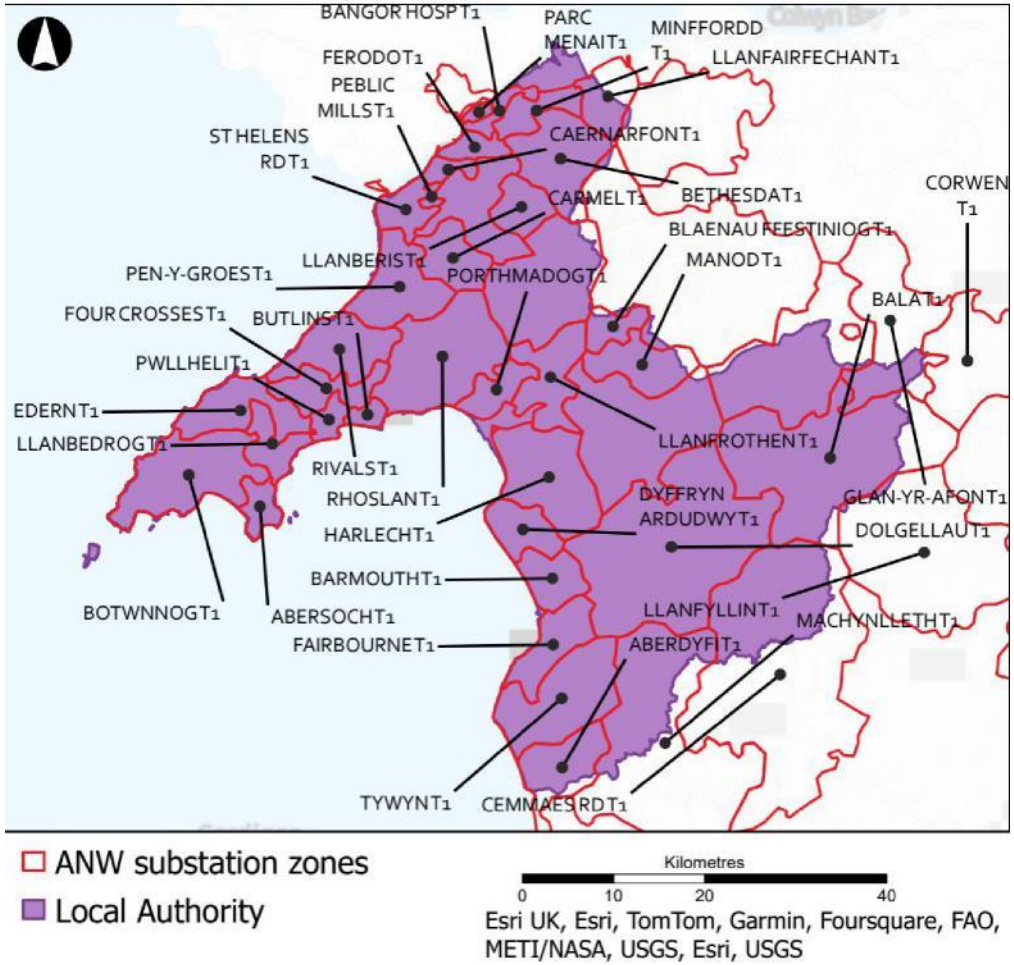


Figure 3.1.3: Electricity substation zones used to model Gwynedd's energy system

3. The current local energy system

Methodology – buildings energy demand

Carbon Trust has a well-established address-level database that uses a "bottom-up" approach for both domestic and non-domestic properties. 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) (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 - see Appendix B3.

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.
Domestic heat and electricity demand profiles	Profiling tool commissioned by NGED and developed by Hildebrand[T09]	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 3.1.2: Baseline data sources (buildings)

3. The current local energy system

Methodology – building energy demand

Archetyping and profiling

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 statistics[T05] is 3.1% 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[T05].

We have highlighted two statistics in the table below as potential sources for the difference. 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. See Appendix B3 for a detailed list of energy benchmarks.

Cyngor Gwynedd	% difference
Domestic electricity demand difference	3.1%
Domestic heat demand difference*	-54%
Non-domestic electricity demand difference	-16%
Non-domestic heat demand difference	-49%
Un-occupancy (Census 2021) T11	19%
% non-domestic properties with no archetype	15%

Table 3.1.3: Demand differences between sub-national energy consumption statistics and building profiles

*DESNZ's statistics[T05] report gas consumption which was used as a proxy for heat demand.

Methodology – buildings energy demand

Domestic building archetypes	
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

Non-domestic building archetypes	
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 3.1.4: (Left) Summary of domestic building archetypes used and (Right) Summary of non-domestic building archetypes used

3. 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 TfW transport models[T12] to estimate annual road mileage data between different parts of a local area. TfW's data provided the number of trips between two different 'travel zones' (defined by TfW) on an average day according to vehicle type. In this data, a trip is defined by the zone where a vehicle's journey starts and the zone where it ends; therefore vehicles which pass through a 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 travel zones to substation zones. We summed over vehicle types to produce the map shown on the right in Figure 3.1.4.

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 3.1.5: baseline data sources (transport). 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.

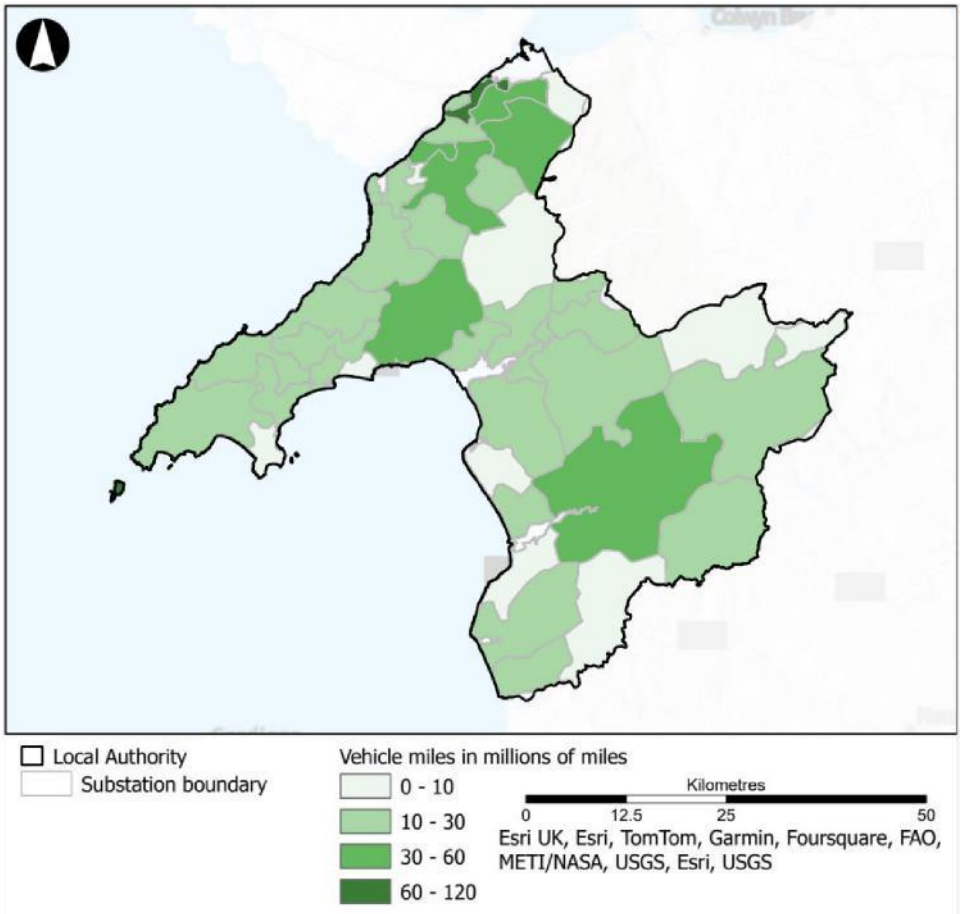


Figure 3.1.4. Estimated annual mileage (million miles / year) for all vehicles for Gwynedd by substation zone (2019)

3. 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]
- 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 (Figure 3.1.6) on the next page.

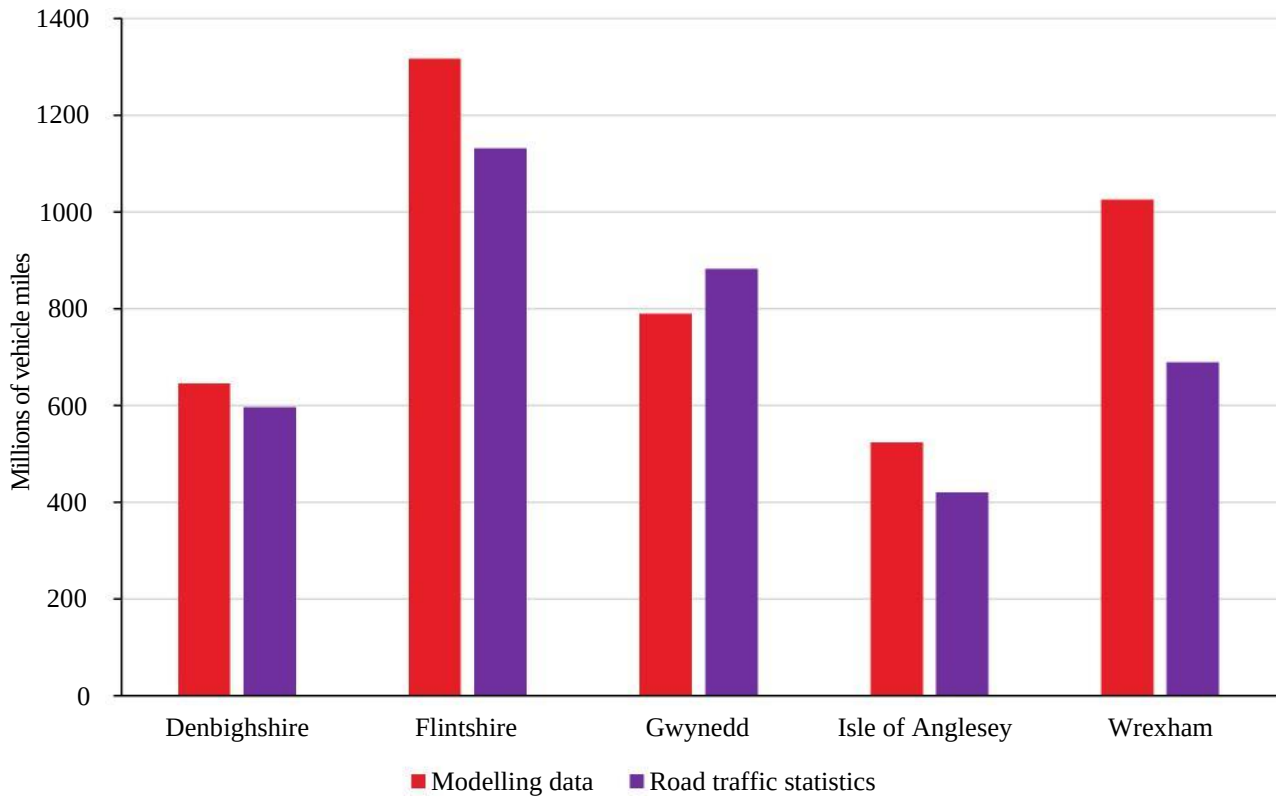


Figure 3.1.5: Comparison of modelling data to DfT road traffic statistics[T13]

3. 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's sub-national fuel consumption statistics. Our estimates are consistently higher than the DESNZ's statistics. In our estimates, we calculate the energy consumption of HGVs to be several times greater than in the DESNZ dataset, which is the major driver of this difference.

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].

For Gwynedd's baseline, we used information from the National Chargepoint Registry[T15] so that it was consistent with data sources used across Wales for reporting and have specified any differences in the following sections where they apply. It was decided that any data provided by the Council wasn't included because it is not clear if (or how many) chargers are duplicated with the mapped National Chargepoint Registry[T15] data.

Exclusions

Note that trips by rail and therefore energy demand from rail transport is not in scope and excluded from the energy baseline. Rail is considered a national asset. Journeys made by off-road vehicles are also excluded.

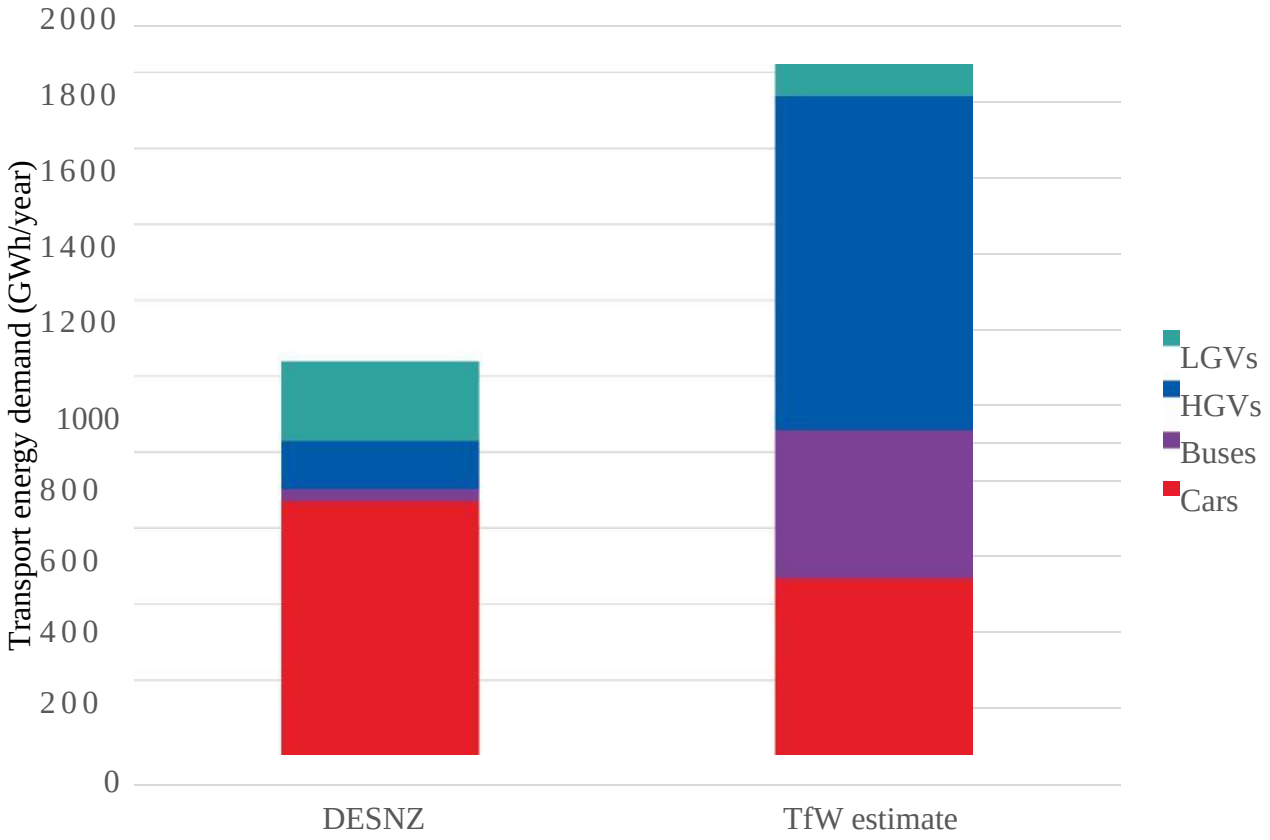


Figure 3.1.6: Annual transport energy consumption; our analysis based on TfW data compared to DESNZ sub-national fuel consumption statistics for Gwynedd

3. The current local energy system

Methodology – transport energy demand

Data input	Data source	Data type	Data quality
Demand tables	North Wales Transport Model (NWTM)[T12]	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 more rural parts of Wales such as the majority of Gwynedd.
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 3.1.5: Baseline data sources (transport)

3. 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) 2020[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].

A RFI was sent to industry stakeholders to try and obtain primary data for the site's annual electricity and gas consumption, to validate calculated industrial energy demands.

There is limited heavy industry across Gwynedd, and as such we did not receive any further information. We therefore 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 from any other sources that could be used for validation.

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	National Atmospheric Emissions Inventory, 2020[T20]	Primary	Only carbon emissions were considered. Other emission types were discarded

Table 3.1.6: Baseline data sources (industry)

3. 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.

Data validation

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) [T22] or SPEN's embedded capacity register (ECR)[TN24]. This was the latest report available at the time of developing the baseline.

As the EGW dataset [T23] 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 also 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) TN24 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 3.1.7: Baseline data sources (local energy generation)

3. 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 3.1.8. 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.

During workshops, a number of stakeholders raised questions about domestic wood fuel consumption (including logs for domestic firewood) for use in closed stoves (wood burners) and open fires. There is limited regional data available on the wood fuel market, including the use of informal 'grey' wood and limitations around volume to mass conversation factor, therefore this has not been accounted for within the baseline.

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. T26
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 3.1.8: Baseline emission factors (local energy generation)

Chapter 3: The current local energy system (stage 3)

Analysis

Figure 3.2.1: Trefor, Gwynedd. Photo provided by Ambition North Wales ©

3. The current local energy system

Analysis – local context

Gwynedd is located in the north-western part of Wales, bordered by Anglesey to the north (located across the Menai Straight) and Conwy, Denbighshire and Powys to the east and Ceredigion to the south. Gwynedd is the second largest county in Wales and is predominately rural in nature, with a unique natural environment, including high value landscape and biodiversity assets such as Eryri National Park and the Llŷn Area of Outstanding Natural Beauty. Across the county, smaller towns are generally located inland, with larger towns such as Bangor, Caernarfon and Pwllheli located along the coast.

Economics

There are two economic sectors that strongly influence Gwynedd's economy, namely tourism and agriculture. Agriculture has traditionally been a cornerstone of the economy and continues to be a key industry that employs over 5,000 people. Alongside agriculture, the tourist industry is also a key employer with an economic value of nearly £1 billion.

Cyngor Gwynedd is continuing to create conditions to attract investment into key strategic sites including Trawsfynydd Power Station, Llanbedr Airfield and Parc Bryn Cegin/ Parc Menai.

Regeneration

Since 2012, Gwynedd Council has been working together with Welsh Government to facilitate the development of two of Meirionnydd's key strategic sites – Trawsfynydd Site and Snowdonia Aerospace Centre, Llanbedr.

Cwmni Egino (CE) was established in 2021 by Welsh Government to deliver a site development plan for Trawsfynydd, focused on socio-economic growth.

Renewable Energy

Common to the rest of Wales, grid capacity across the Transmission and Distribution networks in Gwynedd is still highly constrained which may limit the future connection of new generation.

Solar PV

Cyngor Gwynedd Solar PV Panels scheme - Phase 4 will result in the installation of additional solar panels on 54 of our buildings. Other renewable energy projects in Gwynedd include a recently approved planning application for a 4.99 MW solar PV farm in Llanbedrog, Pwlheli.

Hydropower

Gwynedd has the greatest number of hydropower projects in Wales. Given the environmental designations across the County, there are limited opportunities for deployment of large-scale renewable energy projects. However, there are a number of community energy groups active across Gwynedd, providing future opportunities for micro-generation and community scale development which could contribute to future electricity generation.

Council fleet and local transport

At the start of 2024 we are purchasing an additional 67 vehicles and installing EV charging points for fleet and public use. We are also investigating other alternatives, including projects run by Ambition North Wales to develop hydrogen as a potential fuel source.

The launch of our joint strategic plan for Gwynedd and Eryri 2035, also include proposals for additional EV charging infrastructure, and improved public transport service, within and around the National Park. This includes electric buses on the new TrawsCymru service between Caernarfon, Porthmadog and Blaenau Ffestiniog. There are also community owned transport initiatives across the county, including community car clubs, for example, Car-n-arfon, part of the Co Wheels network.

Housing

The Council does not own any housing stock; social housing in the county is owned by Adra, Grŵp Cynefin and North Wales Housing who are all currently carrying out a number of energy efficiency initiatives with partners, for example, Project Sero Net Gwynedd.

3. The current local energy system
Gwynedd's energy baseline

Progress to date

Cyngor Gwynedd successes to date:

- Invested nearly £8million on carbon management projects including replacing streetlamps with LED lamps, investment in EV charge points at depots and our offices, in addition to purchasing low emission fleet and refuse collection vehicles.
- Undertaken a baseline assessment of our carbon footprint and identified relevant governance, monitoring and reporting mechanisms for our approach to decarbonisation.
- Our energy conservation service has helped 1,671 people with energy vouchers worth £81,773.
- We have achieved a 20% reduction in our carbon emissions from our procurement processes between the 2019/20 baseline year and 2022/23

Cyngor Gwynedd Carbon Management Plans

Gwynedd Council formed a partnership with Carbon Trust in 2009 and, as a result, two Carbon Management Plans have been approved.

The Carbon Management Plans (CMP) were comprehensive strategic plans which outlined:

- Gwynedd Council's carbon performance in the baseline year of 2005/6
- The identification of carbon improvement and reduction opportunities
- The provision of recommendations to improve and reduce carbon
- The setting of carbon reduction targets

In 2005/6, carbon emissions from buildings, street lighting, waste, fleet and business transport were 31,155 tCO_2. In 2020, the council achieved a reduction in carbon emissions of 59.9% across its buildings and 58.3% overall (since original 2005/06 baseline).

Cyngor Gwynedd Energy Conservation Measures:

Cyngor Gwynedd has invested in automated Monitoring & Targeting (aM&T) systems to reduce energy waste across its sites and continues to upgrade its systems. Encompassing the use of half-hourly

Automated Meter Reading device data and energy management software, this technology was the main contributor to the 20.7% reduction in gas use seen by comparing 2019/20 to 2022/23, equivalent to a financial saving of £114,000. The latest upgrade makes use of Artificial Intelligence technology and will take us a step closer to the ultimate goal of zero waste. In parallel with aM&T, Cyngor Gwynedd has also invested in a large number of Building Energy Management Systems allowing centralised control of heating systems.

Cyngor Gwynedd targets	% change from baseline (2005/6 to 2020)
Street Lighting	-80.3%
Fleet	-35.7
Business Travel	-58.0
Waste	-55.5
Buildings and Solar PV	-59.9
Total Emissions Reduction (from baseline)	**-58.3 %**

Table 3.2.1: Cyngor Gwynedd carbon management plan targets and results

3. The current local energy system

Analysis – socio-economic context

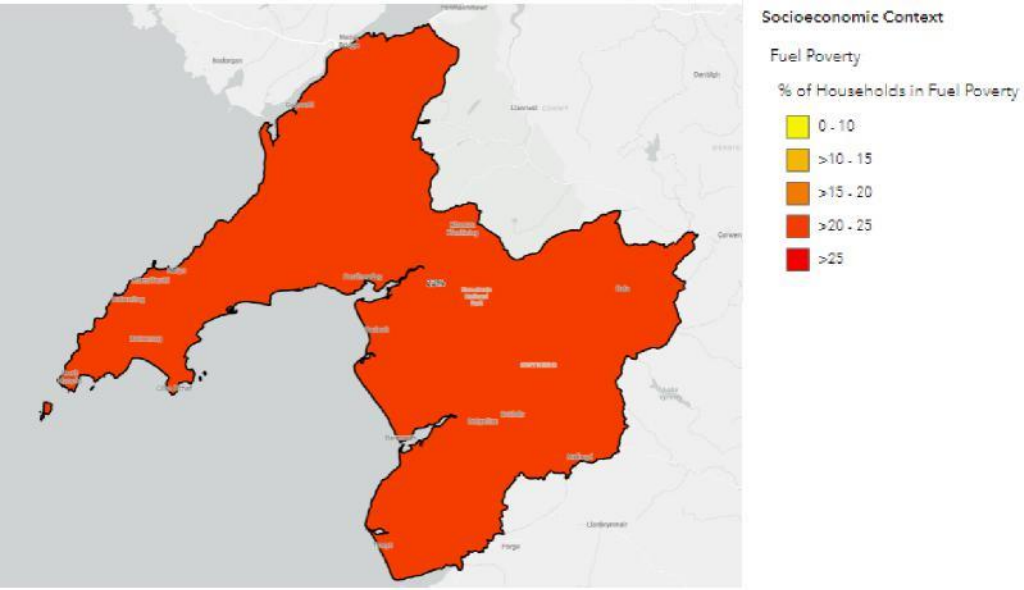


Figure 3.2.2: Fuel poverty by LSOA in Gwynedd in 2019. Note: Data on fuel poverty is only available at the Local Authority level.

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 spend more than 10% of their income on maintaining a satisfactory heating regime. In 2019, a total of 22% of households across Gwynedd were identified to be in fuel poverty (i.e. they are susceptible to relatively small changes in income or energy costs.) in comparison to 14% of households across Wales[T27]. Across Wales, households living in the private rented sector were more likely to be fuel poor compared to owner-occupiers or those in social housing. These figures are expected to increase to around 45% in 2022[T27], largely driven by the impacts of the pandemic.

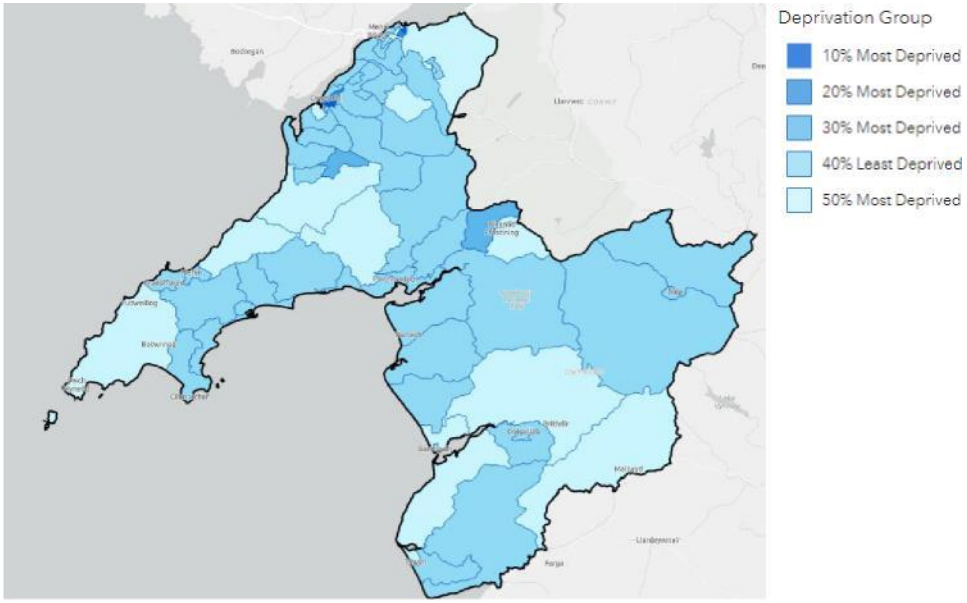


Figure 3.2.3: Index of Multiple Deprivation by LSOA in Gwynedd in 2019

The Welsh Index of Multiple Deprivation 2019 (WIMD) is the official measure of deprivation in small areas in Wales. It is a relative measure of concentrations of deprivation at the small area level. Deprivation refers to wider problems caused by a lack of resources and opportunities. In 2019, 34.2% of the 73 LSOA areas across Gwynedd were ranked in the 50% most deprived.

3. 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 Chapter 2: The current energy system. The emissions shown in Figure 3.2.4 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, GHG emissions per capita were 5.2tCO_2e per capita, ranking the 13th highest of all 22 Welsh Local Authorities.

The largest contributors to GHG emissions in Gwynedd

- **Road vehicles** (56%)
  - 99.9% of total GHG emissions are from the use of petrol and diesel in road vehicles
- **Energy used in buildings** (43%)
  - 50% of total GHG emissions are from the use of natural gas in buildings (gas fired boilers)
  - 37% of total GHG emissions are from the use of oil or LPG

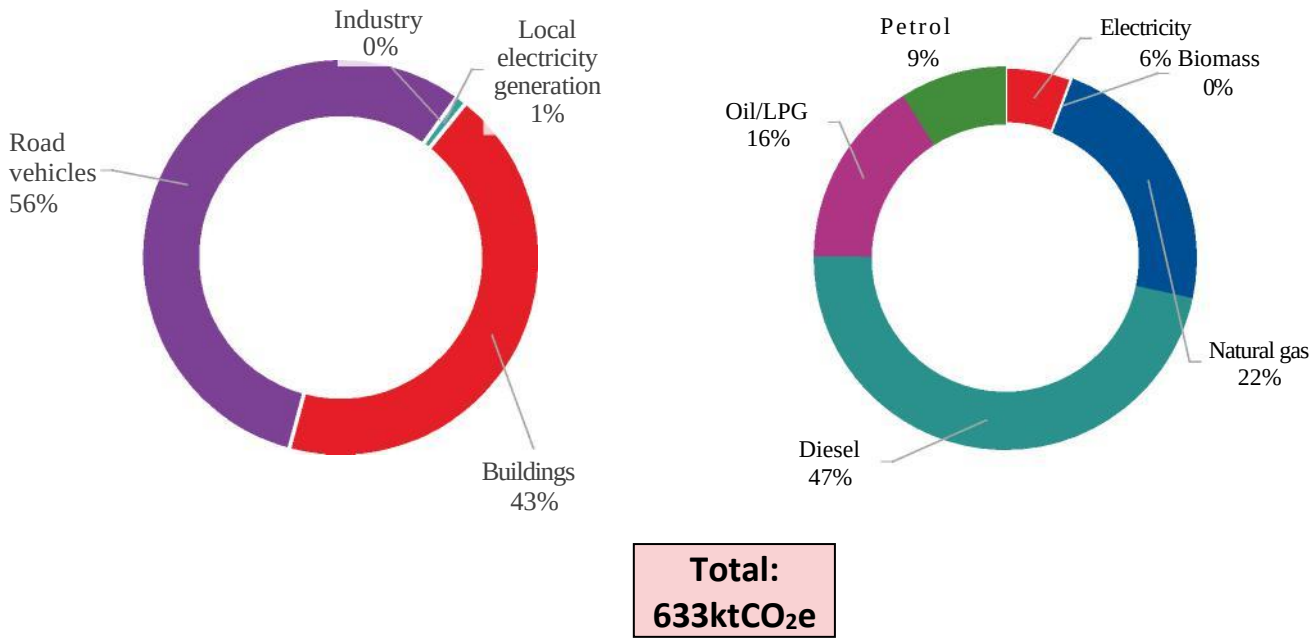


Figure 3.2.4: (Left) Gwynedd's GHG emissions (ktCO₂e/year) by sector (2023) (right) Gwynedd's GHG emissions (ktCO₂e/year) by fuel type
*excludes emissions from waste and land use, land use change and forestry (LULUCF)

3. The current local energy system
How to read a Sankey diagram

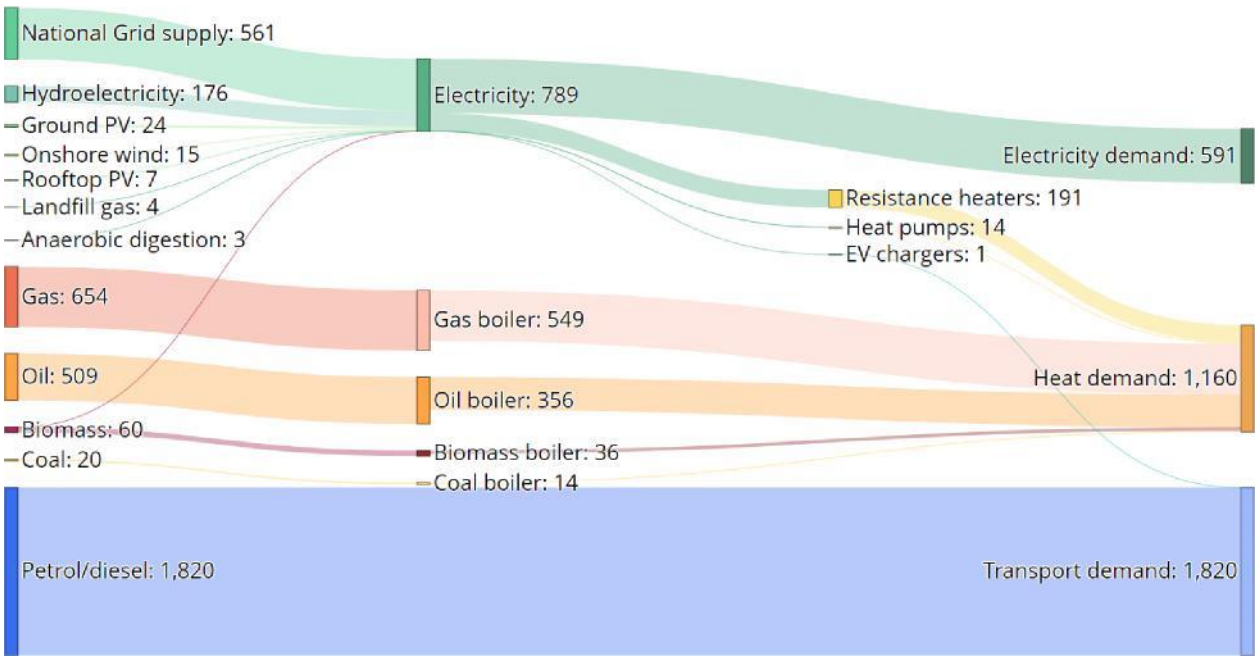
Baseline energy flows – Sankey diagram

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.

The 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 Gwynedd in 2023, apart from the transport (2019) 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 COVID-19.



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 3.2.5: How to read a Sankey diagram (using the baseline Sankey for Gwynedd - units are GWh/year)

3. The current local energy system

Analysis – annual energy flows

The baseline analysis for Gwynedd provides insight into the existing energy system in 2019.

29% of the **electricity supplied to** the local energy system is from local renewable energy sources including:

- 55MW of hydroelectricity installed (176 GWh / year)
- 30MW of ground-mounted solar PV (24 GWh / year)
- 4.4MW of onshore wind (15 GWh / year)

Almost all electricity generated is used to fulfil electricity demand from buildings (i.e. not heat or transport).

Heating comprises the second largest component of energy demand, accounting for 33% of total energy across Gwynedd.

Around half of all domestic properties (50%) are connected to the gas grid (heated using gas boilers), with demand also being met by oil/LPG (24%) and electricity (13%).

Almost all **vehicles** in Gwynedd have internal combustion engines (ICEs), with relatively low uptake of electric vehicles (EVs). Combustion vehicles lead to **significant energy losses**, with over half of petrol/diesel energy lost during combustion.

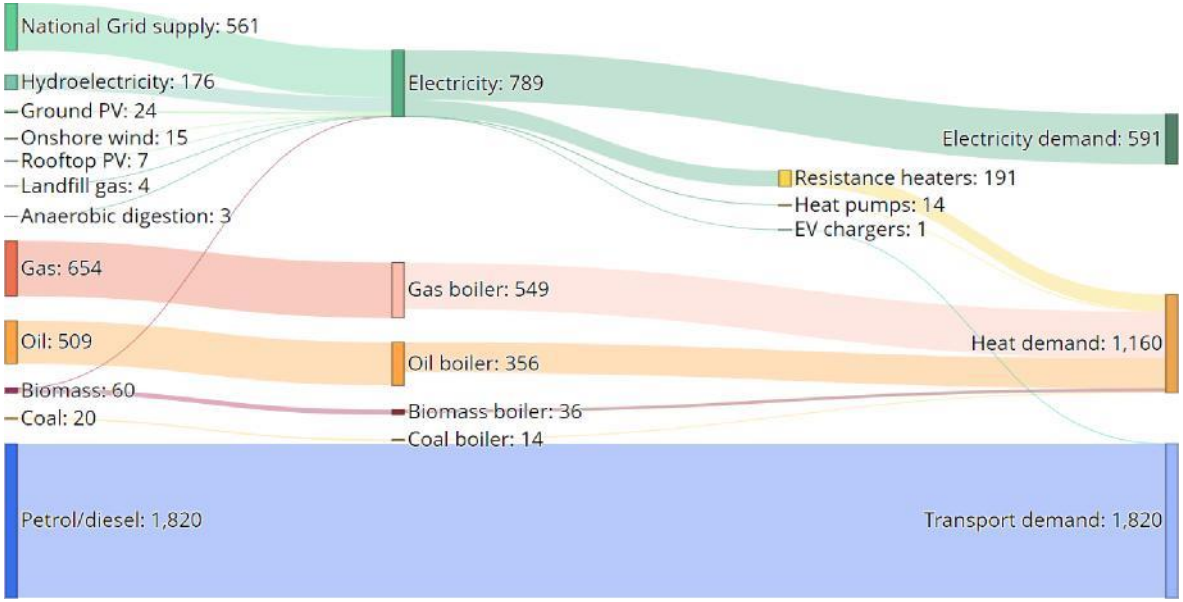


Figure 3.2.6: Baseline Sankey diagram, representing energy flows in Gwynedd in GWh/year (2019)

3. The current local energy system

Analysis – buildings energy demand

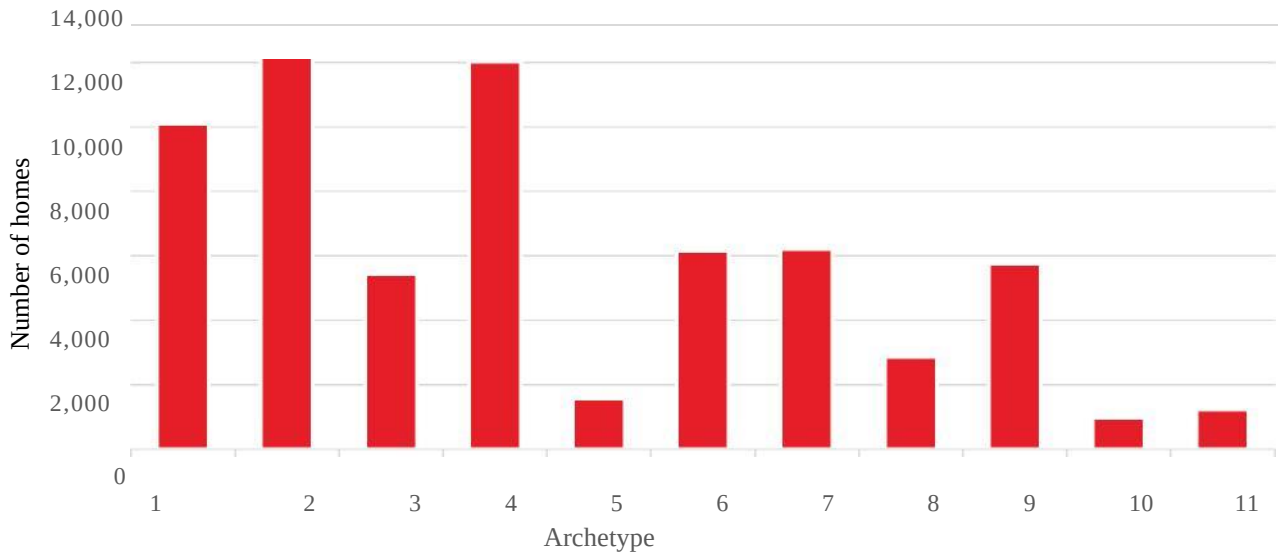
Buildings in Gwynedd contributed 247ktCO2e, 43% of total energy demand in 2023.

In total, around 64,000 domestic buildings are present in Gwynedd including 40,000 detached and semi-detached (60%), 17,000 terraced houses (27%), and 8,000 flats (12%).

Unoccupied buildings in Gwynedd account for 19% of the total stock, which is much larger than the Welsh average of 7%[T11] and could be due to transactional properties and second homes.

Gwynedd also has high levels of houses off the gas grid, with approximately only half of properties (50%) having gas connections.

Homes that are not connected to the gas network mostly use oil, electricity, LPG or a combination for heating.



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

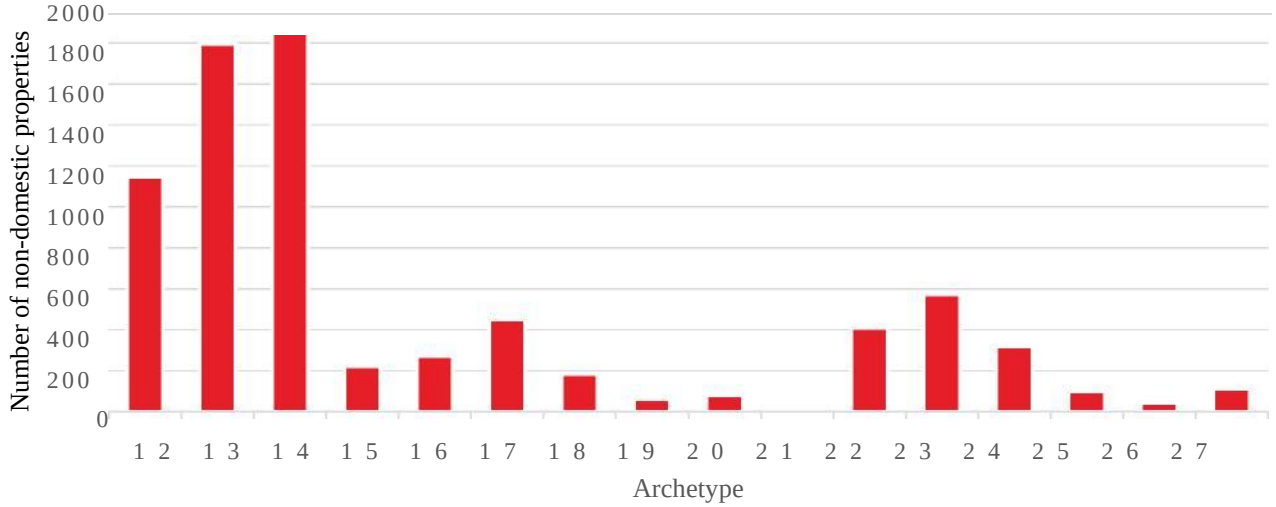
Figure 3.2.7: Distribution of domestic properties by archetype

3. The current local energy system

Analysis – buildings energy demand

In Gwynedd there were an approximate total of 7,600 non-domestic properties, with Hotels and Hostels being the predominant business type, accounting for 24% of non-domestic buildings. This reflects the importance of tourism across the county.

Other prominent building archetypes included retail (1,800 properties) and offices (1,100 properties).



No.	Description	No.	Description
12	Office	20	Emergency services, local gov services, law, military
13	Retail	21	Hospital
14	Hotel/hostel	22	Warehouse
15	Leisure/sports facility	23	Restaurant/bar/café
16	Schools, nurseries and seasonal public buildings	24	Religious building
17	Museums/gallery/library/theatre/hall	25	Transport hub/station
18	Health centre/clinic	26	University campus
19	Care home	27	Other non-domestic

Figure 3.2.8: Distribution of non-domestic properties by archetype

3. The current local energy system

Analysis – monthly buildings energy demand profile

Energy demand has been presented on an annual basis in this report, but it is important to recognise that demand for different sources of energy varies on a monthly and daily basis, and this can influence how we design a net zero local energy system to meet demand.

For example, Figure 3.2.9 shows monthly electricity and heat demand. Heat demand is much higher in the colder months compared to the summer months, and electricity demand stays relatively consistent across each month. These trends will influence what technologies or energy sources are best suited to deploy for consistent demands and others that are less predictable and similarly, what types of energy supply might be available all the time (dispatchable) compared to those that are not (intermittent).

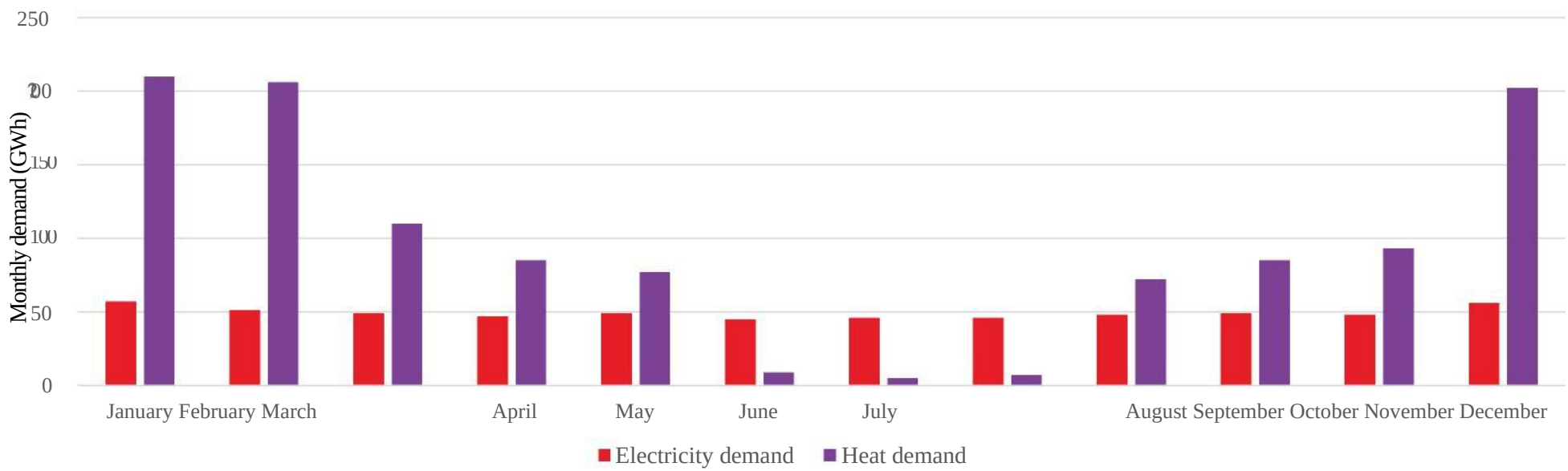


Figure 3.2.9: Monthly buildings energy demand profile for Gwynedd (GWh)

3. The current local energy system
Gwynedd's energy baseline

Analysis – buildings and Industry energy demand

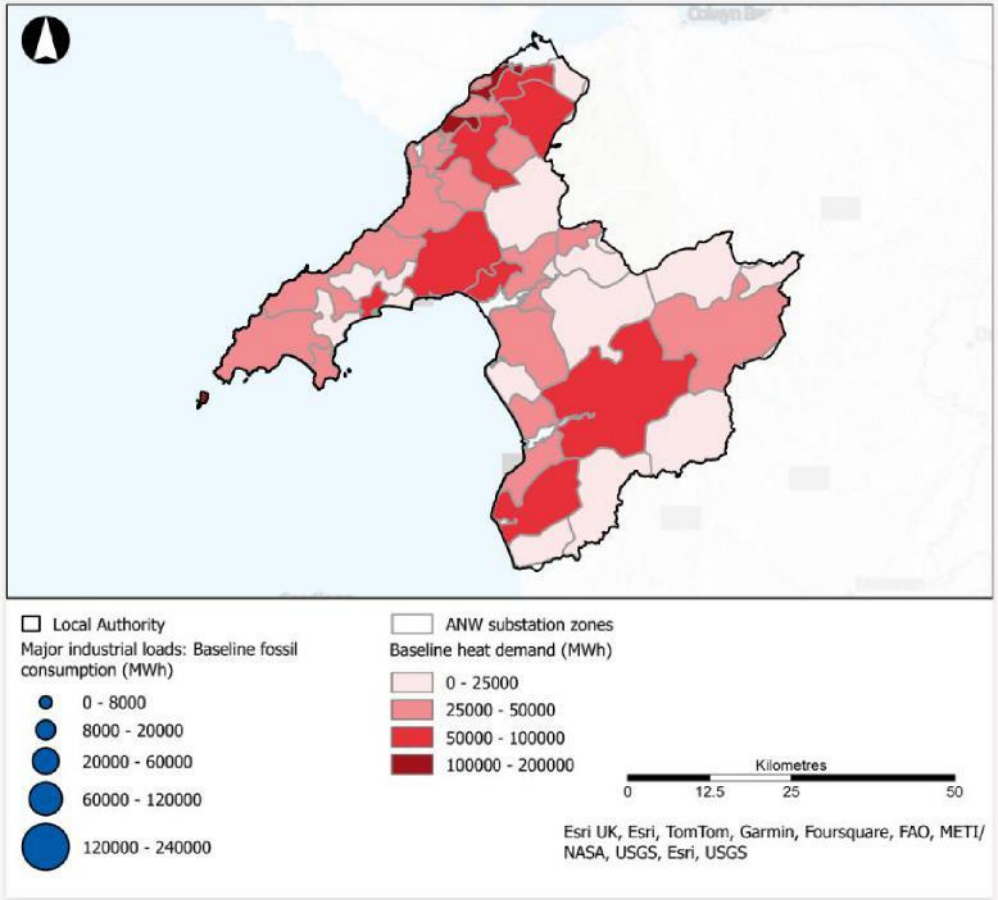


Figure 3.2.10: Major industrial loads and baseline heat demand by substation zone across Gwynedd in 2023. The data is based on meter level gas consumption data and is presented in megawatt hours per year MWh/year)

Gas consumption

Building heat energy demand
The areas of greatest baseline heat demand (for buildings) align with more heavily populated areas across the county, including around Bangor, Porthmadog, Tywyn and settlements around the A494 corridor, where gas boilers are the predominant heating type. There are patterns of lower consumption across the centre of the county, aligned with the less densely populated areas of Eryri National Park.

Less than 50% of properties are connected to the gas grid. Buildings across Gwynedd rely on relatively high levels of heating oil and electricity.

Major Industrial loads

Industrial history of Gwynedd
Historically, the slate industry was the most important industry in Gwynedd. Today, Gwynedd is not heavily industrialised, but some parts (such as industrial estates around Bangor) are more commercialised than others. Cyngor Gwynedd own a number of industrial units, industrial plots of land and 2 Enterprise Centres - Intec, Parc Menai, Bangor and Mentec, Bangor.

Major industrial loads
No major industrial loads were identified across Gwynedd.

3. The current local energy system
Gwynedd's energy baseline

Analysis – electricity demand in buildings (domestic and non-domestic) (MWh per year)

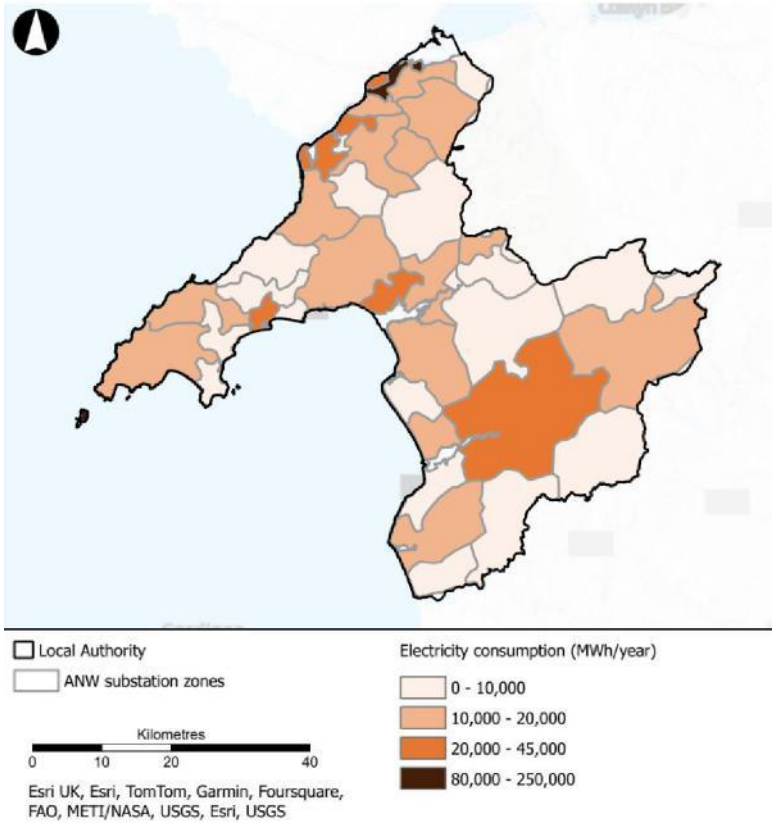


Figure 3.2.11: Electricity consumption (combined total of domestic and non-domestic consumption) by substation zone across Gwynedd in 2023. The data is based on meter level electricity consumption data and is presented in megawatt hours per year (MWh/year)

Electricity consumption

Electricity trends

Electricity consumption (total domestic and non-domestic) varies across the county. Areas of lower electricity energy consumption are around Bangor, in the north of the county.

Areas of higher energy consumption tend to be located around the more rural areas of coastline, around Bangor, and in the south of the county (possibly due to an increased number of buildings being off the gas grid, resulting in increased consumption of electricity for heating).

3. The current local energy system

Analysis – buildings (domestic) energy efficiency

The energy efficiency of the housing stock varies. On average, properties here exhibit below average levels of insulation (e.g. 31% of homes have less than <100mm loft insulation), influencing overall energy performance. Only 24% of properties achieving A-C EPC ratings, much below the Welsh average of 40%. This is the third lowest proportion of energy efficient homes across England and Wales, partially due to the age of building stock.

Half of all properties are not connected to the gas network. This is most prominent around Llanbedr to the west, the Llŷn Peninsula and the east of the county around Eryi National Park.

- 50% of properties use natural gas for heating
- 24% of properties use oil or LPG for heating
- 13% of properties use direct electric for heating
- C.3% of properties use wood burners for heating.

Remaining properties use air or ground source heat pumps or coal for heating

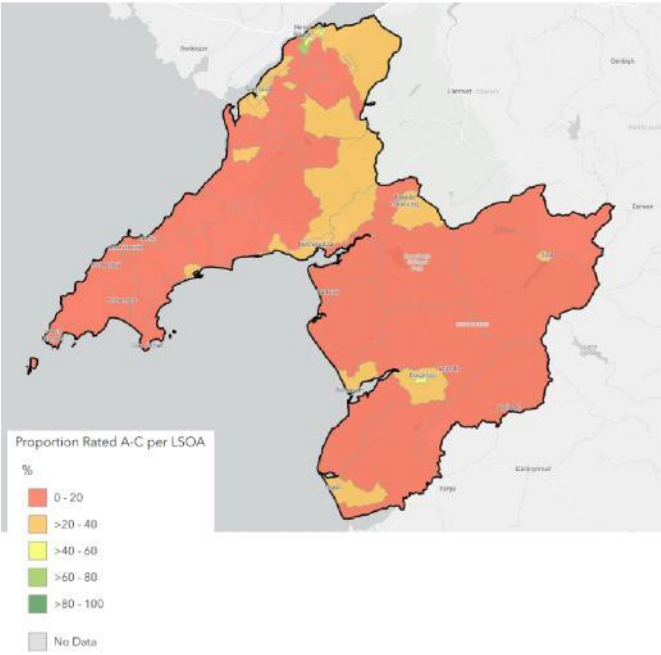


Figure 3.2.12: Energy efficiency of domestic properties across Gwynedd by LSOA, rated EPC A-C (2023)

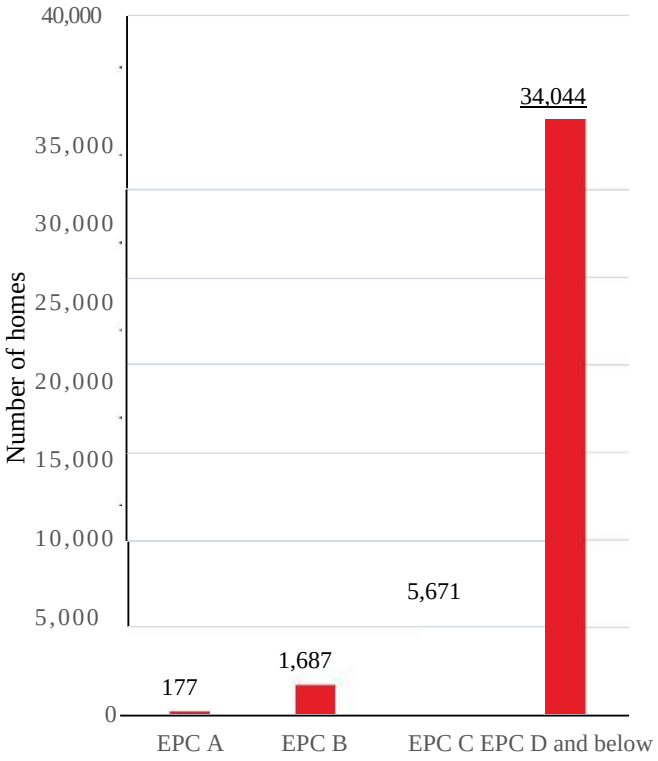


Figure 3.2.13: Proportion of domestic homes by EPC rating in Gwynedd, rated EPC A-C and EPC D and below (2023)

3. The current local energy system

Analysis – transport energy demand

In 2019, transport in Gwynedd contributed 353 $ktCO_2e$ to the total emissions, accounting for 56% of the overall emissions. 63% of total vehicle miles are covered in cars, 18% are covered by HGVs.

Gwynedd is mainly rural in nature, with the A5, A55, A587 and A470 and the North Wales Rail Line providing key transport links and connects part of the area with the remainder of North Wales. This network has a significant impact on local employment, fostering economic growth and job opportunities.

Transport behaviour in Gwynedd reflects its rural characteristics. There is a reliance on private vehicles due to limited public transport options in rural areas and longer travel distances to essential services. In more rural areas outside the town centres, road links are sparser, especially across the Llŷn Penisula and around the Eryri National Park.

Cars are the main source of transport emissions accounting for 29% and 103 $ktCO_2e$. HGVs account for 44% of emissions and 156 $ktCO_2e$, despite only accounting for 18% of mileage due to their higher emissions intensity (gCO_2e/km).

In Gwynedd, 0.22% of vehicles (as of Q4 2019) are electric or hybrid, similar to the Wales-wide average.

Gwynedd displays a distinctive pattern of car ownership when compared to the national average. 79% of households in the area own cars, with an average of 1.10 cars per household, which is slightly below the national average.

To support a shift to active travel modes, the North Wales Metro programme has allocated funding for an improved transport connectivity project in Bangor focussed on rail, bus and active travel. Additionally, Gwynedd Council has recently been successful in accessing funding to improve the walking and cycling connections around Ysgol Godre'r Berwyn, Bala.

Electric vehicle uptake

To support the growing EV fleet, Gwynedd has invested in EV charging infrastructure.

According to the National Chargepoint Registry, there were 29 chargepoints Gwynedd in May 2023[T15]. These points are distributed in areas with comparatively high EV concentration and along major transportation routes to facilitate convenient charging for residents and visitors.

To support an anticipated increase in the number of electric vehicles, Cyngor Gwynedd is actively investing in charge points for its public fleet and for public use with funding provided by Welsh Government.

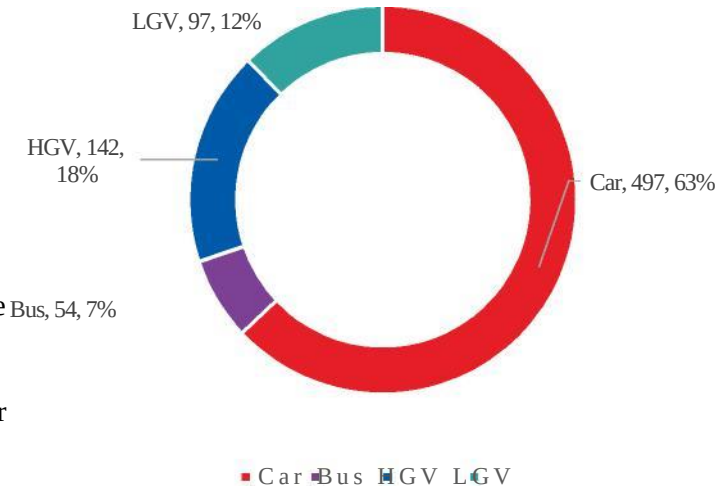


Figure 3.2.14: Total mileage (million miles / year) by vehicle type across Gwynedd (2019)

3. The current local energy system

Analysis – transport energy demand

Transport related energy consumption varies across the local authority. Areas of higher energy consumption tend to align with the main thoroughfares of the A5, A55, A587 and A470 as well as rural areas, where car usage is increased due to limited public transport options. This is because the numbers of journeys starting and ending in these locations is higher than in areas with lower population densities and smaller commercial centres.

Areas of lowest energy consumption tend to be in and around main towns such as Bangor in the north, Porthmadog in the west, likely due to better public transport connections and active travel routes through key towns. Areas that are more rural in nature, along the coastline and the Llŷn Peninsula where there are fewer roads, also display low energy consumption.

Figure 3.2.15 spatially displays the locations of chargepoints installed in 2019. From the maps, it is evident that most chargepoints were installed in close proximity to arterial roads.

It is important to note that the chargepoints shown are from 2019 extract of the National Chargepoint Registry (NCR) and do not include private installations, leading to an underestimation of the total number in Gwynedd. Furthermore, chargepoint viewer platforms such as Zapmap can be used to supplement these findings

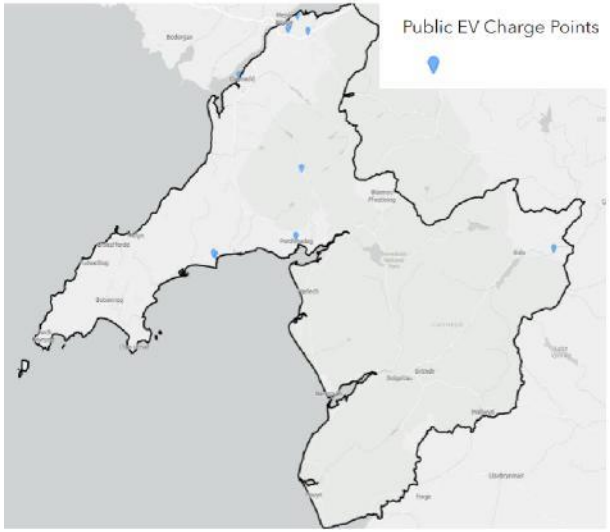


Figure 3.2.15: Public EV chargepoints registered on the National Chargepoint Registry across Gwynedd (data extracted: May 2023)

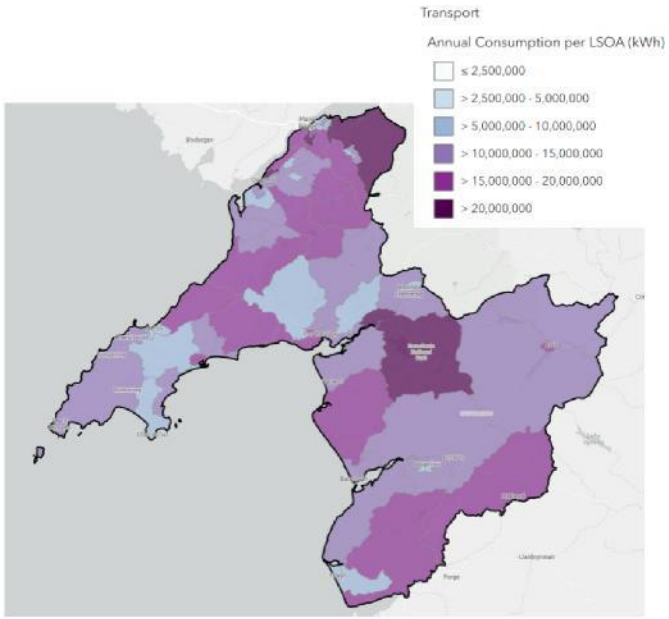


Figure 3.2.16: Transport energy consumption (combined total across cars, light goods vehicles (LGV) and heavy goods vehicles (HGV) by LSOA (2019)

3. The current local energy system

Analysis – industrial energy demand

Historically, the slate industry was the most important industry in Gwynedd. Today, Gwynedd is not heavily industrialised, but some parts are more commercialised than others. Industry contributes only a small proportion to the area's carbon footprint (circa. 0% of GHG emissions by sector in 2023).

There were 16,010 businesses, enterprises and community companies in Gwynedd in 2019 with the tourism industry being a key employer. Gwynedd's employment rate (71.6%) was lower than across Wales as a whole in the year ending September 2023.

Across the County other key employment and business sites include Coleg Menai and Coleg Meirion-Dwyfor, large further and higher education colleges (both now part of Grŵp Llandrillo Menai), and Bangor University, Bangor. A significant part of the county lies within Eryri National Park, which extends from the north coast down to the district of Meirionnydd in the south and tourism provides seasonal employment.

Since 2012, Gwynedd Council have been working together with Welsh Government to facilitate the development of two of Meirionnydd's key strategic sites – Trawsfynydd Site and Snowdonia Aerospace Centre, Llanbedr.

In 2021 Cwmni Egino was set up by the Welsh Government to develop proposals to deliver a site development plan for Trawsfynydd, focused on socio-economic growth.

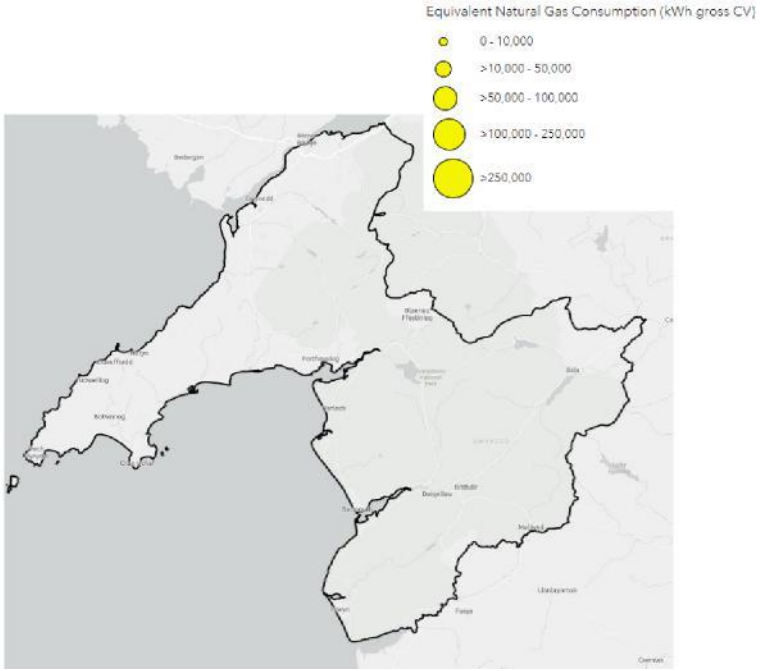


Figure 3.2.17: No identified major industrial loads in Gwynedd

3. The current local energy system

Analysis – local energy generation

In 2023, Gwynedd had a renewable electricity generation capacity of 92MW. These generators play an important role in meeting the energy demands of the region's residents, businesses, and industries. Assets over 100MW are not in scope of this LAEP because these are considered national assets. See overleaf for a map of existing electricity generation in Gwynedd (Figure 3.2.18).

Hydropower is the most prominent renewable energy source harnessed in Gwynedd. In 2023, there was a was total installed capacity of 56MW. The majority of this comes from the Maentwrog hydro-electric power station and Cwm Llan hydropower.

Solar power also plays a vital role in the local energy mix. Solar PV capacity amounted to 30MW of ground-mounted solar PV and 9MW of rooftop solar PV across the county in 2023.

Onshore wind power is not as prominent (4.4MW). Although areas of Gwynedd upland topography may be good locations for harnessing optimal wind speeds for turbines, with Eryri National Park covering a large part of the central and southern area of the county, and large areas of best-most versatile land, it poses challenges in obtaining permissions for development. Given environmental designations and importance of best-most versatile land across the County, growth of onshore wind within Gwynedd is limited.

In addition to these renewable sources of generation, Gwynedd also generated some of its electricity from non-renewable sources. Fossil fuel use (gas) accounted for 4.5MW.

While Gwynedd is a significant contributor to its electricity needs through local generation, it also imported a portion of its electricity to meet the overall demand, totalling on average 560GWh in 2023. This import ensures a reliable and continuous supply of power.

Due to a lack of centralised data for existing district heating systems, heat demand met by heat networks in 2023 was not calculated. Gwynedd do not have any active heat networks. Potential heat network opportunity areas are identified where heat networks may be able to deliver heating at lower cost than individual air source heat pumps. 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.

3. The current local energy system

Analysis – energy generation in 2023 Rooftop solar PV

In 2023, there was a total of 9 MW of rooftop solar PV capacity across Gwynedd. Figure 3.2.18 shows where these systems are located.

Interestingly, there is slightly more capacity reported in the north of the county and west (Llyn peninsula including properties with outwards codes 'LL5') compared to the east and the south. The 'LL53' area, covering the Llyn Peninsula, had the highest capacity of rooftop PV. More rural areas in Eryri National Park and the west coast also have fewer buildings, resulting in lower rooftop PV capacity.

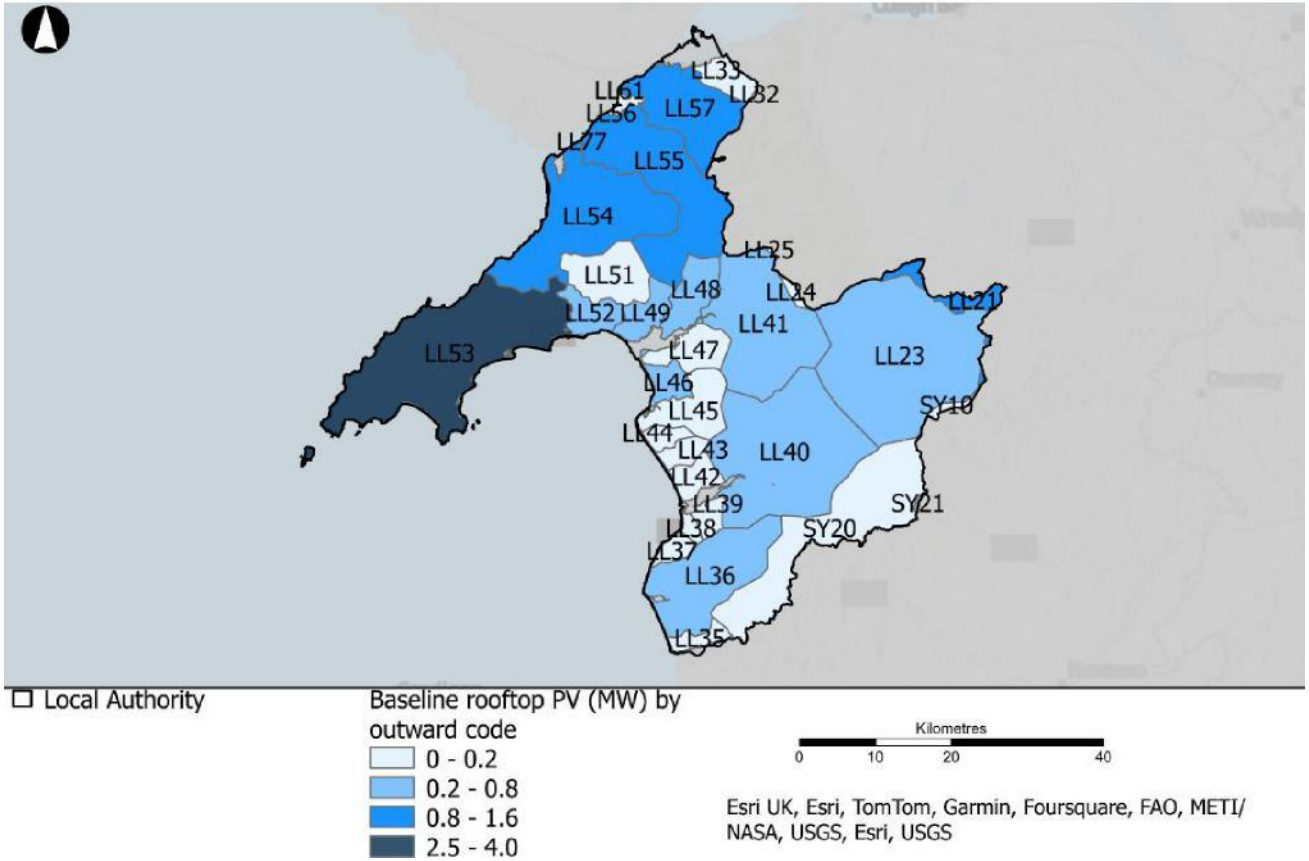
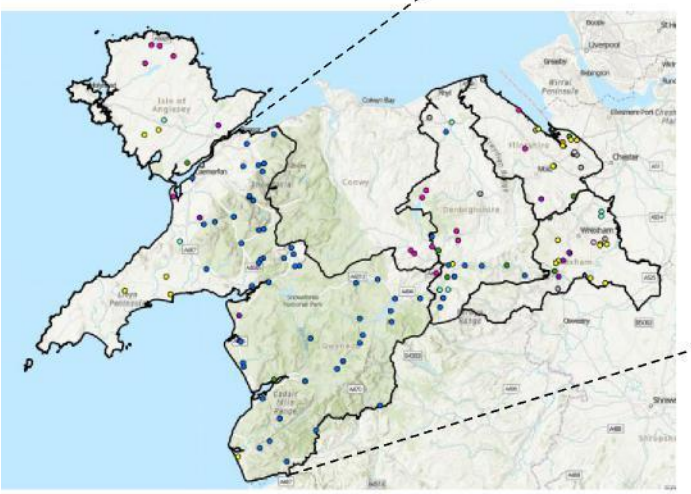


Figure 3.2.18: Domestic and non-domestic rooftop solar PV (MW) by outward code (2023)

3. The current local energy system

Analysis – electricity generation



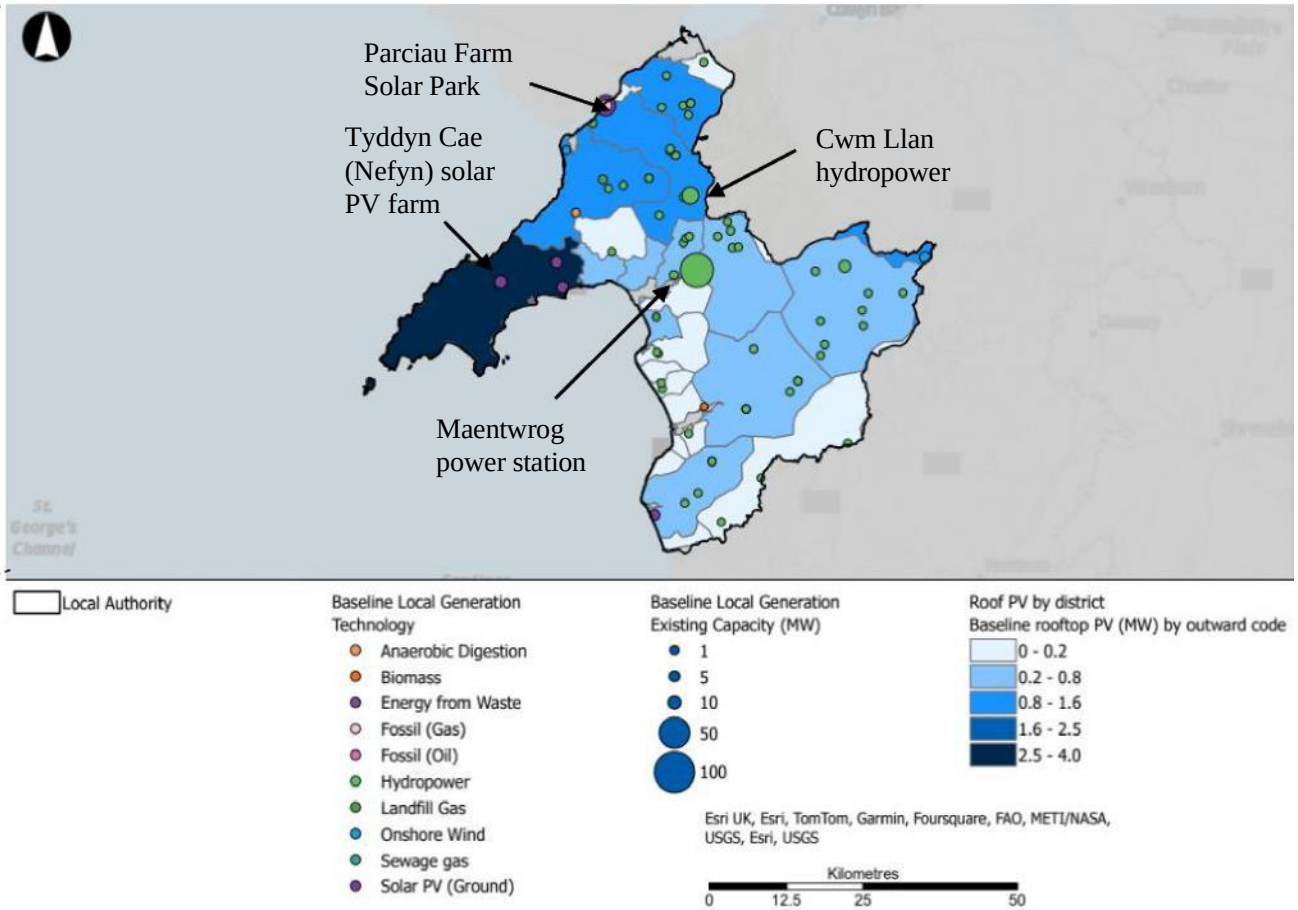


Figure 3.2.19: Local energy generators found in North Wales (2023)

Figure 3.2.20: Local energy generators in Gwynedd and their respective capacities (MW) and domestic and non-domestic rooftop solar PV (MW) by outward code (2019)

3. The current local energy system

Analysis – electricity distribution network

Generation and demand headroom in a local authority's electricity distribution network refers to the remaining primary substation capacity at the time of peak generation or demand, crucial for maintaining a stable and reliable power supply to meet the community's needs.

Presently, Gwynedd faces challenges due to existing grid limitations, which often lead to delays in new connections and substantial associated connection cost. These constraints impact the ability to develop new energy sources and infrastructure, highlighting the need for grid upgrades and enhancements.

To illustrate, the maps in Figures 3.2.21 and 3.2.22 show demand and generation headroom at primary substations in Gwynedd. Note that substation and LSOA boundaries do not typically align, and the headroom has been distributed proportionally among LSOAs by area.

Demand headroom in Gwynedd varies across the region, from near zero to 8 MW per substation.

Supply headroom follows approximately the same trends as generation headroom, with relatively high demand and generation headroom around Eryri National Park and the northeast of the county.

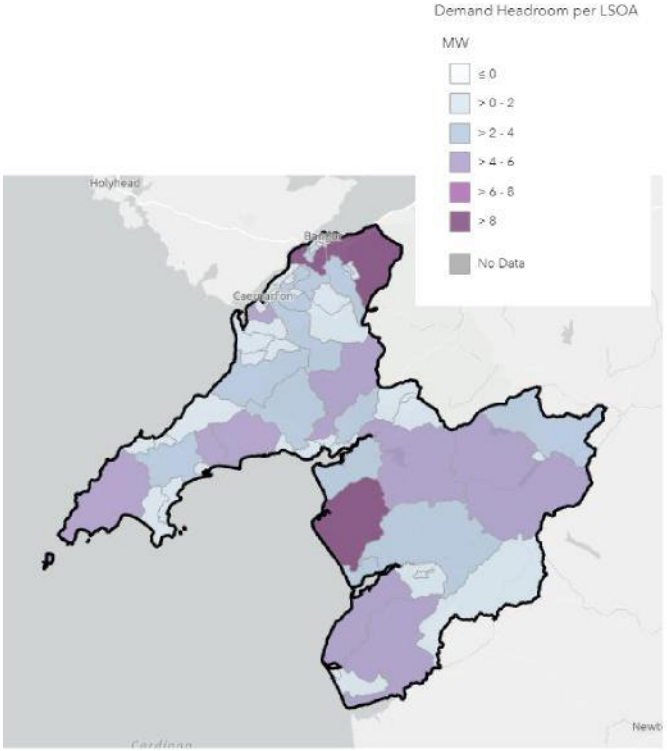


Figure 3.2.21: Electricity demand headroom in Gwynedd by LSOA

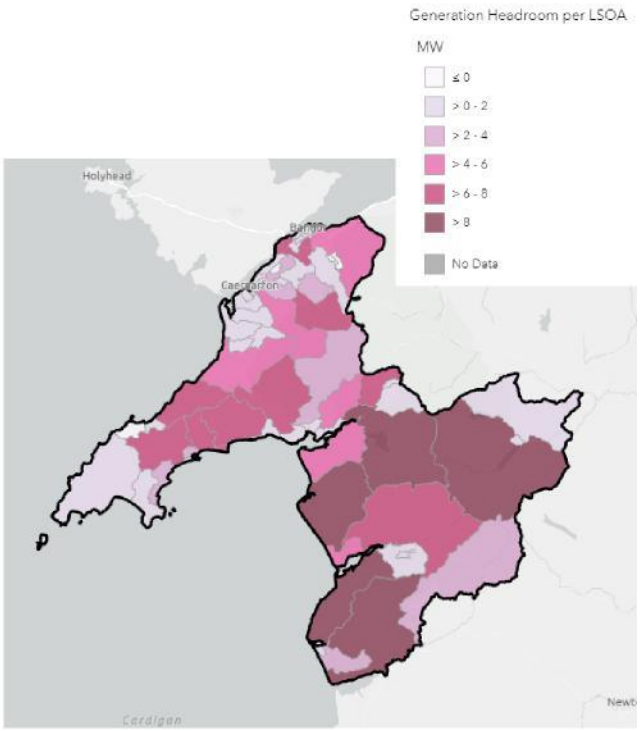


Figure 3.2.22: Electricity supply headroom in Gwynedd by LSOA

3. The current local energy system

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

The gas grid is used to heat around half of the (50%) of properties in Gwynedd. This means that half of the properties in Gwynedd are not connected to the gas network, which is most prominent around Llanbedr to the west, the Llyn peninsula and the east of the county around Eryri National Park.

Approximately a quarter of those properties (24%) that are not connected to the gas network use oil or LPG for heating. This is generally consistent across the whole county.

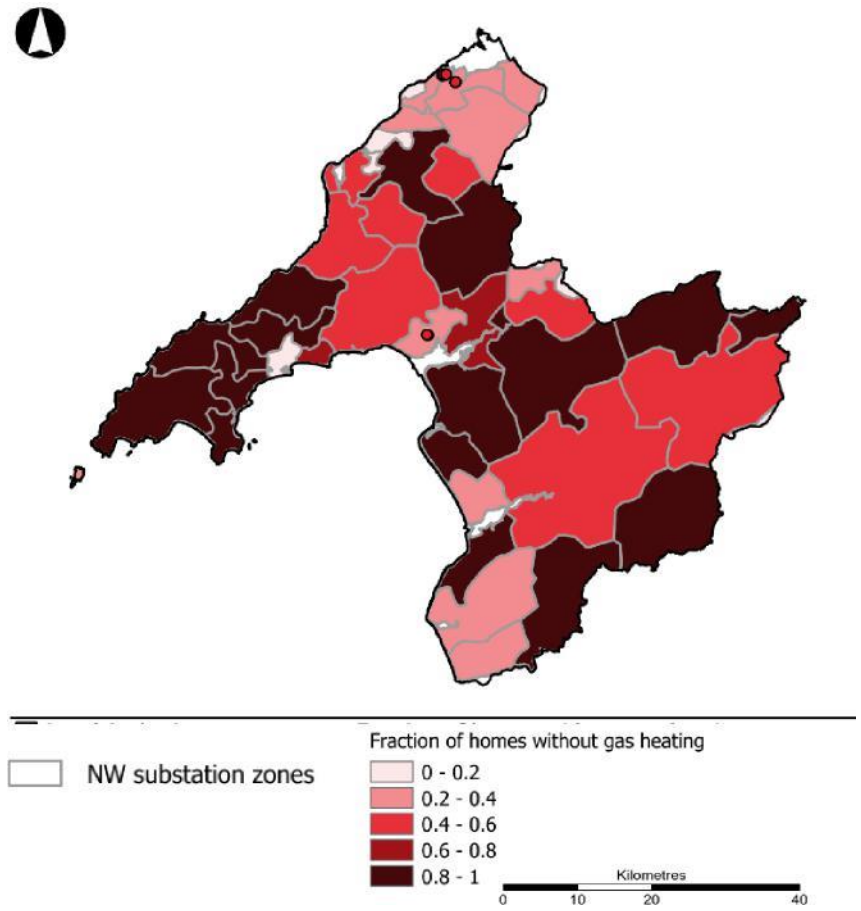


Figure 3.2.23: Percentage of properties that are not connected to the gas distribution network (2023)

Chapter 4: The future local energy system (stages 4-5)

Methodology

Figure 4.1.1: Image provided by Cyngor Gwynedd ©

4. The future local energy system
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, near-term" 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. This is described in more detail in this section and in Appendix A1. 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.

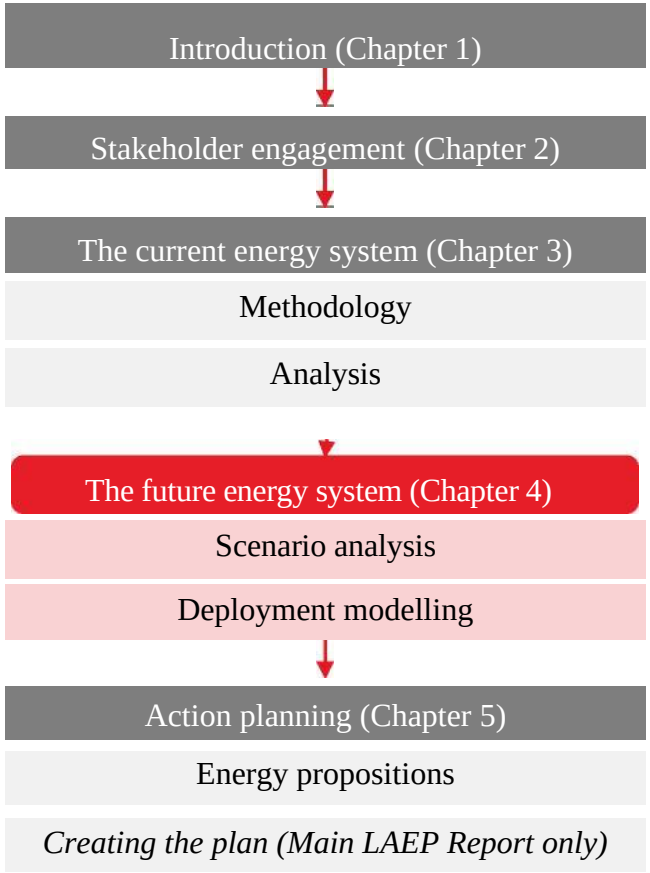


Figure 4.1.2: Overview of methodology

4. 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 energy supply trends, energy sources and renewable technologies that play a part in multiple energy futures and use this to inform Cyngor Gwynedd's investment decisions and prioritisation when planning for the energy transition.

Scenario analysis is used to explore how different assumptions about the future can impact how a particular desired outcome is achieved. The future for Cyngor Gwynedd'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 is 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 Cyngor Gwynedd 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 Cyngor Gwynedd'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, ANW 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 4.1.3 for a description of each scenario and its scope. The final scenario was agreed by Cyngor Gwynedd and was informed by the Council's existing principles, strategic objectives and energy priorities.

4. The future local energy system
Scenario analysis

Summary of future energy scenarios

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 no use it in optimisation modelling.
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 national assets and outside the scope of the LAEP)
Low Demand	• Considers the lowest future energy demand across different sectors. • Explores the impact of energy-reducing initiatives such as 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
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
Islanded: Community-focussed	• **Bespoke scenario:** This scenario considers an energy system that does not import electricity across the local authority boundary, but can export, looking to maximise opportunities for community owned renewable or low carbon energy, bringing forward ambition to decarbonise the energy system at an accelerated rate. • Considers the highest plausible future energy demand across sectors. • Considers a moderate shift to active travel and public transport and a reduction in car use. • Import not allowed over the local authority boundary but export is allowed to test the scale of opportunity. • Uses a cost- and carbon-optimal range of technologies to meet predicted future energy demand.

Figure 4.1.3: Summary of future energy scenarios

4. 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 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 such as for Gwynedd), 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 24-hr runs.

4. The future local energy system
Scenario analysis

Methodology – optimisation

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 suggest the most cost- and carbon-optimised generation profile using a mix of low-carbon technologies that could be used to meet the future energy demand profiles estimated in each future energy scenario.

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.

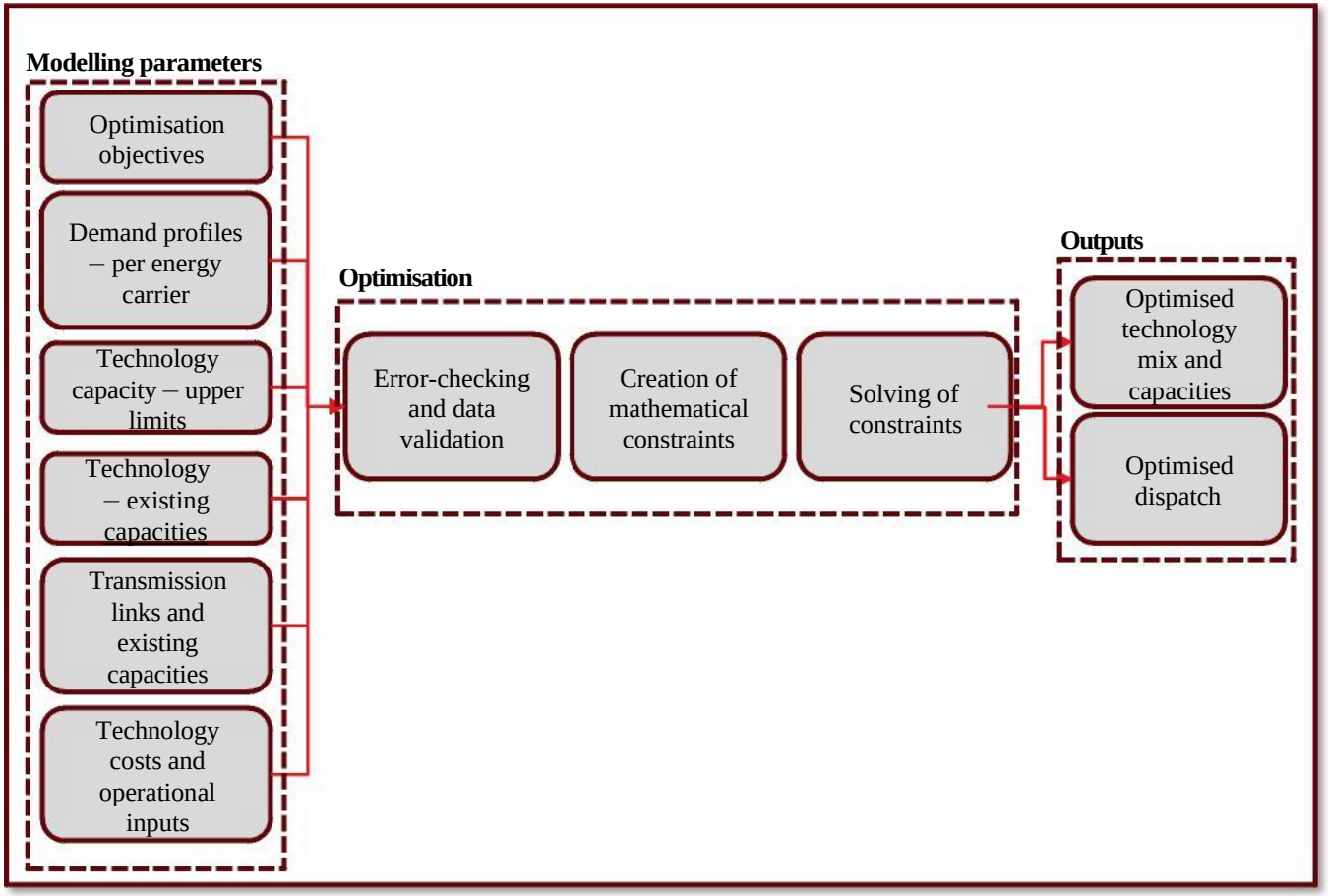


Figure 4.1.4: Optimisation modelling input data and desired outputs

4. 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 4.1.5 overleaf shows the technologies and carriers (energy vectors) that were modelled for Gwynedd's LAEP.

For each technology we collected key information defining costs, GHG emissions, deployment and relationships with other technologies. The key parameters collected are summarised in Table 4.1.1 (see Appendix B7 for more details). 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 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 4.1.1: Technology parameters

4. The future local energy system
Scenario analysis

Methodology - technologies considered

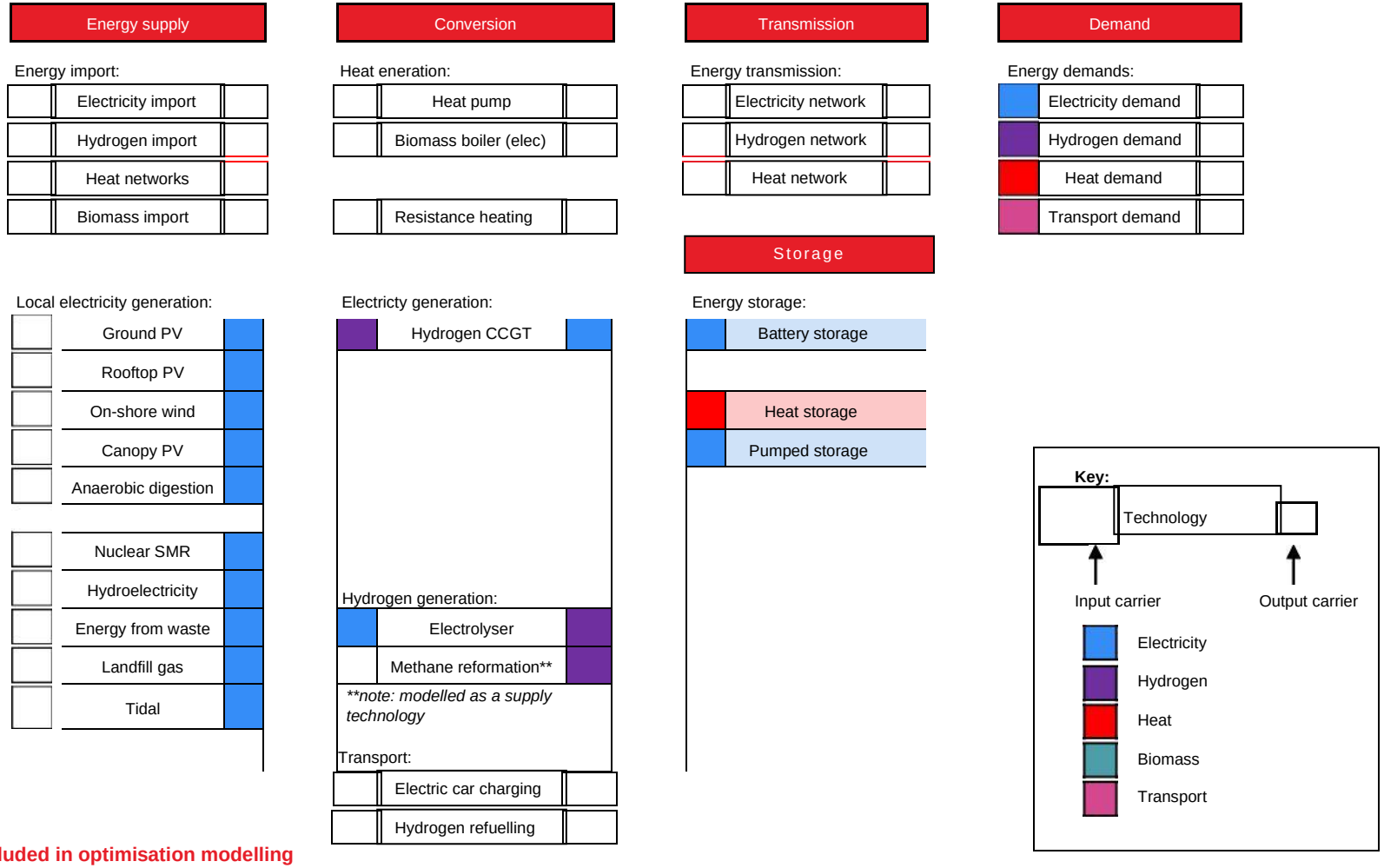


Figure 4.1.5: Technologies included in optimisation modelling

4. 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 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 4.1.2 for domestic buildings and in Table 4.1.3 (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 modelling zones.

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 demand	Low demand
	Scenarios that this applies to	**National Net Zero, High Demand, Islanded: Demand community-focussed**	**Low**
DOMESTIC	**Electricity demand**	No change from baseline	5% reduction from smart appliances
DOMESTIC	**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 homes. 34,200 retrofits completed between 2023 and 2050.	All buildings below EPC A upgraded with insulation measures associated with EPC A-rated homes. 60,500 retrofits completed between 2023 2050.
DOMESTIC	**New development build rate**	LDP targets extrapolated to 2050: 19% increase in number of homes from 2023 to 2050	Historic rates applied: 6% 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) (Appendix B3)	2 days with Beast from the East (-7°C lowest temp) temperature profiles
DOMESTIC	**Interventions for retrofit considered**	See Appendix B3 for details on measures Options dependent on archetype	**High demand interventions**, plus additional measures. See Appendix B3 for more details on measure applied Options dependent on archetype

Table 4.1.2: Assumptions for domestic buildings in each future energy scenario

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. Appendix B3 describes the types of retrofits and sources of retrofit costs.

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 hugely.

		High Demand	Low Demand
	Other scenarios this applies to	**National Net Zero, High Demand, Energy Island**	**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 11% increase in commercial floorspace from 2023 to 2050	LDP employment land allocations/jobs projection (proxy) extrapolated to 2050 8% 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 4.1.3: Assumptions for non-domestic buildings in each future energy scenario

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 North Wales Transport Model (NWTM)[T12] to determine transport demand across Gwynedd. 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 (FES) (2022) - Leading the Way[T31] percentages to the baseline annual mileage figure. Refer to Table 4.1.4 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 NWTM to account for modal shifts. The selection of growth factors varied based on the specific scenario considered. Table 4.1.5 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 4.1.4: Assumptions for vehicle fuel type in the high and low demand future energy scenarios

Methodology – future energy demand for transport (continued)

	High demand	Low demand
Scenario application	High Demand, Islanded: Community-focussed	National Net Zero, Low Demand
Fuels of vehicles	National Grid's FES (2022) T31 – leading the way	National Grid's FES (2022)[T31] – leading the way
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[T31].	Mileage for: **Cars** – 13% decrease (based on Wales' Transport Strategy Llwybr Newydd[T53]) adjusted by Local Authority-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 (based on Wales' Transport Strategy Llwybr Newydd[T53]). **HGVs** - Increase by 6% (FES (2022) Leading the Way scenario[T31]) **LGVs** – Increase by 15% (FES (2022) Leading the Way scenario[T31])

Table 4.1.5: Assumptions for future transport energy demand in each future energy scenario

4. The future local energy system
Scenario analysis

Methodology– future energy demand for industry

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

Limitations

Companies that owned the industrial sites across Gwynedd 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.

NAEI database[T20] doesn't include all large point sources as some information is deemed disclosive. Therefore, companies that owned industrial sites in the Isle of Anglesey were sent a request for information (RFI), requesting the annual electricity and gas consumption and expected change in fuel consumption for 2050 for their site(s). This was not provided, so industrial energy demand was estimated using the NAEI database [T20] as a proxy. Any more detailed assumptions would need verifying with the site owners.

This database identified no large point sources across the county and therefore we assumed that industrial energy demand was zero in 2023 (used as the baseline), and that there would be no large industrial energy demands (and no associated GHG emissions) in the future energy scenarios that we modelled.

Methodology – maximum potential capacities for ground-mounted solar PV and onshore wind

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 Chapter 2) and the 2050 renewable resource (discussed below) for each technology.

2050 renewable resource – onshore wind and ground-mounted PV

The maximum theoretical resource was calculated using local authority-specific renewable and low carbon energy assessments and/or local development plans (LDP). These areas, along with an estimate of the equivalent land requirement land area are shown in Table 4.1.6. A full breakdown of sources and associated shapefiles used during the mapping exercise is presented in 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. Further information can be found in Appendix B5.

Pipeline projects

Pipeline projects were compiled using the REPD[T23] and ECR[TN24] 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 Chapter 4: Deployment mode

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].

	Maximum theoretical capacity (MW)	Equivalent land area (km^2)
Ground-mounted solar PV	495 MW	8.9 (0.35% of land in Gwynedd)
Onshore wind	12 MW	1 (0.04% land in Gwynedd)

Table 4.1.6 Maximum theoretical capacities (inc. operational sites) and total area suitable (inc. operational sites) for ground-mounted solar PV and onshore wind

Methodology – maximum potential capacities for ground-mounted solar PV and onshore wind

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].

Figure 4.1.6 shows the location of different land packages that could be suitable for ground-mounted solar PV, onshore wind or both, and the generation capacity that is available in each substation zone. This overlay helps to highlight the locations where there is renewable potential and where there is available capacity, which would make conditions more favourable for development. This is discussed in more detail in Chapter 5: Action planning, where we introduce the different "priority focus zones" across Gwynedd that have favourable conditions for different low carbon technologies, including ground-mounted solar PV and onshore wind.

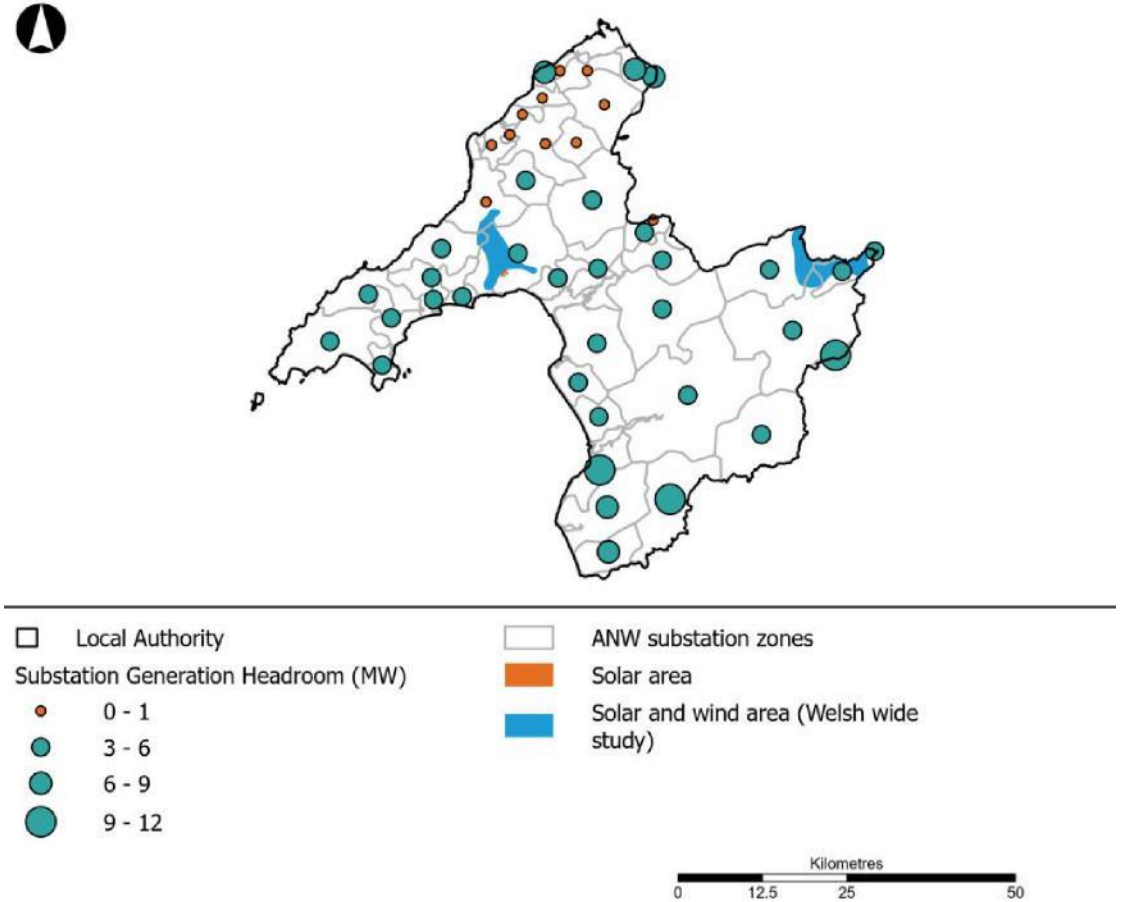


Figure 4.1.6: Map showing areas suitable for wind and ground-mounted solar PV development in Gwynedd, based on a Wales-wide study completed by Arup in 2019 and substation generation headroom (MW) by substation zone

4. 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 4.1.8 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 was split proportionally between its modelling zones by area. 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.

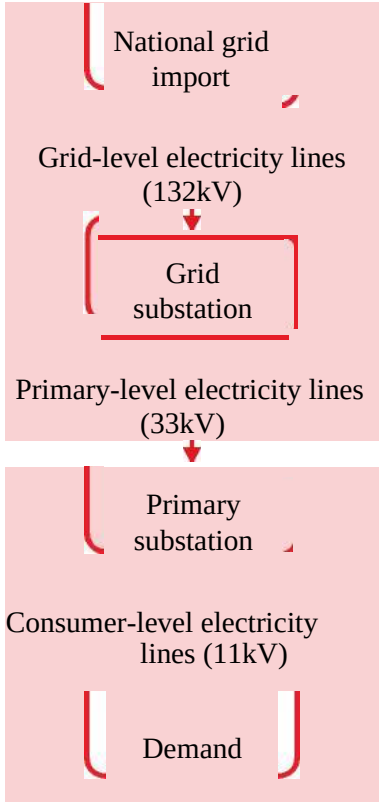


Figure 4.1.7: Modelled electricity flow for each substation zone

4. 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.

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 LA 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 Gwynedd or Wales.

	Low hydrogen
Scenario application	**National Net Zero, Low Demand, High Demand, Islanded: Community-focussed**
Industry	*No processes classified as "industrial" in Gwynedd*
Transport	A proportion of vans and HGVs use hydrogen.
Domestic / commercial heat	Hydrogen is not considered for domestic/commercial heat.

Table 4.1.7: Summary of assumptions related to hydrogen demand applied to future energy scenarios

4. 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 graph (a series of nodes connected by edges) of the road network, and then uses a prize collecting Steiner tree algorithm to evaluate networks by assigning 'prizes' to nodes and 'costs' to edges based on their heat demand and their length respectively. A built-in discounted cashflow model evaluates the LCoH of resulting networks. See Appendix B6 for the model's techno-economic inputs.

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 Gwynedd for including in the model. Figure 4.1.8 shows the waste heat sources identified in Gwynedd. 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.

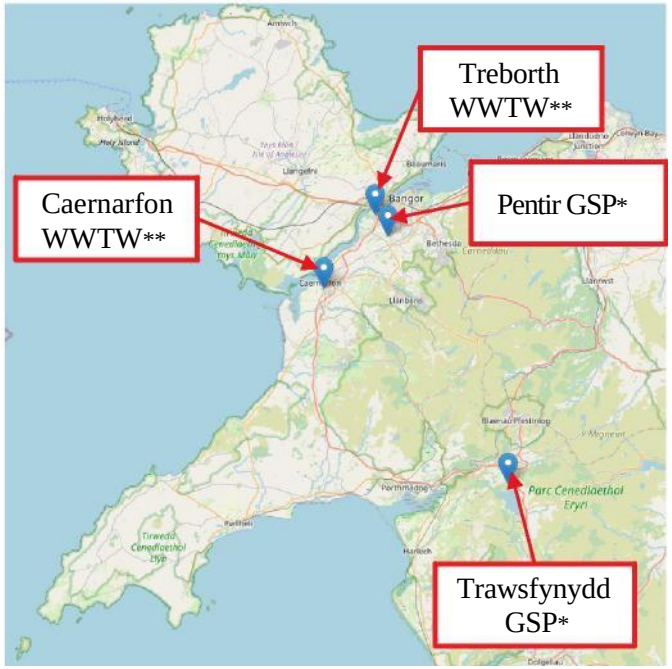


Figure 4.1.9: Heat sources identified in Gwynedd
* Grid supply point (GSP)
** Wastewater treatment works (WWTW)

Analysis

Figure 4.2.1: Image provided by Meilyr Tomos ©

4. 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 (Figures 4.2.2 to 4.2.5) are an output from our modelling and show four potential future energy systems for Gwynedd. These hypothetical future energy systems are a result of modelling a cost- and carbon-optimised system based on a set of pre-defined modelling parameter and assumptions about the future energy system in the local area. They were optimised for each three-hour interval that made up a period of one year (more details can be found in Chapter 4: 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 Gwynedd's near-term action plan.

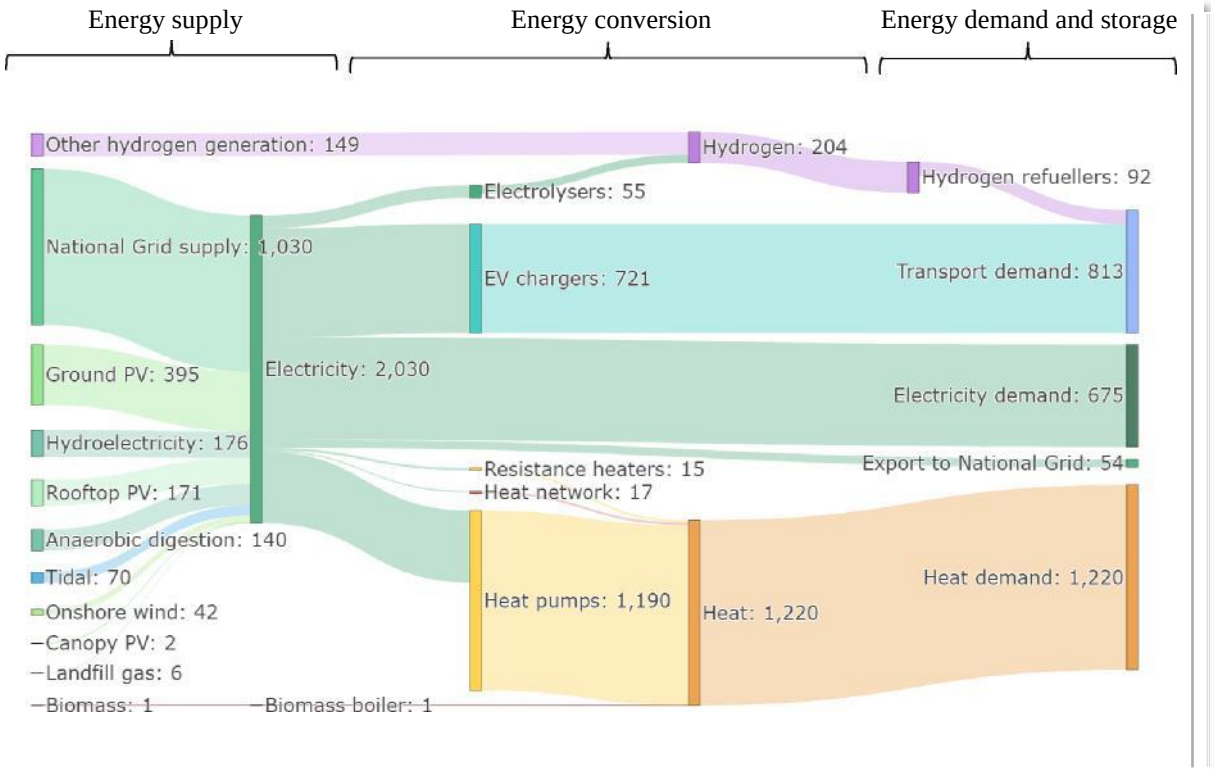
4. The future local energy system
Analysis

National Net Zero scenario – annual energy flows (GWh, 2050)

There could be a significant increase in renewable energy generation compared to baseline, particularly ground-mounted solar PV (17 times) rooftop PV (24 times) and anaerobic digestion (47 times).

Tidal is introduced and could produce 70 GWh per year.

Small contribution from canopy PV, which serves both electricity and heat demand.



The average Welsh home uses 3.325MWh/year of electricity, which is 0.003GWh for comparison with the scale on the Sankey. In terms of gas, a typical home uses 12MWh/year, which is 0.012 GWh for comparison with scale on the Sankey.

Hydrogen could be imported or generated from electrolysis to power Heavy Goods Vehicles.

Majority of transport demand met electricity could be supplied through EV chargers. Hydrogen refuellers could meet 11% of demand.

Future energy system could have a small portion of the generated electricity exported (2.7%).

Annual electricity use could be up to 2.6 times larger than the baseline.

Heat supply could be predominately met by heat pumps (98%).

Figure 4.2.2: Sankey diagram for a potential future 2050 energy system – National Net Zero scenario (GWh). Based on a 24-hour timestep

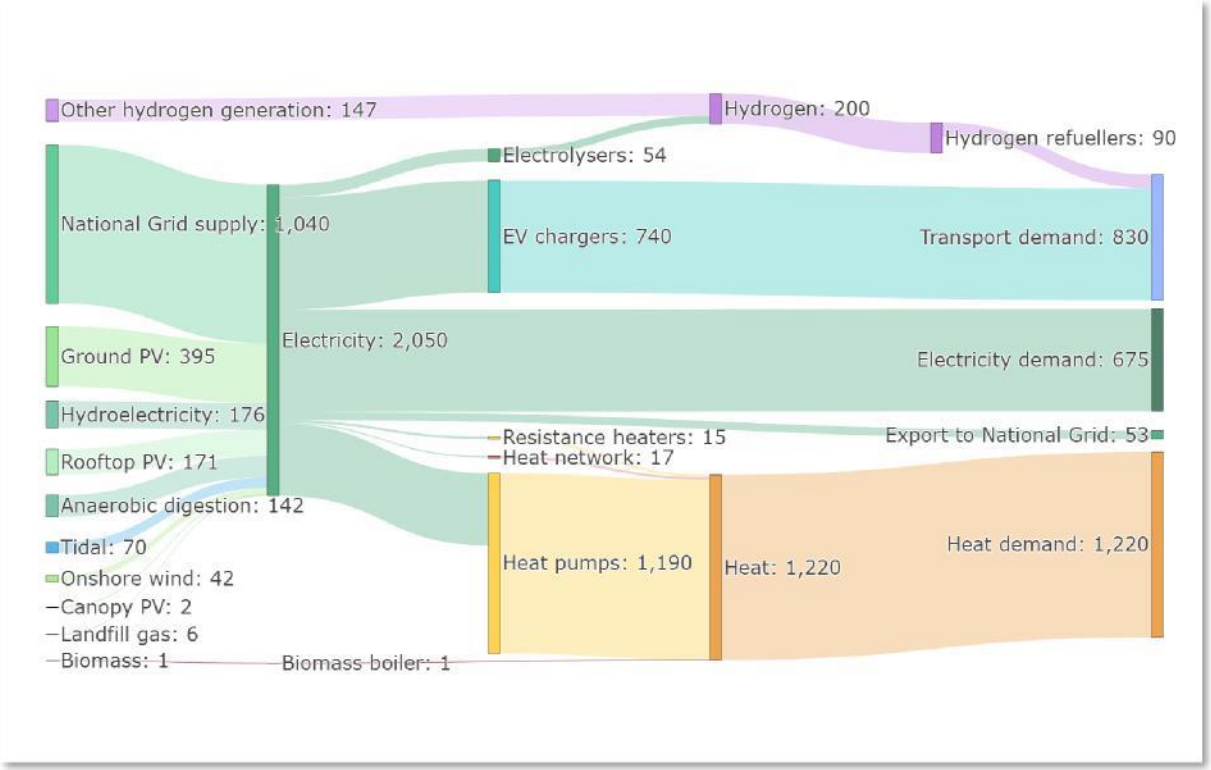
4. The future local energy system
Analysis

High Demand – annual energy flows (GWh, 2050)

There could be a significant increase in renewable energy generation, especially ground-mounted PV and onshore wind.

The National Grid supply could increase by 84% from the baseline.

Anaerobic digestion could increase by 139 GWh from the baseline whereas biomass could decrease by 59 GWh.



Majority of transport demand could be met by electricity supplied through EV chargers with the remainder from hydrogen refuellers.

Hydrogen generation and imports could contribute to transport and industrial demands. <10% of industrial demand met by hydrogen.

Heat could be predominately met by heat pumps, with small contributions from heat networks, biomass boilers and resistance heaters.

Figure 4.2.3: Sankey diagram for a potential future 2050 energy system – High Demand (GWh). Based on a 24-hour timestep

4. The future local energy system
Analysis

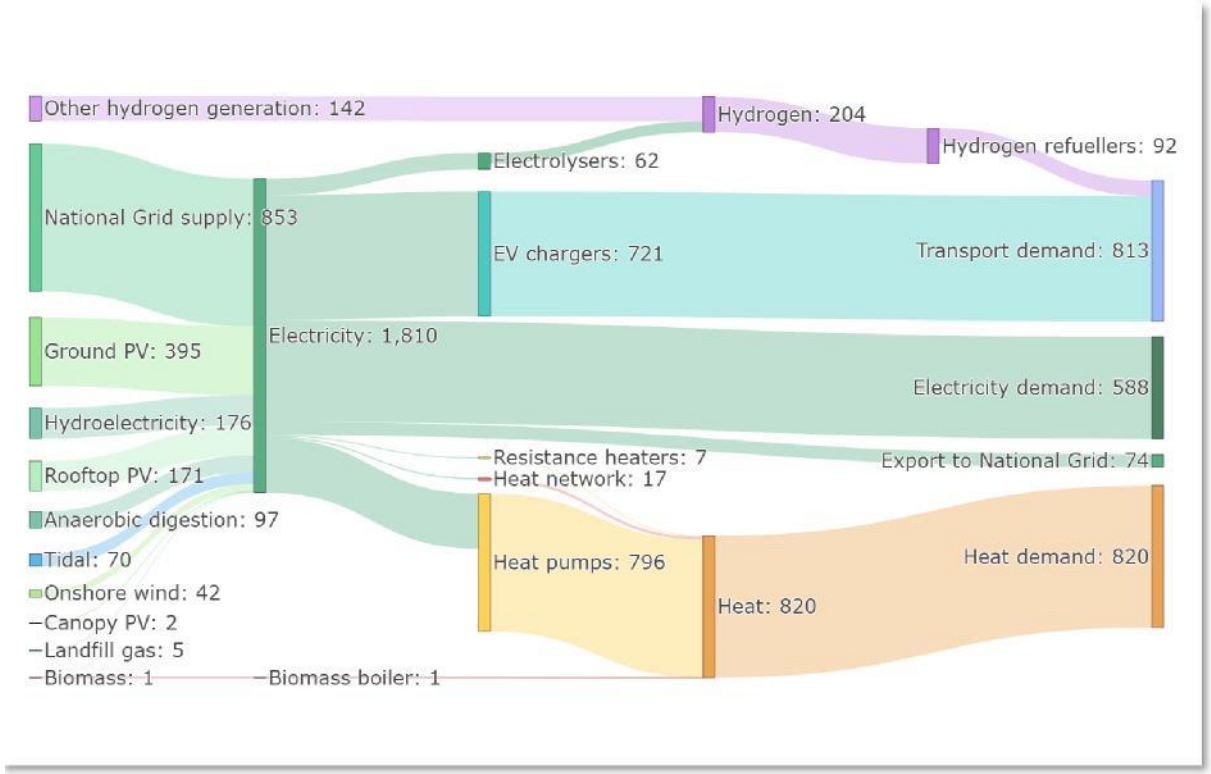
Low Demand – annual energy flows (GWh, 2050)

22% of electricity demand could be met by Ground PV, an increase from the baseline where only 3% was met by Ground PV.

GWh produced by hydroelectricity could stay the same compared to the baseline but tidal could be introduced, generating 70 GWh.

Anaerobic digestion could increase from 3 GWh at baseline to 97 GWh.

Small contribution from biomass which could be lower than the baseline by 59 GWh.



Transport demand in this scenario is 91% supplied by electricity via EV chargers. The remaining 9% is supplied by hydrogen refuellers.

Almost all heating demand could be met by heat pumps. Small amount of biogas boilers and resistance heaters could needed for the remainder.

Electricity demand is 3 GWh lower than the baseline.

Figure 4.2.4: Sankey diagram for a potential future 2050 energy system – Low Demand (GWh). Based on a 24-hour timestep

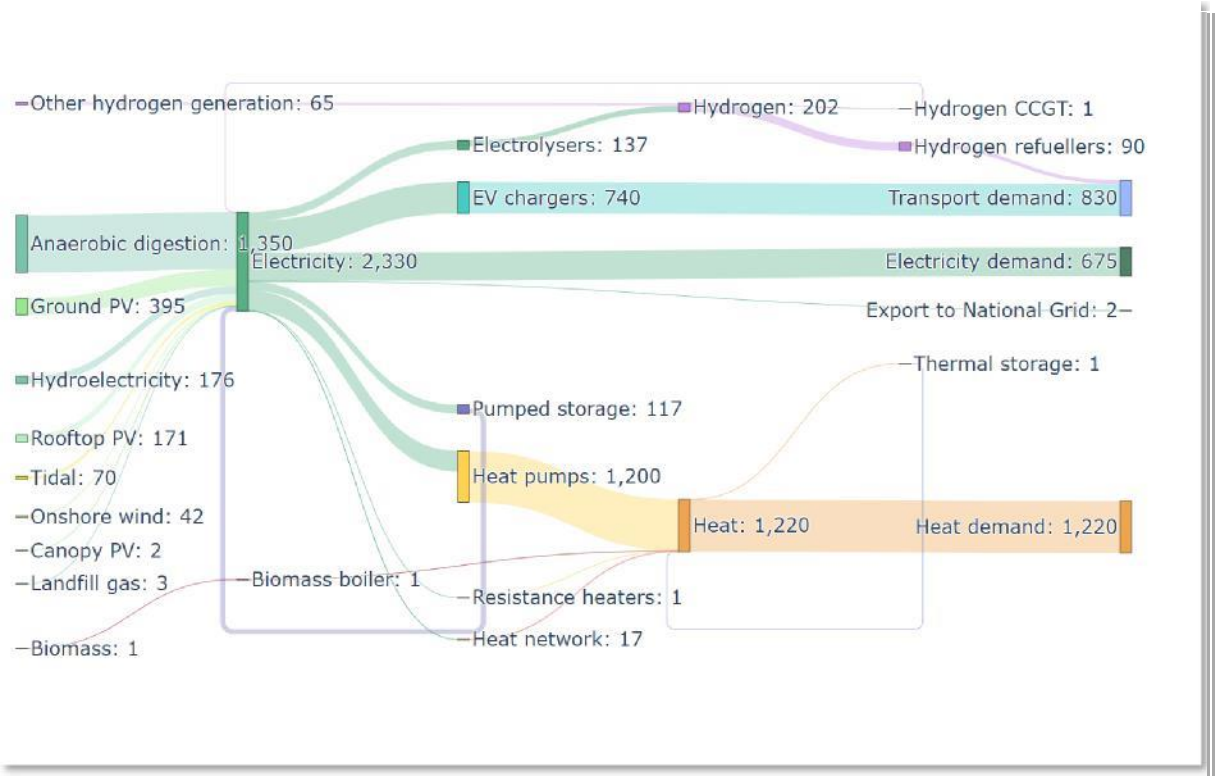
4. The future local energy system
Analysis

Islanded: Community Focussed – annual energy flows (GWh, 2050)

There could be no electricity supplied by the National Grid, although electricity supply could increase by 195% from the baseline.

Anaerobic digestion could experience a big increase from 3 GWh at baseline to 1,350 GWh.

Renewable generation technologies would see increases in supply from baseline including rooftop PV (164 GWh), tidal (70 GWh) and onshore wind (27 GWh).



Much of hydrogen supply could be used for hydrogen refuellers to meet transport demand with a small volume also going to hydrogen CCGT.

89% of transport demand would be met by EV chargers.

Electricity demand could be slightly higher than baseline by 89 GWh.

Heat demand could be 60 GWh higher than baseline with heat pumps meeting the majority of this demand. The remainder could be met by biomass boiler, resistance heaters and heat networks.

Figure 4.2.5: Sankey diagram for a potential future 2050 energy system – Islanded: Community–focussed (GWh). Based on a 24-hour timestep

4. The future local energy system
Analysis

Physical energy system components

Table 4.2.1 and Table 4.2.2 (overleaf) show what energy components are present in each future energy scenario and on average, the amount of energy generated/converted/transferred over a one year timescale. This has then been benchmarked against the baseline results.

Optimisation modelling shows ground-mounted, rooftop solar and onshore wind generation consistently increasing across all scenarios; contributing to meeting both Gwynedd's energy demand but also exporting in times of surplus to the National Grid, and serving broader energy needs.

In contrast, biomass generation sees a decline across all scenarios, likely due to a reduced dependency resulting from the enhanced output of solar and wind farms. In contrast, use of coal sees a decline across all scenarios, and hydrogen is generated to meet electricity demand as a dispatchable form of energy, where renewable energy sources are not generating is incorporated into the energy mix in all scenarios, sustaining the transport demands across the county.

Energy system components	Baseline (GWh)	National Net Zero (GWh)	High Demand (GWh)	Low Demand (GWh)	Islanded: Community-focussed (GWh)
Import from Grid	561	1030	1040	854	0 (no import in scenario)
Hydroelectricity	176	176			
Ground-mounted PV	24	395			
Onshore wind	15	42			
Rooftop solar PV	7	171			
Landfill gas	4	6			4
Biomass	60	1			
Coal	20	0			
Canopy PV	0	2			
Tidal	0	70			
Other hydrogen generation	0	149	147	142	65

Table 4.2.1: Comparison of energy sources across the scenarios (GWh in 2050)

4. The future local energy system
Analysis

Physical energy system components

Table 4.2.2 focuses on the different conversion and transfer technologies that the optimisation model has chosen:

- We see a significant uptake in EV chargers to meet the increased uptake of electric vehicles, and hydrogen refuellers used to supply hydrogen to heavy goods vehicles that service the area.
- Heat pumps are the dominant conversion technology used for heat in buildings, and this is consistent across all scenarios. While heat networks and other technologies contribute to this demand, their usage is comparatively less.
- We also see surplus electricity exported to the National Grid in all scenarios serving wider energy needs.
- Anaerobic digestion increases substantially in the bespoke "Islanded: community –focussed" scenario. Since this scenario does not allow import from the national grid, and other technologies such as ground-mounted PV and solar have reached the maximum capacity (due to constraints applied such as best most versatile land), anaerobic digestion is selected to meet the electricity demand in the system. This is a demonstration of the capacity that would need to be met by reasonably on-demand sources.
- Pumped storage has been included within the bespoke scenario to take account of the Glyn Rhonwy pumped storage project. The scheme was granted a Development Consent Order in 2017.
- There was no additional capacity identified for hydropower schemes across Gwynedd. Data on hydropower resource is limited due to lack of information on 'existing barriers' (e.g. weirs / waterfalls). There may be future opportunities arising for small scale or larger scale pumped hydropower (or pumped storage) opportunities across Gwynedd, however this will require further analysis.

Energy system components	Type	Baseline (GWh)	National Net Zero (GWh)	High Demand (GWh)	Low Demand (GWh)	Islanded: Community-focussed (GWh)
Anaerobic Digestion (plant)	Conversion	3	140	142	97	1,350
Pumped storage	Storage	0	0	0	0	117
Electrolyser	Conversion	0	55	54	62	137
EV chargers	Transfer	1	721	740	721	740
Export to National Grid	Transfer	0	54	53	74	2
Heat pumps	Transfer	0	1,190	1,190	796	1,200
Heat networks	Conversion	0	17	17	17	17
Resistance heaters	Conversion	191	15	15	7	1
Biomass boilers	Conversion	36	1	1	1	1
Hydrogen refuellers	Transfer	0	92	90	92	90
Hydrogen CCGT	Conversion	0	0	0	0	1

Table 4.2.2: Comparison of energy conversion / transfer technologies across the scenarios (GWh in 2050)

4. The future local energy system
Analysis

Electricity generation and consumption

Our previous results have shown annual averages for energy generation and consumption. Figure 4.2.6 shows monthly averages for one year for optimised generation and consumption of electricity to show what balancing could look like in the High Demand scenario.

Electrification of transport could make up a significant amount of the final electricity demand. This is due to their higher well-to-wheel efficiencies compared to hydrogen vehicles. Electricity demand from EV chargers is unaffected by the time of year.

Electrolysers could also consume electricity in the modelled systems to generate hydrogen, but this is a small proportion of total energy demand and tends to be higher between March and September.

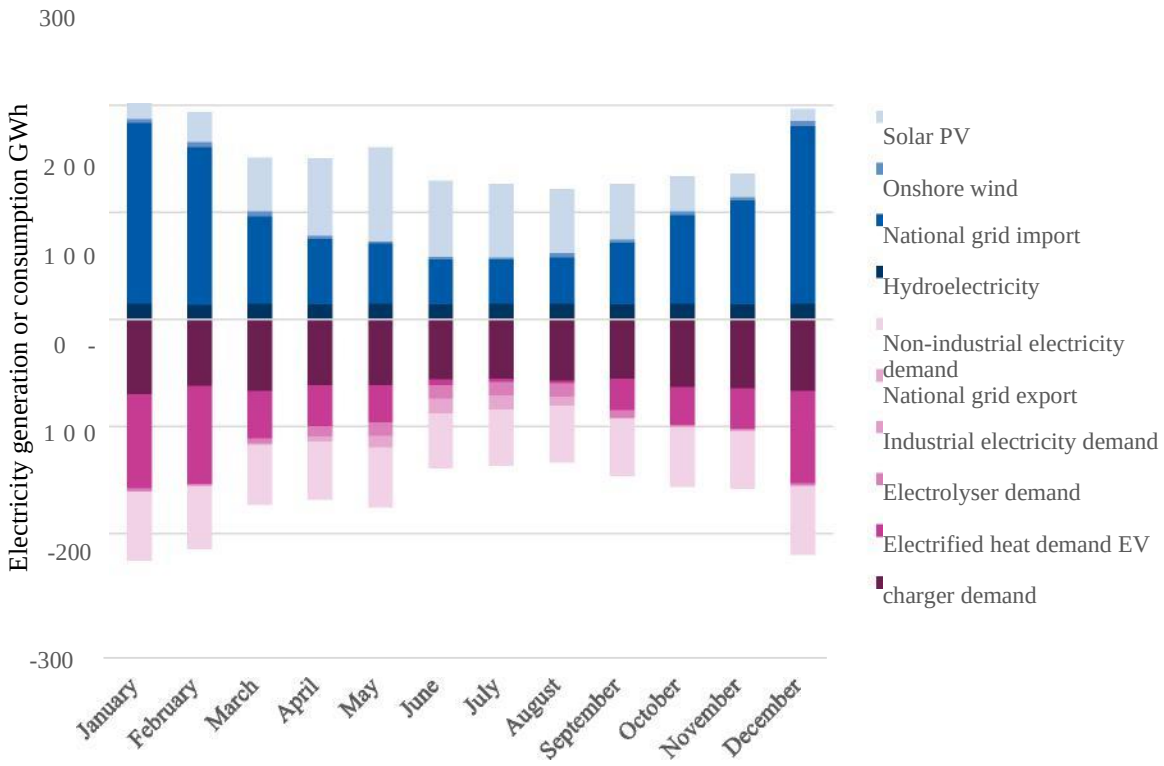


Figure 4.2.6: Monthly electricity generation and consumption in the High scenario

Solar PV and onshore wind are two of the most cost- and carbon-efficient technologies for producing electricity and could make up a significant proportion of generation each month, but generation is intermittent and less predictable over time. “Imports” from outside the local energy system increase when renewable electricity generation is not available to ensure that demand is met.

Electrified heat demand is relatively low in the summer months compared to the winter months, and the graph shows that in these months more electricity is “imported” from the electricity grid to meet the additional demand, when renewable electricity generation is not available.

4. The future local energy system
Analysis

Buildings

Figure 4.2.7 shows the different technologies that are deployed to meet heat demand in homes and commercial properties in 2050, compared to 2023.

- In 2023, gas boilers and oil/LPG boilers were the most common heating technology installed. In all future energy scenarios, all fossil fuel heating systems could be replaced by heat pumps, a small number of resistance heaters either as the main heating system or as a back-up for the heat pump. This result is likely due to the high efficiency of heat pumps (generates on average, 3kWh of heat for every 1kWh of electricity used) compared to other technologies, and a lower capital cost.
- Heating systems are generally set-up with heat storage which can help to reduce peak demand by storing heat when there is less demand on the electricity grid and release it when it there is higher demands. Heat storage also reduces GHG emissions and costs by making sure energy is used when it's cheaper and when there is a higher proportion of renewables on the grid.
- Heat supplied to buildings is lower in the Low Demand scenario for 2050 compared to the other scenarios because we assume that significant energy efficiency measures have taken place in a larger number of homes to the level associated with EPC A ratings, which improves their thermal performance and reduces overall energy demand on the system.

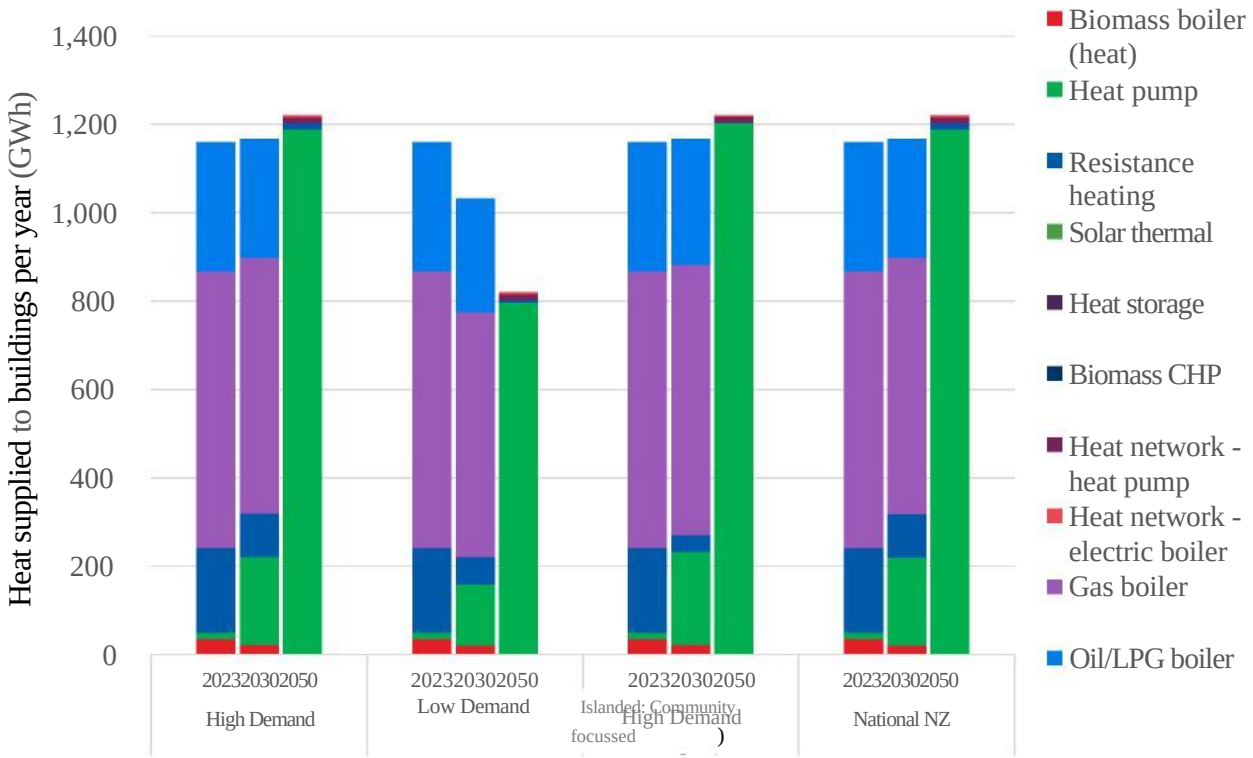


Figure 4.2.7: Proportion of heat supplied to buildings by technology in 2050 for each scenario

4. The future local energy system
Analysis

Comparing future energy scenarios - Buildings

Figure 4.2.8 shows the total number of energy efficiency measures that need to be completed between 2023 and 2050 and their relative proportions in each scenario. In the High Demand scenario, our approach considers the most cost-effective package of retrofit measures for each archetype to reach heat loss measurements associated with an EPC C-rated home or building. This means that in the High Demand scenario, cavity wall and loft insulation is fitted, but more expensive measures such as solid wall insulation and triple glazing are not.

In the Low Demand scenario, all practical measures are installed where possible regardless of cost, which is why we see deployment of solid wall insulation and triple glazing, as well as an increase in the deployment of floor insulation measures.

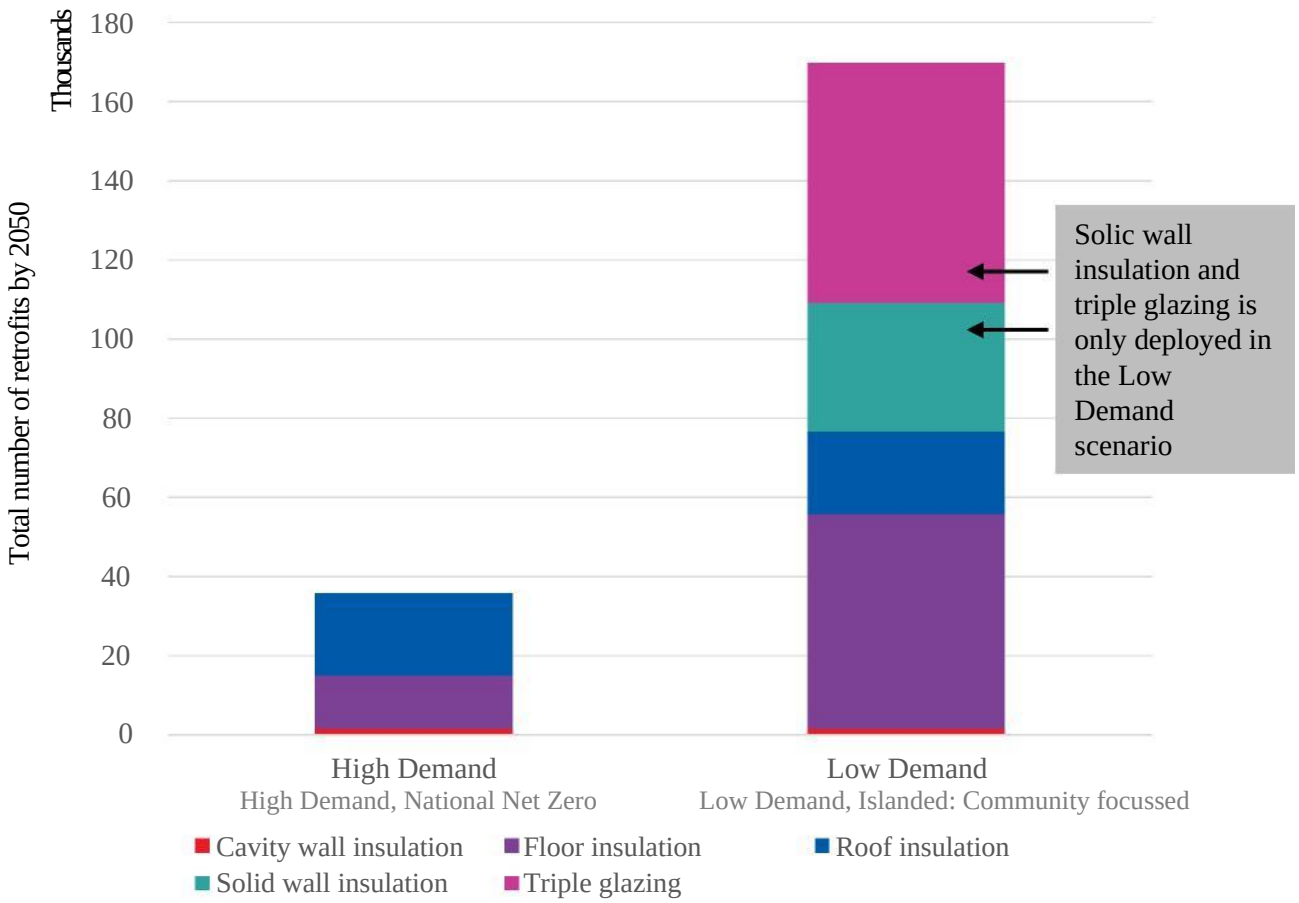


Figure 4.2.8: Proportion of homes with insulation measures

4. The future local energy system
Analysis

Comparing future energy scenarios - buildings

Table 4.2.3 shows the number of existing homes that would need different types of retrofit in the National Net Zero, High and Low Demand scenarios. The following five maps (overleaf) show where insulation measures (cavity wall, solid wall, floor, loft and triple glazing) could be deployed in the Low Demand scenario, aggregated to substation zone. The measures deployed depend on how technically viable it is to deploy each one in different housing archetypes. Scenario modelling explores what deployment of these measures looks like in 2050, in two scenarios:

High 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 ratings. Up to 34,200 domestic properties and 2100 non-domestic properties could be completed between 2023 and 2050.

Low Demand: All buildings below EPC A upgraded with insulation measures associated with EPC A ratings. Up to 60,500 domestic properties and 6000 non-domestic properties could be completed between 2023 and 2050.

Insulation retrofit measure	**Unit**	**High Demand** *Applies to: High Demand, National Net Zero, Islanded: Community-focussed*	**Low Demand** *Applies to: Low Demand*
Existing homes	Number	64,500	
Cavity wall insulation	% of homes	2.5% (1,600)	2.5% (1,600)
Floor insulation	% of homes	21% (13,400)	84% (54,000)
Loft insulation	% of homes	32% (20,800)	32% (20,800)
Solid wall insulation	% of homes	0	51% (32,600)
Triple glazing	% of homes	0	94% (60,500)
Existing commercial units	Number	7,600	
Cavity wall insulation	% commercial units	2.5% (175)	2.5% (175)
Floor insulation	% commercial units	1% (75)	62% (4700)
Loft insulation	% commercial units	10% (75)	12% (900)
Solid wall insulation	% commercial units	0	26% (1,950)
Triple glazing	% commercial units	15% (1,150)	80% (6,050)

Table 4.2.3: Proportion of total homes that receive different insulation retrofit measures in each 2050 future energy scenario. Note: These counts show measures undertaken at properties that are already constructed today and exclude new developments. More than one measure can be installed at the same property

Comparing future energy scenarios - Buildings

Figure 4.2.9 shows the most buildings needing loft insulation are generally located in the north and west of Gwynedd. A substation requiring high amounts of each type of retrofit is Dolgellau towards the southeast of Gwynedd.

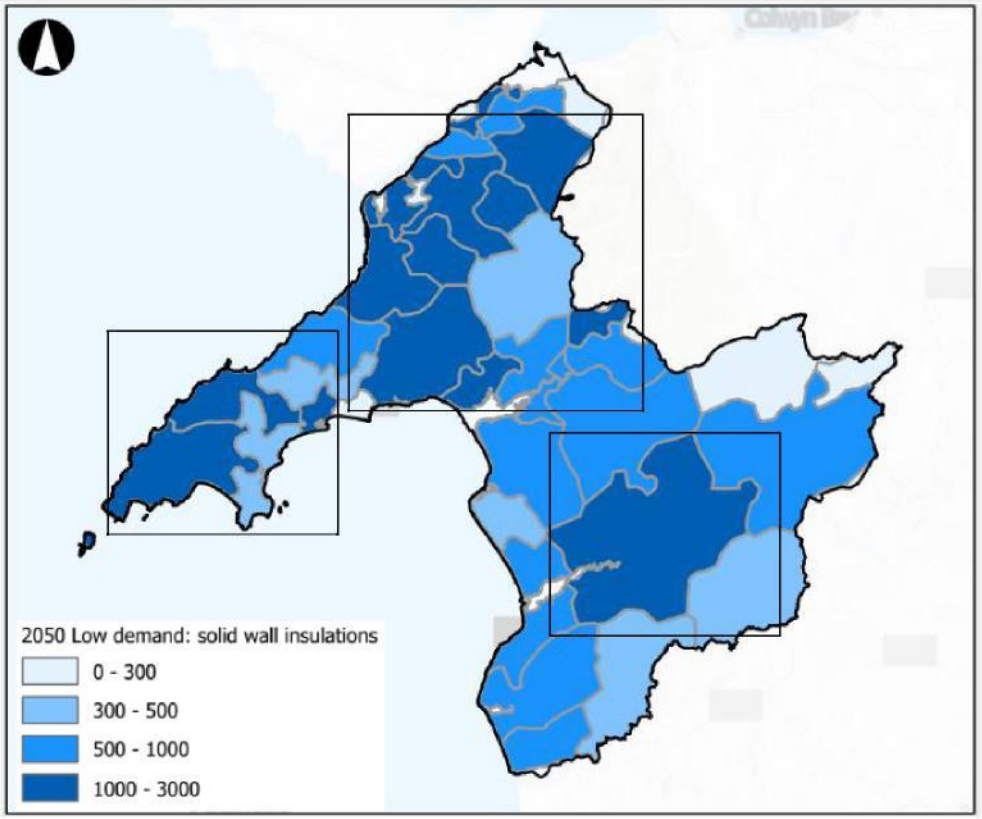


Figure 4.2.9: Map showing the number of solid wall insulation measures fitted by 2050 by substation zone in the Low Demand scenario

Figure 4.2.10 shows the area requiring the most cavity wall insulations is Bangor, with moderate amount of cavity wall insulations needed throughout Gwynedd.

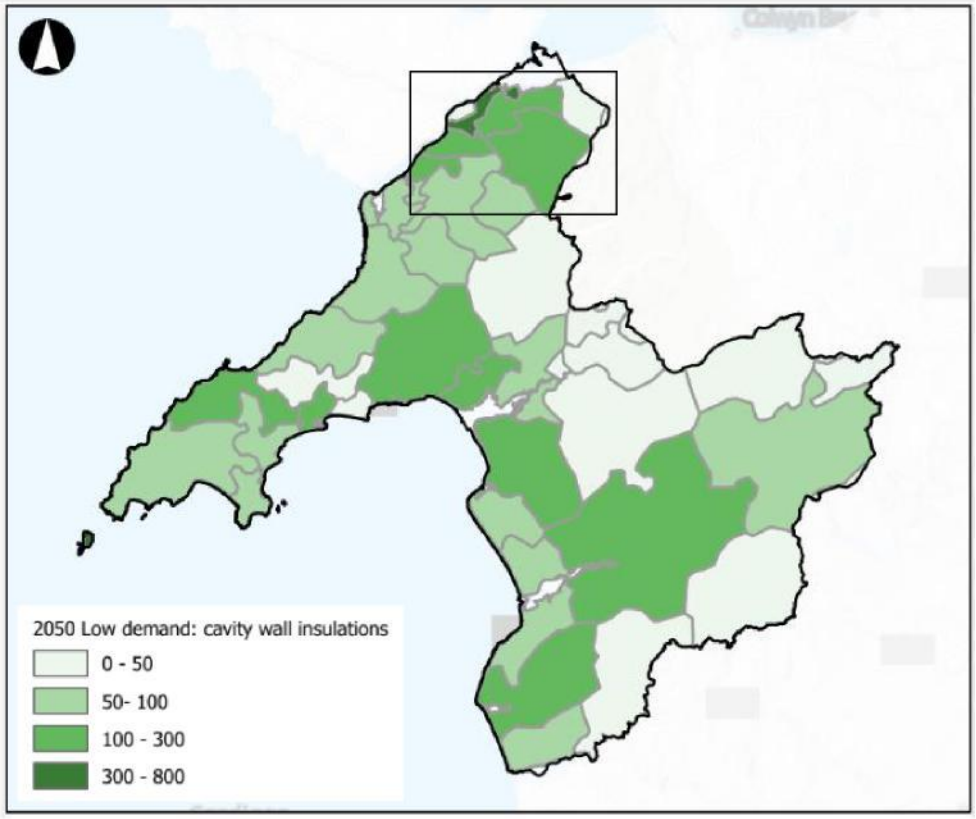


Figure 4.2.10: Map showing the number of additional cavity wall insulation measures fitted by 2050 by substation zone in the Low Demand scenario

4. The future local energy system
Analysis

Comparing future energy scenarios - Buildings

Figure 4.2.11 shows that buildings requiring loft insulation are scattered across Gwynedd, with substation zones located along the coastline, around Bangor and Llyn Peninsula identified as requiring loft insulation retrofit.

Figure 4.2.12 shows that floor insulation is required primarily in substations in the north of Gwynedd, but with need in other around Bangor and Llyn Peninsula and Llanfachreth identified as requiring floor insulation retrofit.

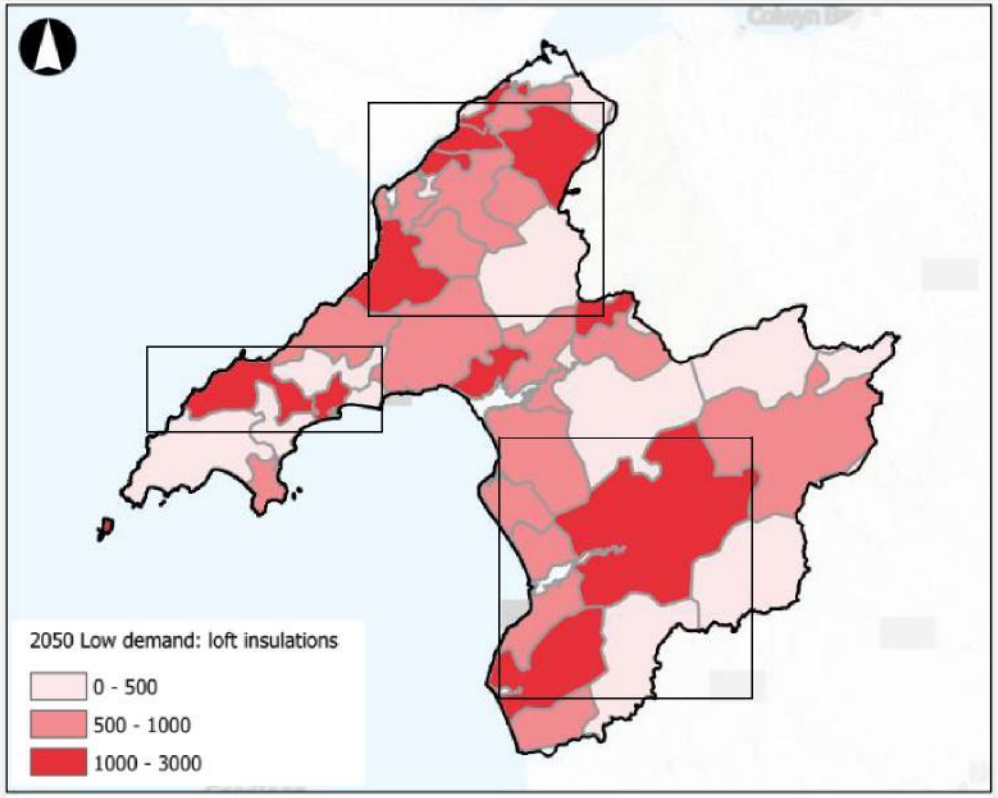


Figure 4.2.11: Map showing the number of additional loft insulation measures fitted by 2050 by substation zone in the Low Demand scenario

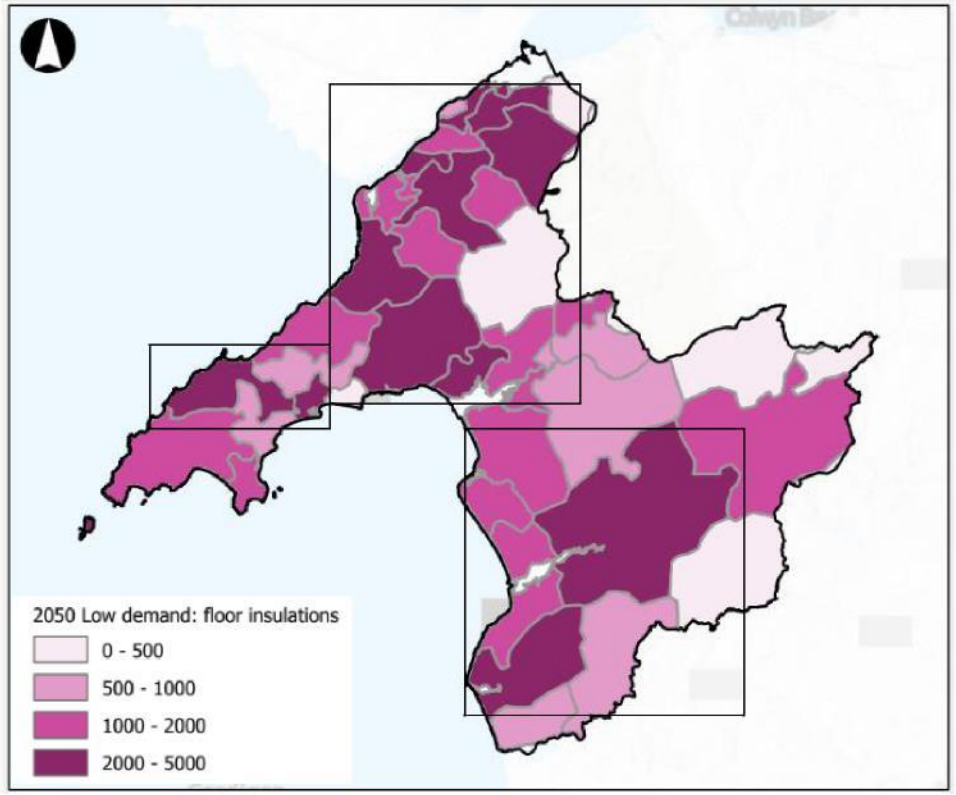


Figure 4.2.12: Map showing the number of additional floor insulation measures fitted by 2050 by substation zone in the Low Demand scenario

4. The future local energy system
Analysis

Comparing future energy scenarios - Buildings

Figure 4.2.13 shows triple glazing is most needed in the north, specifically in the Bangor, Bethesda and Caernafron substations. Requirements for triple glazing retrofit measures also remain high in other areas throughout the county.

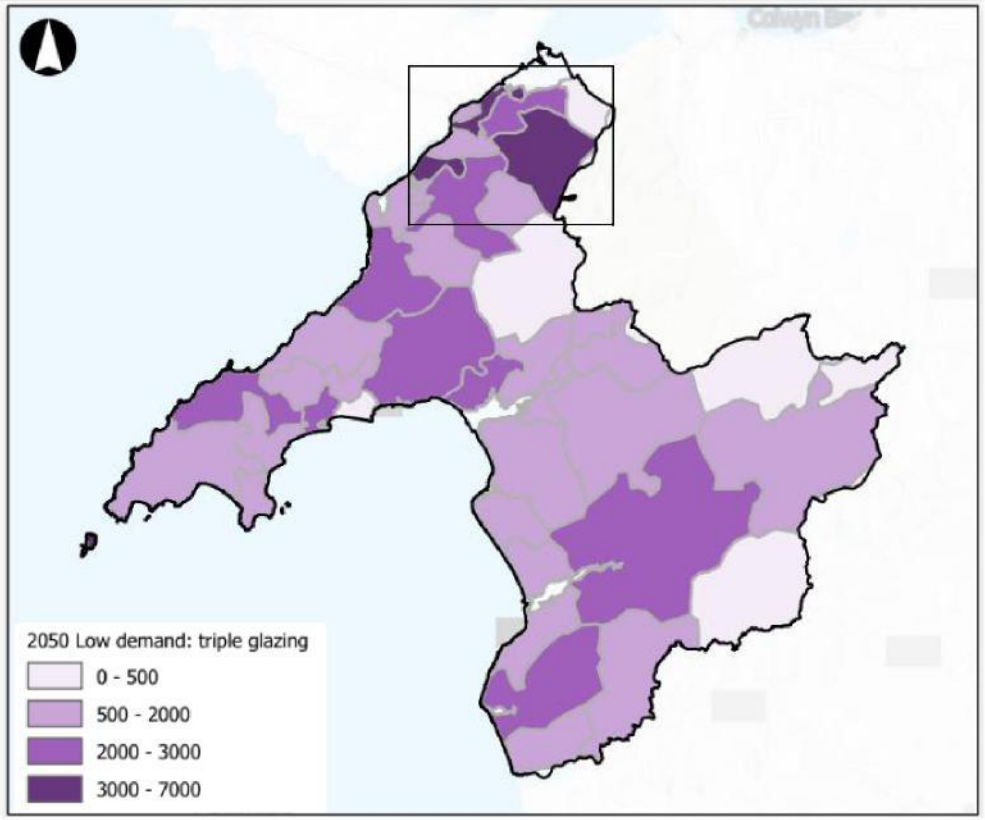


Figure 4.2.13: Map showing the number of additional triple glazing fittings completed by 2050 by substation zone in the Low Demand scenario

Figure 4.2.13 identifies where listed buildings are located, these are generally in and around Llanfachreth and south of Eryri National Park. These buildings are more likely to be challenging to retrofit due to their protected status.

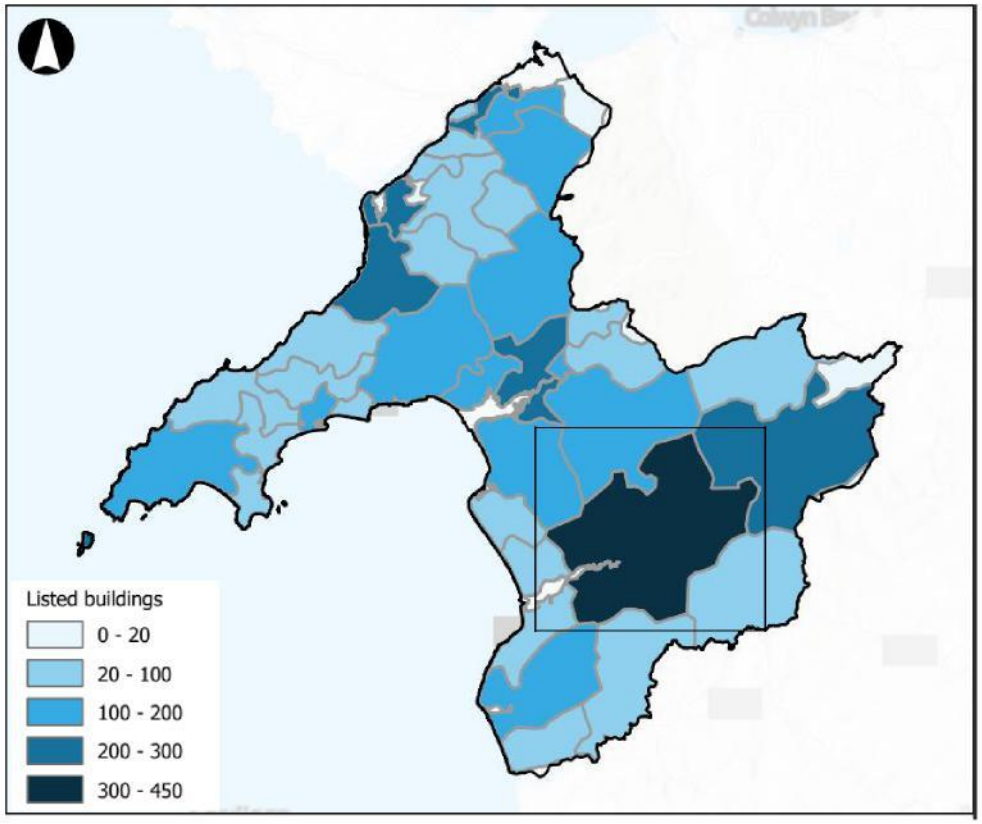


Figure 4.2.14: Listed buildings in Gwynedd

4. The future local energy system
Analysis

Comparing future energy scenarios - Heat networks

This section will analyse potential heat networks in Gwynedd, under the low and high demand scenario.

Figure 4.1.8 identified potential waste heat sources, however there were no networks identified with these sources.

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.

The potential heat network opportunity areas identified for Gwynedd are all associated with ASHP plants (rather than location-specific heat sources). These include locations around:

- Bangor (high street)
- Llanygai Industrial Estate
- Porthmadog

How to read the heat network diagrams:

Low heat demand

A larger and darker circle represents a location or "node" with relatively high heat demand compared to other nodes on the network.

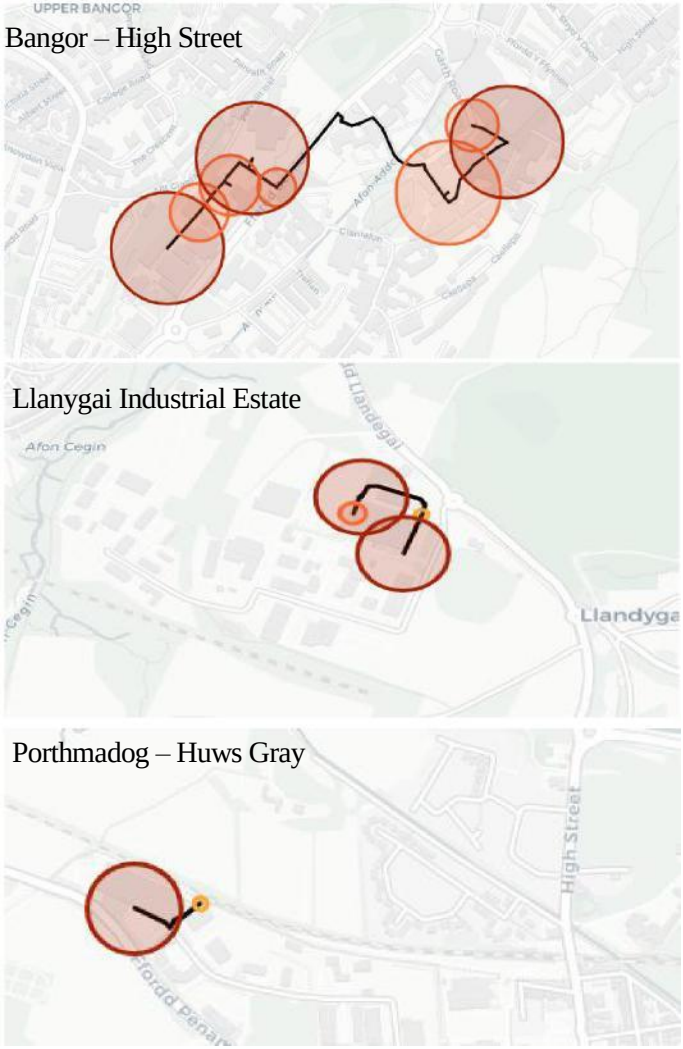


Figure 4.2.15: Map of identified zones for heat network potential

4. The future local energy system
Analysis

Comparing future energy scenarios - transport

Figure 4.2.16 shows the total number of vehicle miles covered in one year by vehicle type and scenario.

- Car mileage could decrease by 13% in the Low Demand scenario but increase by 6% in the High Demand scenario. This reflects the assumption that in the Low Demand scenario, people choose to take public transport or use active travel where possible, rather than using their car for shorter journeys.
- In both scenarios, 96% of mileage could be covered by electric vehicles and 4% by hydrogen vehicles. These are mostly hydrogen HGVs and buses.
- There are several factors that could influence a greater uptake of hydrogen HGVs:
    - Hydrogen refuelling can be done in 3-8 minutes, compared to at least 60 minutes needed for rapid charging, or overnight for standard charging.
    - Hydrogen HGVs are projected to have up to 50% range advantage over battery electric models (800km compared to 1,200km).
    - If the uptake of hydrogen HGVs is driven by wider factors such as their range and ease of recharging, and hydrogen becomes widespread in the future, then a significant proportion of HGVs could be powered by hydrogen.

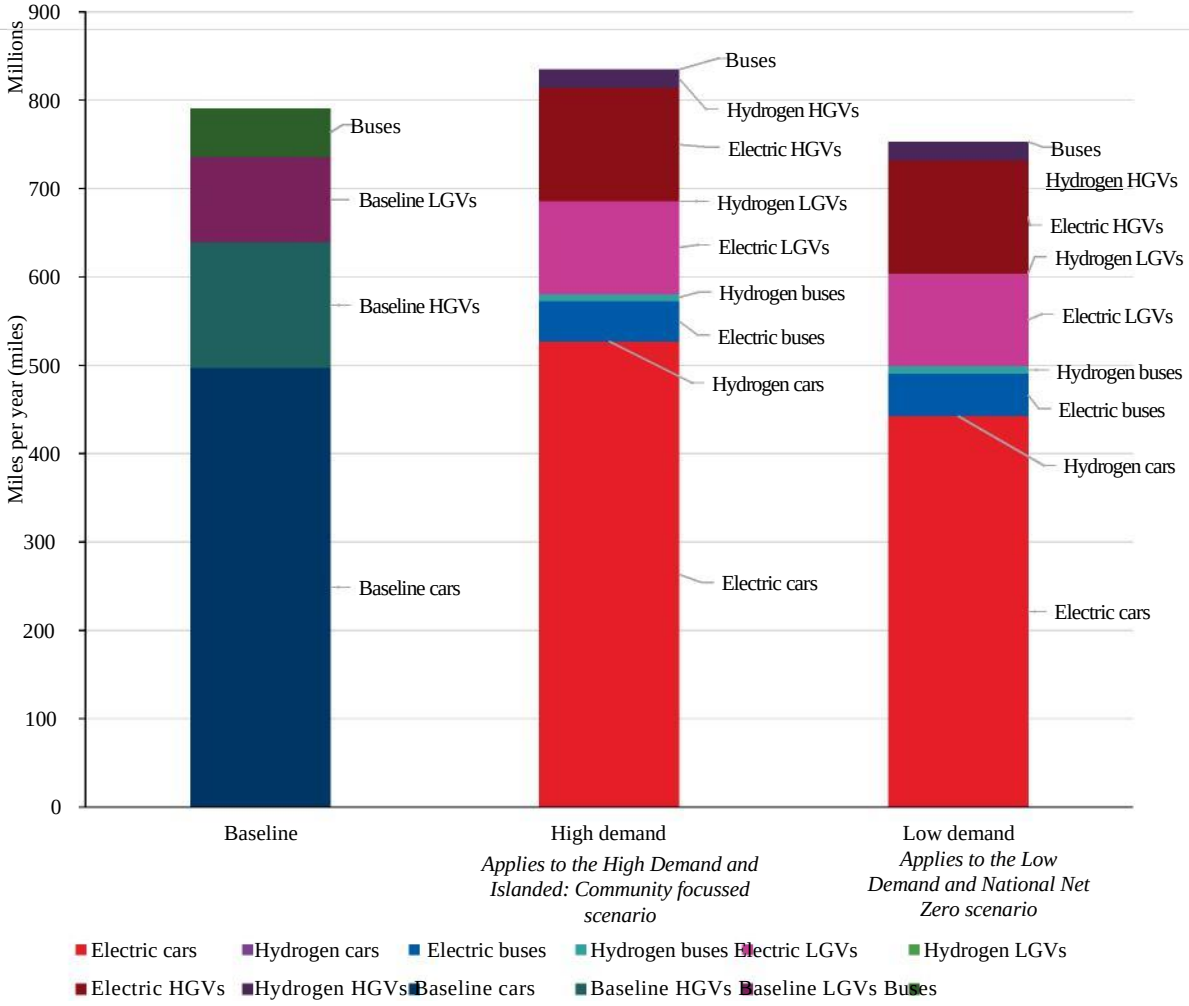


Figure 4.2.16: Total annual vehicle miles per year by scenario and vehicle type

4. The future local energy system
Analysis

Comparing future energy scenarios - Onshore renewables (electricity generators)

Our models indicate a significant expansion of ground solar PV generation due to it being the most cost-effective and carbon-efficient solution to meet the forecasted energy demands. In all scenarios, including National Net Zero, Low Demand, High Demand, and Islanded: Community–focussed, all suitable land was used for ground PV, with a generation capacity of c.500 MW. Rooftop solar PV and onshore wind also deployed in all scenarios, at 215 MW and 12 MW, respectively.

Anaerobic digestion increases substantially in the bespoke "Islanded: community –focussed" scenario. Since this scenario does not allow import from the national grid, and other technologies such as ground-mounted PV and solar have reached the maximum capacity (due to constraints applied such as best most versatile land), anaerobic digestion is selected to meet the electricity demand in the system. This is a demonstration of the capacity that would need to be met by reasonably on-demand sources. For Gwynedd, this is unlikely to be a realistic representation of a future energy scenario for Gwynedd as there is no current aspiration for large investment in Anaerobic Digestion.

The other technologies such as hydroelectricty are limited to the same capacity as the baseline, we do not expect them to grow. In practice, we know that it will be challenging to roll out the levels of deployment in the optimisation modelling, and there is a big gap between the amount of renewables installed per year now, to that needed to get to the levels of deployment in the modelling.

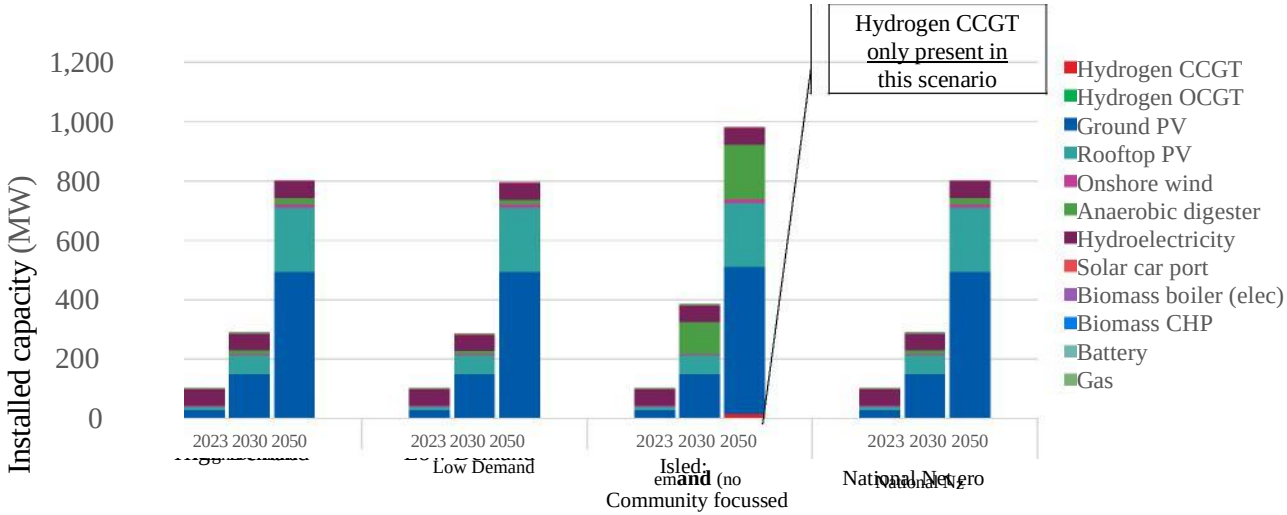


Figure 4.2.17: Future capacity of onshore renewables in each scenario for Gwynedd

** Battery storage was included within the model however no capacity was selected based upon the 24 hour timestep*

Renewable technology	Existing capacity (MW) (2023)	Additional capacity indicated across scenarios (MW)	Percentage of total maximum theoretical capacity across scenarios (%)	Estimated land area requirement (km^2)
Ground-mounted solar PV	29.8	+465	98%	8.9 (0.35% of land in Gwynedd)
Rooftop solar PV	9.27	+206	c.100%	n/a
Onshore wind	4.40	+8	c.100%	1 (0.04% land in Gwynedd)
Anaerobic digester	0.49	+21	n/a	n/a
Hydroelectricity	55.67	-	n/a	n/a
Tidal lagoon	0	+40	n/a	n/a

Table 4.2.4: Existing and maximum future capacity of onshore renewables

4. The future local energy system
Analysis

Electricity infrastructure - upgrades

The modelling results provide insights to the anticipated future requirements for electricity infrastructure upgrades, considering the current capacities of primary substations. For example, when a substation has limited demand headroom, but the projected increase in demand for the area it serves exceeds its current operational capacity, the need for reinforcement can be identified.

In some cases, the marginal cost of upgrading and connecting an additional unit of capacity to the substation is less than the marginal cost of installing an additional unit of battery or thermal storage capacity to reduce peak demand enough that the upgrade wouldn't be needed. Figure 4.2.18 shows the degree of upgrades required in the High Demand scenario, which explores a future scenario where electricity demand is high because of limited rollout of demand reduction measures and consumer behaviour changes.

The primary substations that service the northeastern areas of Eryri National Park (Bethedat$_1$ and Caernarfont$_1$) are most likely to require between 15-30 MW in upgrades. This modelling considers up to the primary substation; there will be further upgrades required to the 11kV network out from the substations which is not included within the modelling.

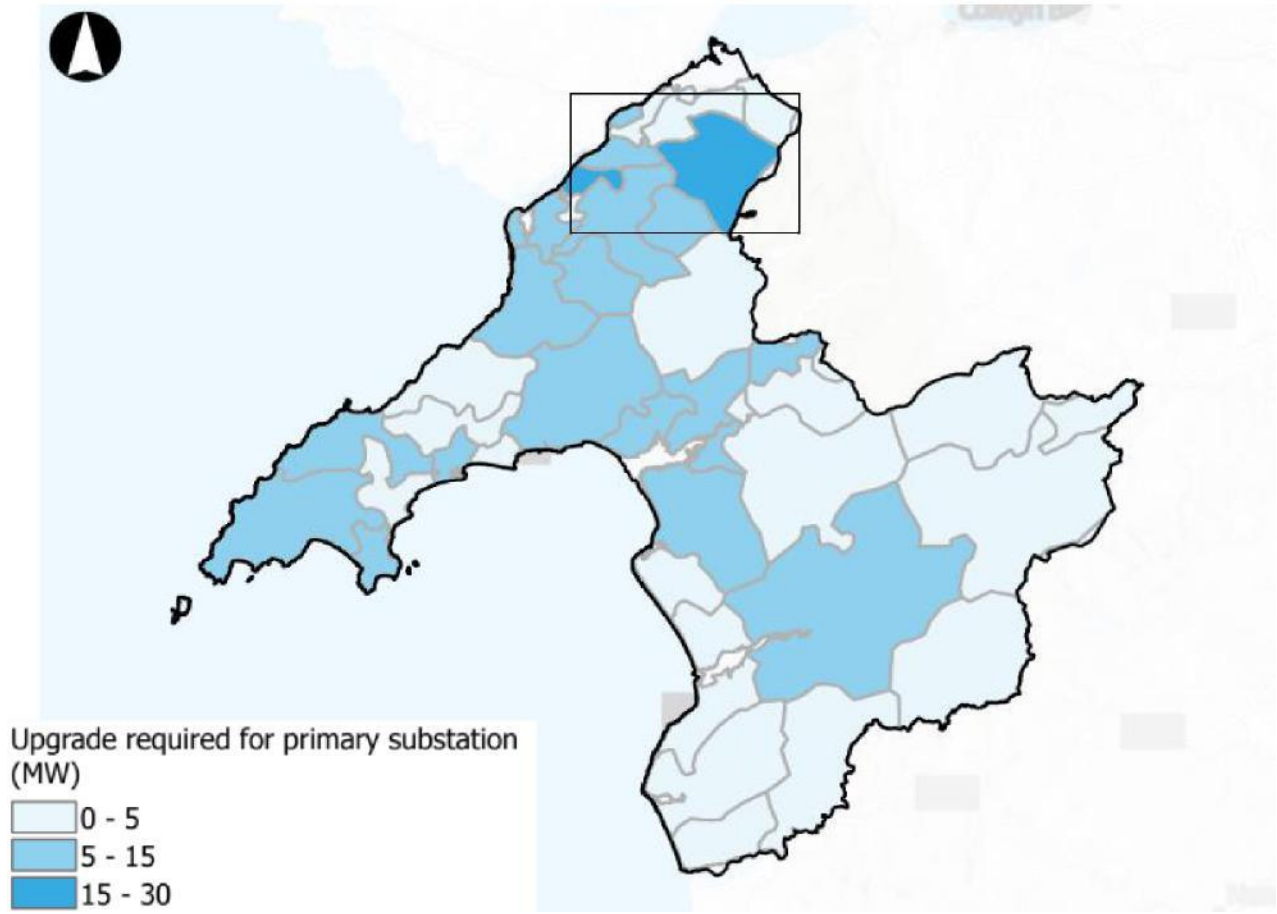


Figure 4.2.18: Map of electricity network upgrades in the High Demand scenarios

4. The future local energy system

Uncertainties and limitations

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

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

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

Table 4.2.5 summarises the impact of key sensitivities and uncertainties on the future energy system scenarios.

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 vs hydrogen boilers
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 4.2.5: Impact of key sensitivities on The future local energy system

4. 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 4.2.19 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
- 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 4.2.19: Trends from optimisation model runs

Deployment modelling

Figure 4.3.1: Eryri National Park, Gwynedd. Photo provided by Ambition North Wales ©

4. 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 4.3.2 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 4.3.1 summarises the data sources used to inform deployment rates for different technologies that were assessed in our optimisation modelling. A full list of technologies deployed, their metrics, and relevant policies can be found in Appendix B6.

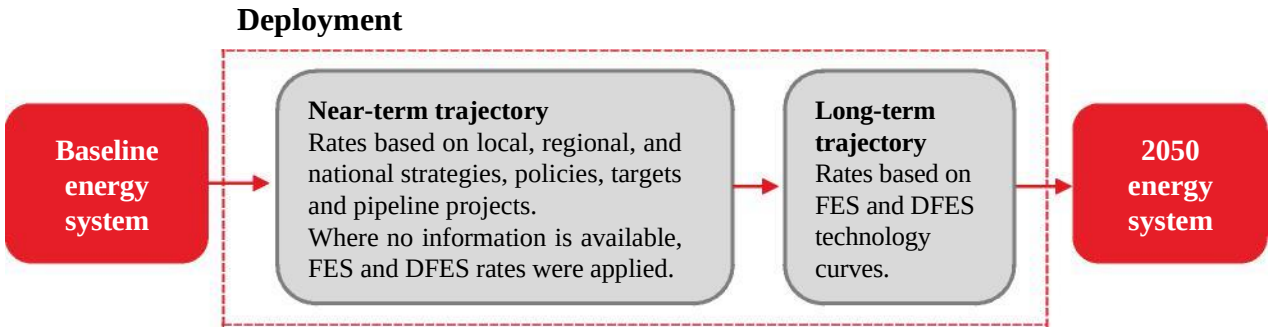


Figure 4.3.2: Deployment model overview of assumptions used to determine rates

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)[TN34]	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 4.3.1: Summary of data sources used to inform deployment modelling

4. The future local energy system
Deployment modelling

Impact on total energy demand (GWh)

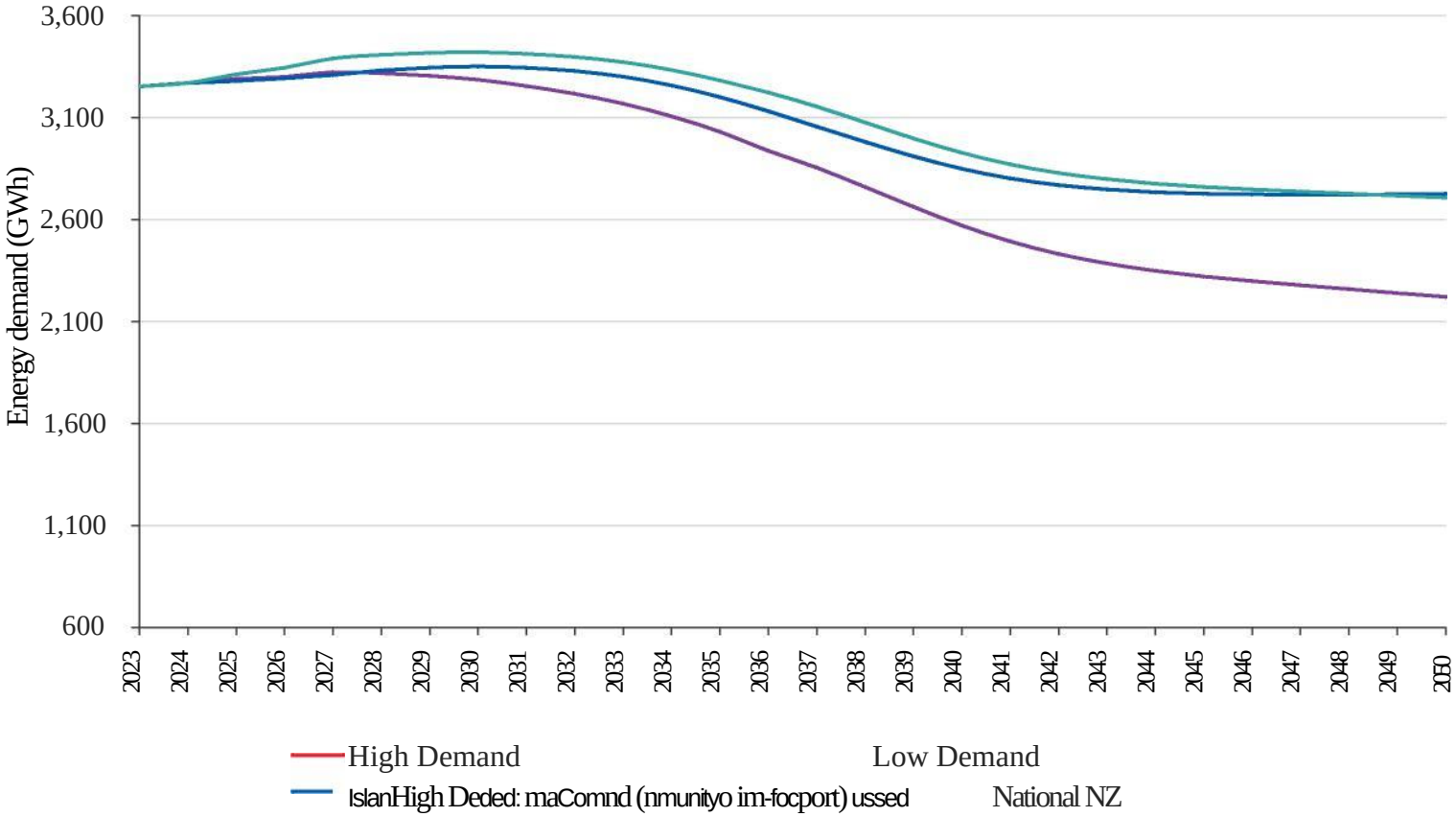


Figure 4.3.3: Change in total energy demand by scenario (GWh)

Now - 2023

Energy demand increases initially as a result of growth in housing and commercial property, before efficiency measures, and electrification of heat and transport take over.

2030

Total energy demand decreases between 2032 – 2042 in all scenarios driven by a switch to more efficient EVs and improving the energy performance of homes and commercial properties.

2040

In 2042 and later, energy demand starts to level off. This is likely due to the housing and commercial property growth matching the energy reductions achieved through energy efficiency measures and the switch to EVs slows down.

2050

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

4. The future local energy system
Deployment modelling

Energy demand from buildings (GWh)

Both electricity and heat demand in buildings increases to 2050 in the National Net Zero, High Demand and Islanded scenarios. This is primarily because the modelling assumes an increase in the number of homes and commercial buildings between now and 2050. High Demand, National Net Zero and Islanded: community-focussed scenarios all plot the same curve, since the data input is the same.

In the Low Demand scenario, the electricity demand remains constant, and the heat demand decreases to 2050, despite the increase in the number of buildings. This is due to prioritising reducing heat demand through improving insulation in existing and new buildings.

The average heat demand of each individual domestic property decreases from approximately 13,000 to 11,000kW$_{hheat/home}$ in the High Demand, National Net Zero and Islanded: community-focussed scenarios, and to 8,000kWh$_{heat}$/home in the Low Demand scenario for domestic properties.

For non-domestic properties, the heat demand decreases from 99 to 94kW$_{hheat/m2}$ in the High Demand, National Net Zero and Islanded scenarios, and to 75kW$_{hheat/m2}$ in the Low Demand scenario.

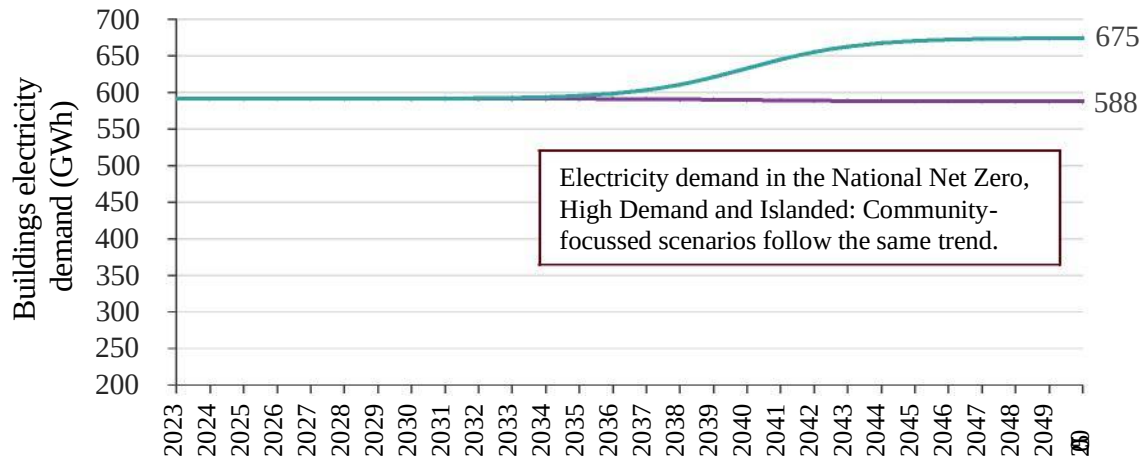


Figure 4.3.4: Projected electricity demand for buildings in each scenario for Gwynedd

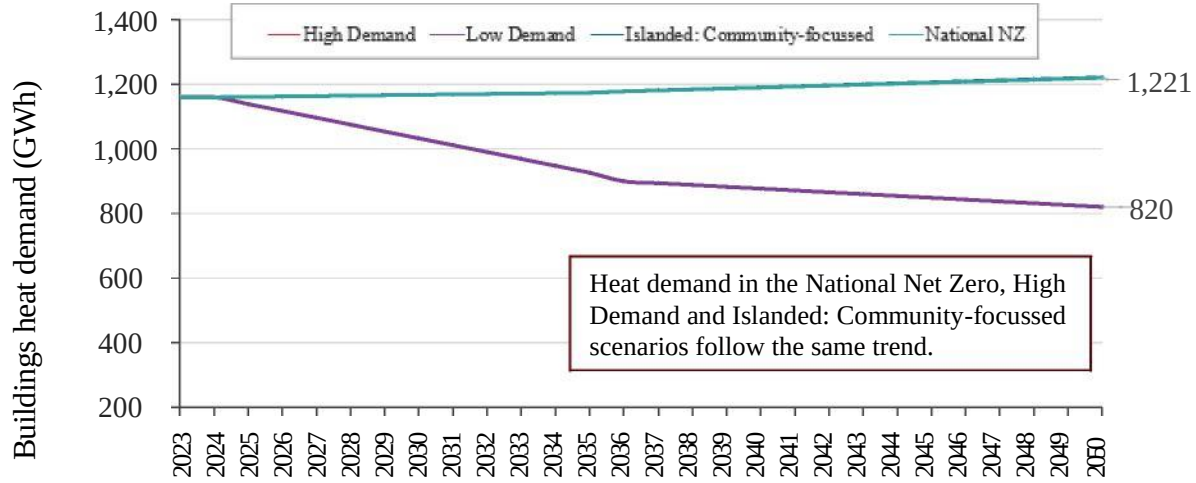
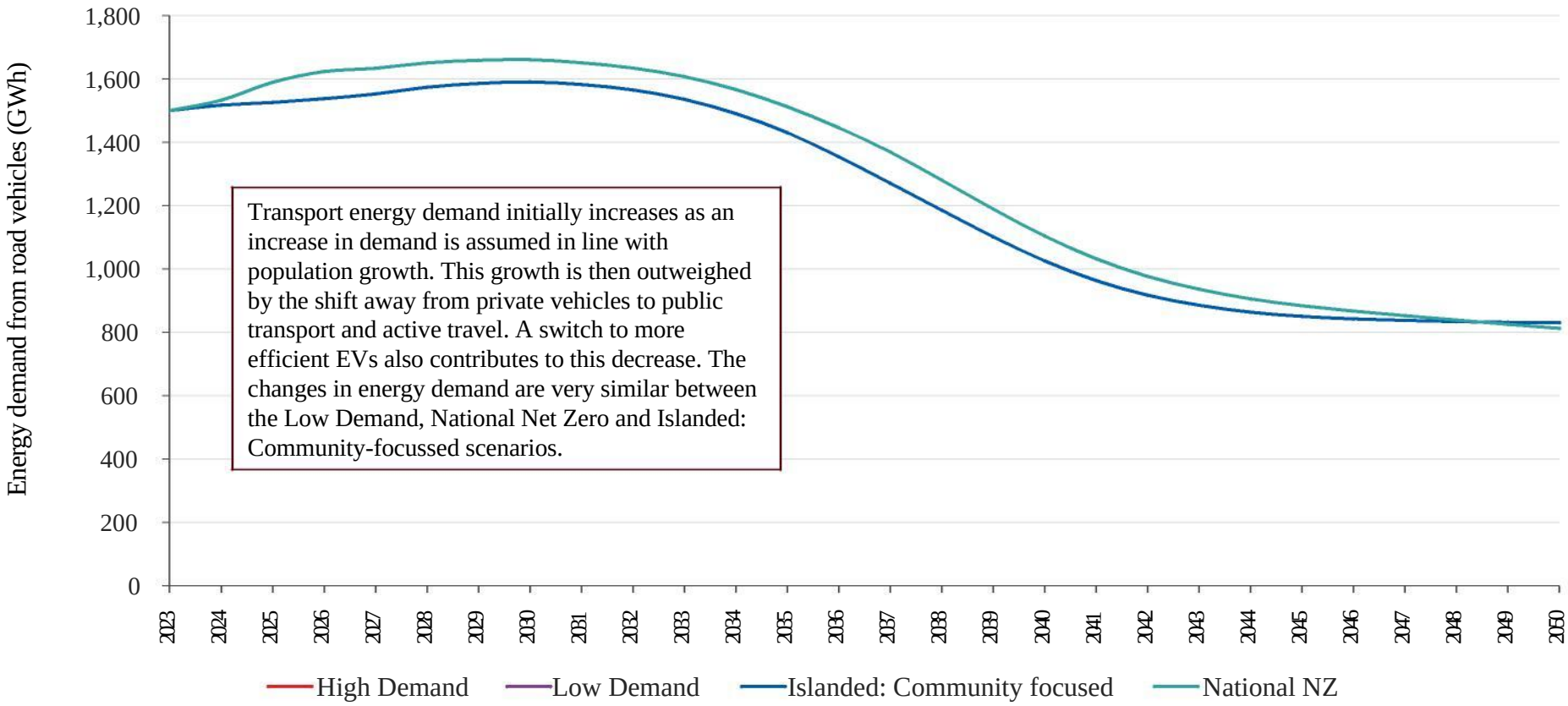


Figure 4.3.5: Projected heat demand for buildings in each scenario for Gwynedd

4. The future local energy system
Deployment modelling

Energy demand from transport (GWh)



Transport energy demand initially increases as an increase in demand is assumed in line with 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. The changes in energy demand are very similar between the Low Demand, National Net Zero and Islanded: Community-focussed scenarios.

Figure 4.3.6: Projected energy demand from road vehicles by scenario for Gwynedd

4. The future local energy system
Deployment modelling

Summary of deployment of critical energy components across Gwynedd

Figure 3.7 summarises the deployment rates* for near-term system components, so we can better understand where we are now and where Gwynedd needs to get to, providing a starting point to frame the challenge for more detailed analysis.

It's important to note that there is still a high degree of uncertainty associated with this deployment modelling as there are many variable factors and unknowns. For example:

- Technological advance and innovation
- Supply chains and how they develop
- Large scale activity to decarbonise infrastructure at other levels: regional, UK and beyond.

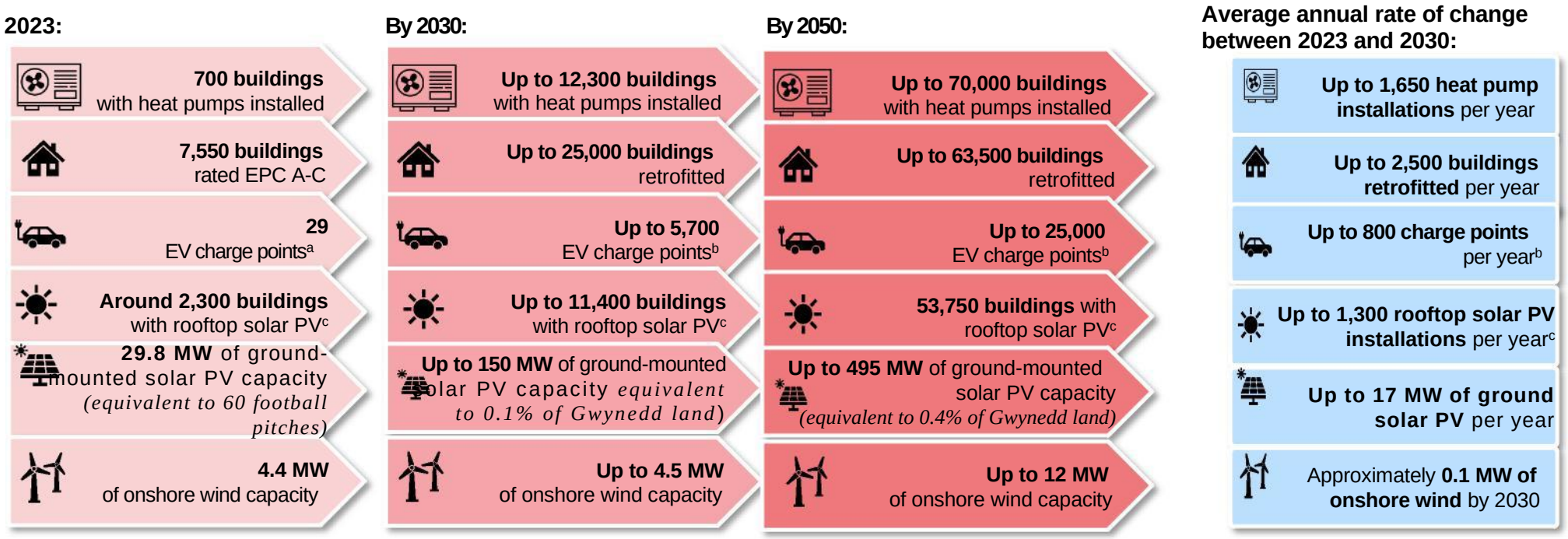


Figure 4.3.7: Summary of key deployment metrics from optimisation modelling

[a]According to the National Charge Point Registry[M43] 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. Based on the Wales EV Charging Strategy[M23], most chargers in Gwynedd are likely to be slow chargers (<7kW) with a small number of fast (7-22kW) and rapid (42-350kW) EV chargers.
[c]Assuming 4kWp per roof and per installation.
* This is an indicative capacity to be brought forward e.g. for ground-mounted solar PV deployment, this could comprise different sized solar farms.

4. The future local energy system
Deployment modelling

Impact on GHG emissions

Figure 4.3.8 compares projected GHG emissions for each future energy scenario (see Chapter 4. The future energy system (methodology) for a description of scenarios).

Table 4.3.2, the GHG emissions from each scenario are compared to the Welsh Gov targets, which are relative to the 1990 emissions level of 1,100ktCO_2e in Gwynedd. As of 2023, Gwynedd already has a GHG emissions reduction of 40% to 660ktCO_2e.

The "Do Nothing" scenario assumes that Gwynedd continues operating as it is today, with no further action. Any change can largely be attributed to the forecasted decarbonisation of the electricity grid.

All four modelled scenarios miss the Welsh Gov 2030 target of a 63% reduction. The High Demand and Islanded scenarios meet the 2040 target of 89% reduction, with the Low Demand and National Net Zero coming close, with reductions of 87% and 88% respectively.

None of the scenario's fully reach net zero by 2050 due to residual emissions of 17ktCO_2e. The most common sources of residual emissions in 2050 are from electricity demand (77%) (FES projection for grid carbon factor is low, but not zero or negative) and electricity generation from natural gas that might be used to produce hydrogen (23%).

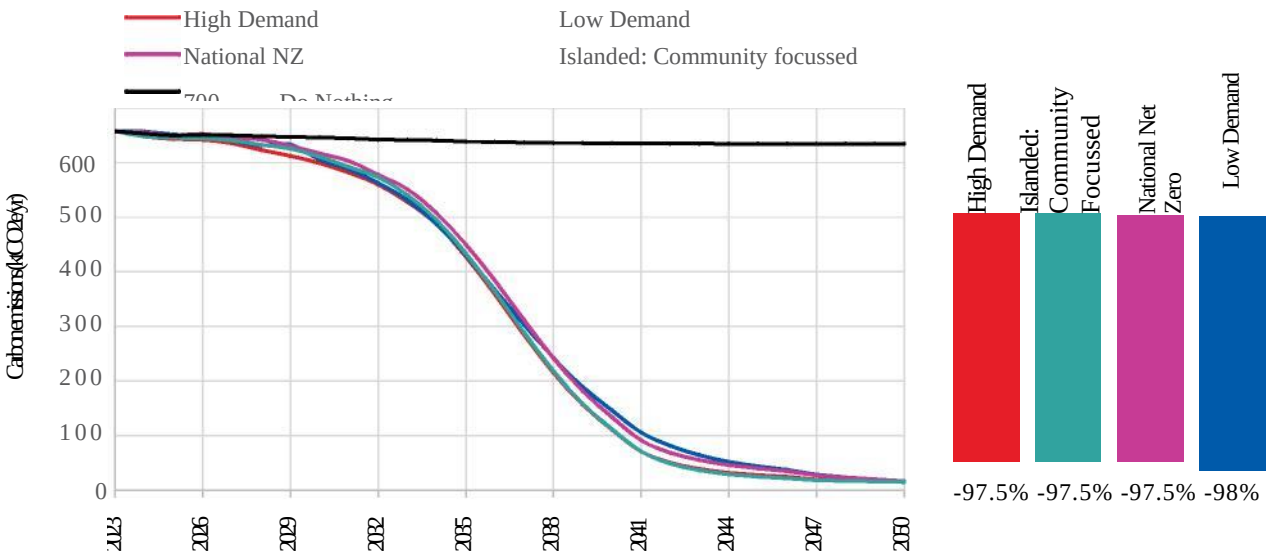


Figure 4.3.8: GHG emissions (ktCO_2e) to 2050 for each modelled scenario compared to the Do Nothing scenario

Scenario	2030	2040	2050
Welsh Gov targets	**-63%**	**-89%**	**-100%**
National Net Zero	**-44%**	**-88%**	**-98%**
High Demand	**-46%**	**-90%**	**-98%**
Islanded: Community focussed	**-44%**	**-90%**	**-99%**
Low Demand	**-45%**	**-87%**	**-99%**
Do Nothing	-41%	-42%	-42%

Table 4.3.2: 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

4. The future local energy system
Deployment modelling

Impact on employment

Reducing the amount of energy we use and using renewable energy can have wider benefits so it is important that they are understood to support decisions that impact the future of the energy system. The benefits realised can be economic, social and environmental. 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].

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[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 and EV chargepoints 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 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 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.

4. The future local energy system
Deployment modelling

Impact on employment

Results

Values in Table 4.3.3 are presented in Full-Time Equivalent (FTE) so that employment impacts can be measured for the lifetime of the project or plant and duration. 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.

Employment impacts are greatest in the Energy Island scenario, which driven mainly by the high levels of biomass modelled (due to no imports being allowed into the system) and partly by the need for greater renewable capacity and significant roll-out of insulation retrofit measures in this scenario compared to others, driving a need for more skilled workers across the supply chain and opportunities for employment in these positions.

Metric	Do Nothing	National Net Zero	High Demand	Low Demand	Energy Island
Energy change (GWh, relative to 2023)	~0	-544 (-17%)	-527 (-16%)	-1,031 (-32%)	-526 (-16%)
Employment impacts between 2023-2050 relative to the Do Nothing scenario (net FTE),	~0	+2,400	+2,400	+4,100	+3,400

Table 4.3.3: Summary of economic impacts for each scenario: employment impacts and air quality activity costs. Figures shown relate to the period 2023 – 2050. Air quality activity costs are presented using 2022 prices and are not discounted

Impact on air quality

The energy system can also impact air quality, which in turn impacts human health, productivity, wellbeing and the environment. Accordingly, understanding the impacts to air quality is important when planning future policy or programmes of work.

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 4.3.4 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. Appendix B8 provides additional details on the derivation and assumptions for each of these costs. 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.

The air quality impacts of EfW are not addressed in this analysis, as the Green Book does not include a factor for EfW or waste incineration. Rather, the air quality impacts are presented only as change in activity cost relative to baseline (2023). This effectively assumes that no new EfW plants are constructed, and so there is no overall difference in air quality impact.

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

Table 4.3.4: Air quality activity cost factors

4. The future local energy system
Deployment modelling

Impact on air quality

Results

Activity costs presented in Table 4.3.5 show estimates for the impact of air pollution per unit of fuel consumed in each future energy scenario and estimates for the employment impacts associated with each future energy scenario, compared to the Do Nothing scenario. It can be seen that a cumulative saving of £390m to £290m due to increased air quality can be achieved through reduced load on local healthcare services.

Figure 4.3.9 presents annual economic savings, with activity costs decreasing to approximately £1m per year by 2050 compared to 2023 for the High Demand, Low Demand and National Net Zero scenarios. The Islanded: community-focussed scenario reduces to slightly higher £6m in annual activity costs due to the increased use of natural gas to produce hydrogen.

Overall, lower energy demand and renewable energy generation uptake equates to less GHG emissions, resulting in better air quality, creating savings through reduced stress on healthcare services.

Metric	Do Nothing	National Net Zero	High Demand	Low Demand	Islanded: Community - focussed
Cumulative air quality activity costs between 2023-2050 (£'million) (2022 prices)	£770 million	£410 million	£380 million	£400 million	£480 million

Table 4.3.5: 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

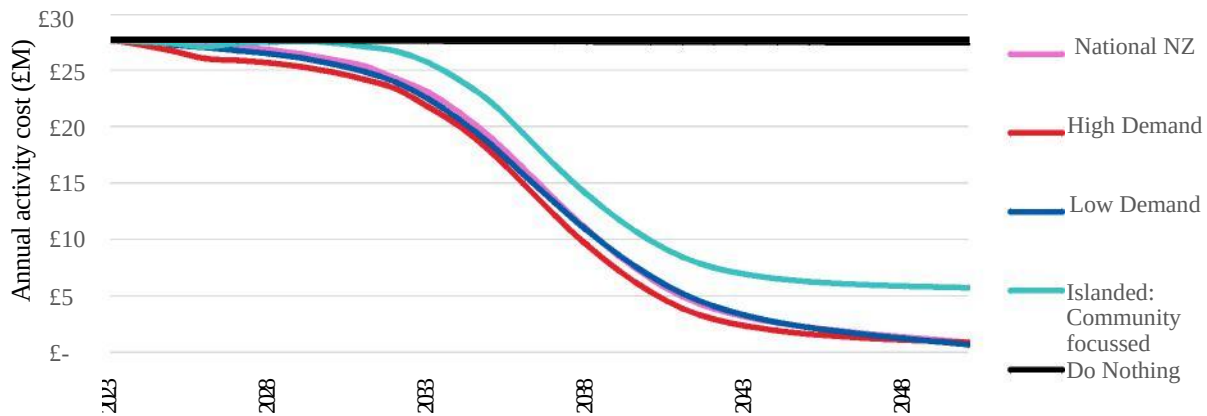


Figure 4.3.9: Annual financial savings stemming from the increase in air quality in each modelled scenario to 2050

4. 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 4.3.6 (overleaf) shows the estimated capital investment (CAPEX) required to build out the critical system components for net zero, that were identified in our scenario analysis. These costs are presented as absolute figures and should be weighted against a suitable counterfactual to understand the additional investment required.

This table shows the parties responsible for these investments and key interdependencies.

Some of these priority intervention areas 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 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 4.3.6 on page 116 (overleaf).
- Priorities - A breakdown of the suggested priority investment areas to 2030 for Gwynedd can be found in the plan on a page found on page 123.
- Buildings – Investment costs for the "Transition to low carbon buildings" proposition can be found in Table 5.1.2 on page 129.
- Transport – Investment costs for the "**Decarbonise the transport system**" proposition can be found in Table 5.1.3 on page 132.
- Renewables – Investment costs for the "**Increase renewable energy generation across the county**" proposition can be found in Table 5.1.4 on page 136.
- Hydrogen: Investment costs for potential future hydrogen energy components can be found on page 139.

4. The future local energy system
Deployment modelling

Investment requirements

	Indicative CAPEX (£m) to 2050	Basis for CAPEX estimate	Party responsible for CAPEX	Dependencies on other investments
1. Maximise energy efficiency of buildings	400 – 4,615	Cost of deep retrofit interventions	Welsh Government, local authority, Registered Social Landlords, building developers, building owners and landlords	
2. Ground-mounted solar PV	200	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	8.3	Build out of onshore wind		Electricity network
4. Maximise rooftop PV	230	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	96 - 98	Build out of EV chargers	Charge Point Operators, local authority, building developers, landowners and landlords	Electricity network, hydrogen networks
6. Decarbonise heat	170 - 320	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 reinforcement	33	Electricity network reinforcement 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.		
0. Roll-out of energy system flexibility	Key uncertainty	Thermal storage costs	Project developers, transmission or distribution network operators, building owners, energy providers, building owners and landlords	Electricity network
Project costs (incl contingency, prelims, professional and development costs etc) (50%)	*570 – 2,800*	*50% of CAPEX above*		
Total	*c.1,700 – 8,300*			

Table 4.3.6: Indicative investment requirements

Chapter 5: Action planning (stages 6-7)

Figure 5.1.1: Community Energy Action ©

5. Action planning

Overview

Figure 5.1.2 shows the process followed to develop the complete LAEP and routemap to transition the local energy system in Gwynedd.

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 **four energy propositions**. These form the strategic foundation for Gwynedd's LAEP and consolidate the evidence to describe what, how and where to prioritise the deployment of these energy system components.

Identifying priority focus zones

We looked at **where** critical system components in each energy proposition could be prioritised for deployment and identified priority focus zones, accounting for technical and social factors.

We considered this alongside other technical and social factors (e.g. generation and demand headroom) to prioritise focus zones with particularly favourable conditions for deployment.

Creating the plan

Developing actions

Using input from stakeholders, highlighted overleaf, we created a routemap and action plan to drive the local energy system transition in Gwynedd 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.

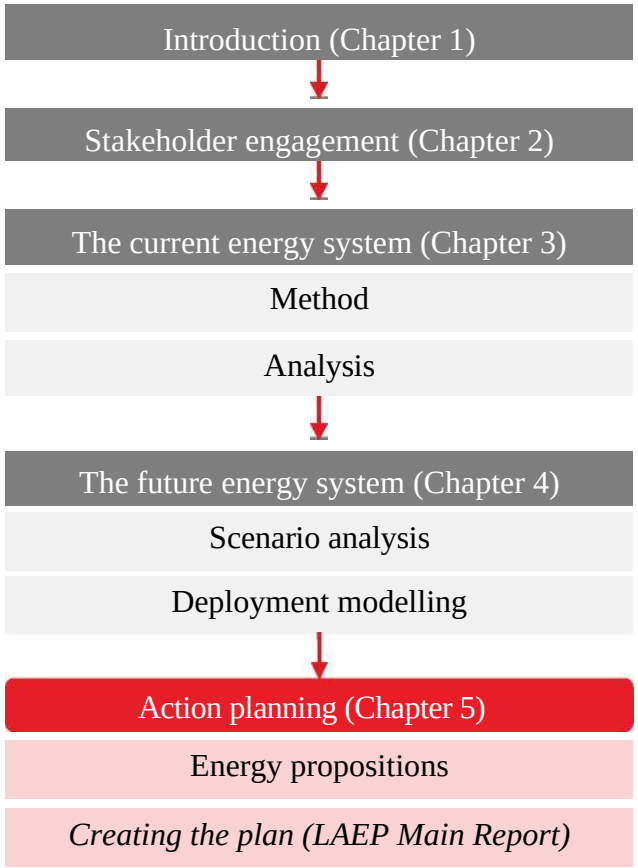


Figure 5.1.2: Overview of the approach taken to develop the near-term recommendations for the LAEP

5. Action planning
Energy propositions

Identifying priority focus zones

Prioritising energy system components

Figure 5.1.3 shows our approach to prioritise low-regrets energy system components in Gwynedd to take forwards when identifying priority focus zones for their deployment. We consulted primary and secondary stakeholders across the county 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 Gwynedd's LAEP?
- Is this energy system component identified as a priority area in North Wales' energy strategy?

We combined this feedback with insights from scenario modelling to develop Gwynedd's energy propositions, which are the framework for the LAEP. Gwynedd'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 onshore wind as a critical energy system component will specify what capacity is needed and by when, as well as indicative investment requirements to achieve it.

5. Action planning
Energy propositions

Identifying priority focus zones

Certainty of outcome

High

Short-term	• Retrofit measures (newer homes) • Retrofit beyond social housing (ECO4) • EV Chargers in urban areas and town centres • Heat Pumps and Rooftop solar PV in off gas grid homes and new builds • Canopy PV • Small scale ground-mounted solar PV • Small scale hydropower	• Heat pumps in gas grid properties coupled with thermal storage and solar PV • Active travel shift in rural areas/visitor hubs • EV chargers in more rural areas • Retrofitting heat pumps in older properties • Onshore wind • Electrical infrastructure upgrades
	• Ground-mounted solar PV • Larger scale solar • Active travel shifts in areas with a higher population density • Electrical infrastructure and grid updates • Energy from Waste (although most of this is exported to Flintshire currently)	• Increasing public transport/buses in rural locations • Anaerobic digestion • Electrolysers • Hydroelectricity • Hydrogen refuellers • Hydrogen imports

Time to deliver

Long-term

Low

Figure 5.1.3: Summary of feedback from workshop 5 (pathway prioritisation) – "prioritising energy system components"

5. Action planning
Energy propositions

Energy propositions in more detail

Proposition 1: Transition to low carbon buildings

Ambition: Reduce heat demand and improve the energy efficiency of existing buildings through retrofitting measures aimed at reducing overall electricity and heating demand, while also transitioning away from fossil fuel-intensive heating systems. Scenarios show heat pumps as the near-term, least regrets technology to decarbonise heating systems in homes. The following actions will be considered:

- Installing rooftop PV (with targeted battery storage)
- Upgrade to LED lighting (with improved controls)
- Improving building fabric
- Installing heat pumps

Proposition 2: Decarbonise the transport system

Ambition: Reduce transport demand, improving active travel routes, enhancing the public transport network and encouraging shared transport modes, thereby minimising dependency on private vehicles. We will facilitate the adoption of EVs by installing charge points and encourage a transition to more sustainable transport modes. The following actions will be considered:

- Installation of EV charge points
- Improving active travel routes and public transport network

Proposition 3: Increase renewable energy generation across the county

Ambition: Investigating opportunities for local and community ownership of renewables, providing low cost, clean energy to residents. Ensure that land suitable for renewable energy assets is identified. Battery storage should be considered to minimise dependency and exposure to grid price volatility and connection challenges. The following actions will be considered:

- Deployment of ground-mounted solar PV
- Deployment of tidal
- Deployment of hydroelectricity
- Smart Local Energy Systems

Proposition 4: Reinforce and transition the energy networks: electricity and gas networks

Ambition: There will be a significant increase in electricity demand between now and 2050, driven by the uptake of electric vehicles, and a shift to electricity for home heating. Make upgrades to the electricity network that are required to ensure increasing electricity demand can be met. Make upgrades to the gas network that are required to ensure future hydrogen demand could be met. This is key to ensuring the success of other propositions. The following actions will be considered:

- Upgrading the electricity network
- Readiness of the gas grid for hydrogen

Figure 5.1.4: Summary of propositions

5. 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 Gwynedd. The map highlights 15 modelling zones identified as priority focus zones for the low-regret energy system components included in Gwynedd'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 modelling zone was ranked using two or more of the considerations in Table 5.1.1, each weighted by the percentage indicated. A modelling zone was only considered for prioritisation if it was greater than 8% of its primary substation service area.

- **Off-gas homes** – prioritise zones with higher baseline proportion of off-gas housing. These homes will be the most challenging to transition to hydrogen and therefore are the most likely no-regrets targets for conversion to heat pumps.
- **Socioeconomics** - prioritise zones with higher baseline rates of deprivation (lower WIMD score).
- **Property ownership** - prioritise zones with the highest baseline percentage of social housing.
- **Substation generation headroom** – prioritise zones with the most baseline generation headroom available.
- **Listed buildings** – prioritise zones with the least number of 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 where the most additional new capacity is built between the baseline and 2050 high demand scenario.

In the map (overleaf), green areas show zones identified as a priority focus zone for at least one energy system component. The callouts 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.

	Heat pumps	EV chargers	Local generation	Insulation retrofits
Off-gas homes[T7]	25%	-	-	-
Socioeconomics[T28]	25%	30%	-	20%
Property ownership[T7]	25%	-	-	20%
Substation generation headroom[TN6]	-	-	50%	-
Listed buildings[T4]	-	-	-	5%
Domestic energy efficiency[T7]	-	-	-	35%
Built additional substation capacity	25%	40%	-	20%
Built EV charging capacity	-	30%	-	-
Built additional capacity of each local generation technology	-	-	50%	-

Table 5.1.1: Input data and relative weighting factors used in "plan on a page" calculations

Gwynedd's Plan on a page - 2030

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 5.1.5 identifies zones with particularly favourable conditions for specific energy components, making them ideal locations for pilot studies. The summary tables (shown below) detail the (i) installed capacity opportunity, (ii) required investment for each component and (iii) total investment necessary for both energy component installation and electricity network infrastructure in each zone by 2030. Ranges have been calculated by taking the minimum and maximum results from each future energy scenarios (see Chapter 3 for more detail).

Note: intervention should still be carried out in 'progress' zones to transition the local area to Net Zero.

Sponsors: Llywodraeth Cymru Welsh Government; Uchelgais Gogledd Cymru Ambition North Wales

Delivery partners: ARUP; CARBON TRUST

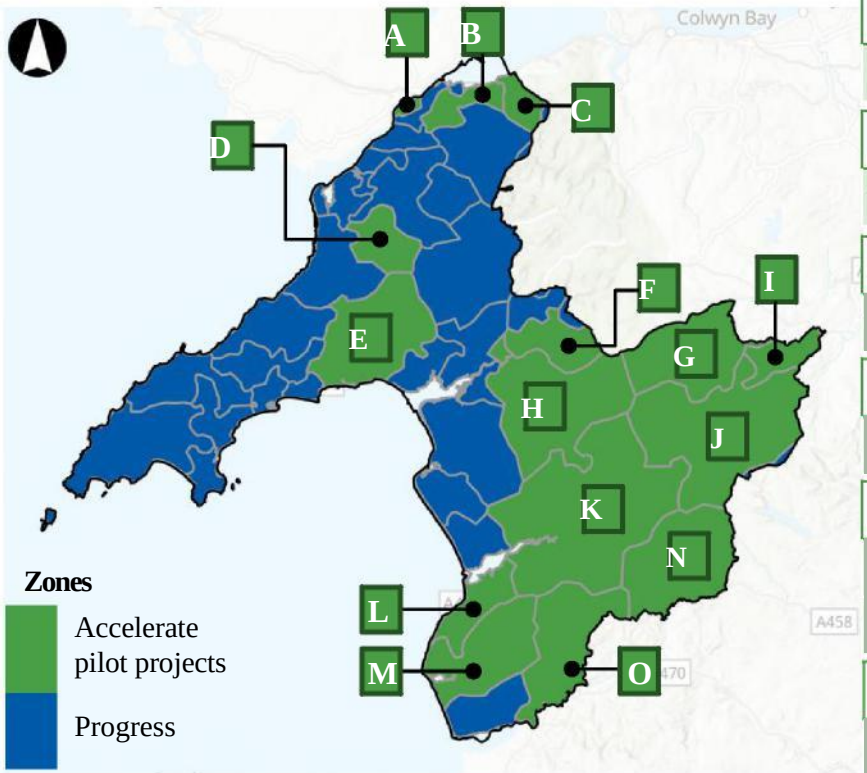


Figure 5.1.5: Gwynedd's spatial representation of opportunities across the four scenarios, including 2030 ambition and investment (million £). Zone boundaries are defined by primary substation service areas.

Heat pumps	Ground-mounted PV	Rooftop PV	
EV charger	Onshore wind	Insulation measures	

	(i)	(ii)	(iii)
A Parc Menai			Zone A total £5.8-19m
	1.6MW	£1.7m	
B Minffordd/Parc Bryn Cegin			Zone B total £7.5-48m
	1.1MW	£870–880k	
C Llanfairfechan			Zone C total £0.46-3.7m
	79kW	£65k	
D Carmel			Zone D total £6.9-60m
	550–730 homes	£4–57m	
E Rhoslan			Zone E total £36-98m
	63MW	£27m	
	500–740 homes	£4–66m	
F Manod			Zone F total £3.3-27m
	240–250kW	£200k	
G Tryweryn			Zone G total £12-21m
	110–220kW	£81–170k	
	24MW	£10m	
H Maentwrog			Zone H total £3.0-26m
	350–750kW	£270–560k	
I Glan-Yr-Afon			Zone I total £11-17m
	80-170kW	£60–130k	
	23MW	£9.8m	
	11MW (2050)	£8.0m (2050)	
J Bala			Zone J total £9.0-57m
	4.2MW	£1.8m	
K Dolgellau			Zone K total £11-78m
	580–910 homes	£5–73m	
L Fairbourne			Zone L total £3.9-37m
	700kW	£770k	
M Tywyn			Zone M total £7.9-63m
	1.9MW	£2.1m	
N Cemmaes Rd			Zone N total £1.9-16m
	180 – 390kW	£130–290k	
	150kW	£120k	
	130–150 homes	£1–15m	
O Machynlleth			Zone O total £2.8-20m
	540kW	£600k	

5. Action planning
1. Transition to low carbon buildings

Introduction

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]. The priority in Gwynedd is firstly to reduce heat demand in homes whilst maintaining comfort levels and minimising the direct cost to consumers for their energy needs, and second to decarbonise the heat source used. Our modelling shows that the most cost- and carbon effective way to achieve this in Gwynedd is through insulation retrofit (discussed here) and replacing gas boilers with heat pumps in most cases (discussed overleaf).

Focus zones for insulation retrofit

We used several factors (refer to Table 5.1.1) to compare each modelling zone's favourability for near-term insulation retrofits. Figure 5.1.6 illustrates the results; the highest-scoring zones are included in Figure 5.1.5 as priority focus areas.

For comparison, Figures 4.2.9 to 4.2.13 show the quantity of insulation retrofits required in the low demand scenarios.

For reference, the zones which are focus zones for heat pump installation (discussed further overleaf) are also highlighted in Figure 5.1.6. 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.

5. Action planning
Proposition 1: Transition to low carbon buildings

Focus zones for retrofit

Focus Zones D and E: Carmel and Rhoslan (around Porthmadog and Y Fron)

There are approximately 4,000 homes in these substation zones. The average energy performance of homes is very low in this area (80% are EPC D or below) and according to the WIMD (2019), the LSOAs covering Porthmadog – Tremadog and Llanberis have high percentage of fuel poverty (around 30% of households). 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.

It should be noted that there is a relatively high number of listed buildings, especially in and around the Porthmadog area which may mean retrofit is more challenging.

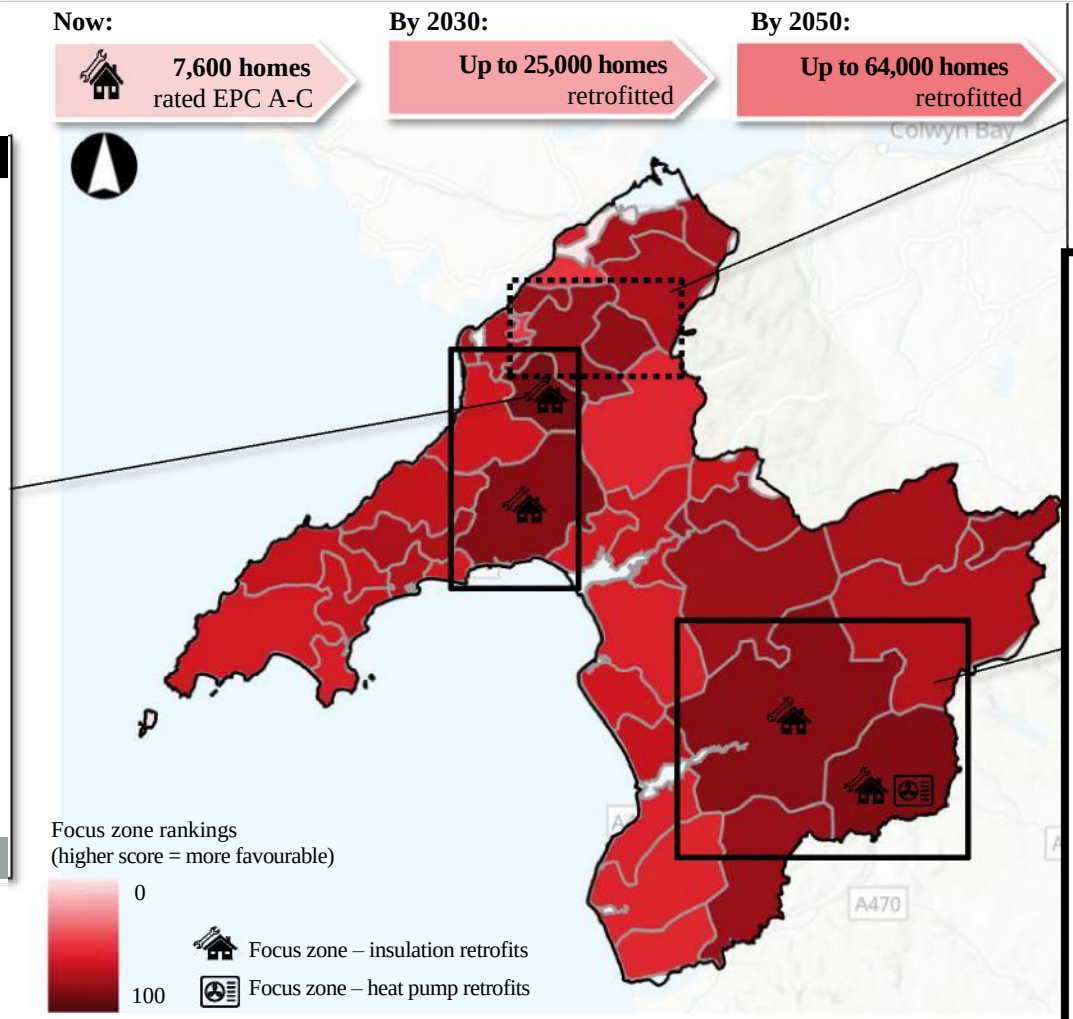


Figure 5.1.6: Focus zone rankings for domestic insulation retrofits in Gwynedd by modelling zone

Around Bethesda

- Although not identified as a focus zone, this is still identified as "progress" zones with favourable conditions for retrofit (high levels of multiple deprivation and proportion of homes with below average EPC ratings).

Focus Zones K and N: around Llanymawddwy and Brithdir

There are approximately 3,000 homes in these substation zones. The average energy performance of homes is very low in this area (75% are EPC D or below) compared to others, and there is a high number of homes that haven't yet received basic insulation measures such as floor insulation. Homes are largely suitable for this measure which presents an opportunity to co-ordinate an area- or street-based approach to installation in this area. The substations that service this area (especially around Brithdir – Machynlleth substation) have limited spare capacity to support an increase in energy demand, so retrofits here would reduce the load on the substation and would be needed before heat pumps could be installed. Around 15% of homes in Brithdir are social housing. The Council should actively engage with Registered Social Landlords including Adra, Grŵp Cynefin and North Wales Housing.

5. Action planning
Proposition 1: Transition to low carbon buildings

Focus zones for heat pump installation

Electrifying building heat (e.g. via heat pumps) could play a dominant role in decarbonising the buildings sector. Building characteristics, and the costs associated with grid upgrades will influence the specific locations for deploying electric heating technologies over others. We used several factors (see Chapter 3 for more detail) to compare each modelling zone's favourability for near-term heat pump retrofits. The highest-scoring zones are included in Figure 5.1.7 as priority focus areas.

For comparison, Figure 5.1.7 also shows the homes in Gwynedd currently not served by the gas network (around 50%). These homes could be low-regrets options for retrofits since they will be the most challenging to serve via a future hydrogen network.

5. Action planning

Proposition 1: Transition to low carbon buildings

Now: **700 buildings** with heat pumps installed

By 2030: **Up to 12,300 buildings** with heat pumps installed

By 2050: **Up to 70,000 buildings** with heat pumps installed

Focus Zone H and N: around Maentwrog and Brithdir

- Almost all homes are off-grid (98% around Trawsfynydd and 99% around Brithdir).
- The substation(s) that service these areas are less likely to require upgrades to meet future energy demand making new connections potentially easier and cheaper to obtain.
- There is only a relatively small proportion of social housing here which means a different approach to engage owner-occupiers and private rental market would be required.

In general, areas across Gwynedd where homes are currently not served by the gas network (around 50%) could be low-regret options for retrofits since they will be the most challenging to serve via a future hydrogen network. Therefore, these will most likely need to be converted to electrified heat sources (such as heat pumps)

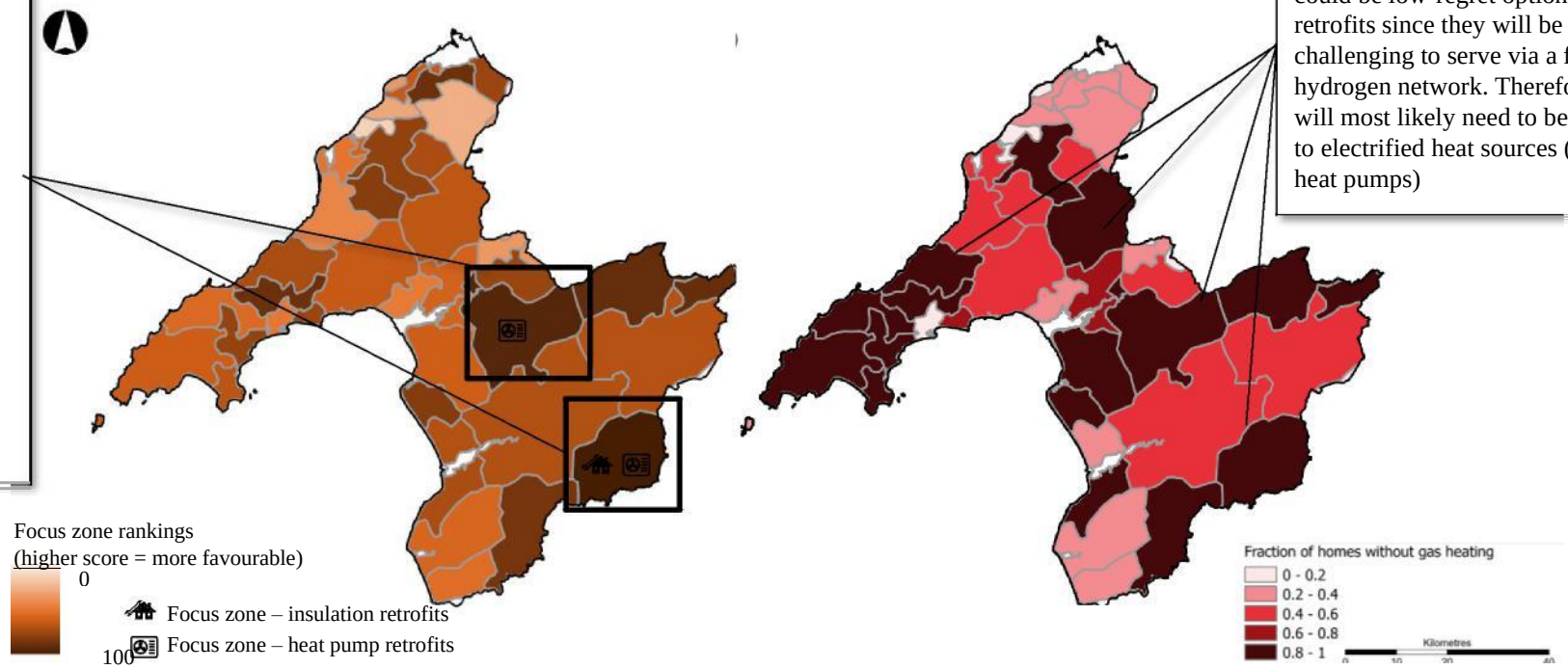


Figure 5.1.7: Focus zone rankings for heat pump installations across Gwynedd by modelling zone

5. Action planning
Proposition 1: Transition to low carbon buildings

Prioritisation of rooftop PV

Across all future energy scenarios, rooftop PV was another prominent technology which featured in Gwynedd'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 5.1.4 These highest-ranking focus zones are aligned with the priority areas identified in the plan of a page (Figure 5.1.5 on page 123).

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.

Now: **2,300 buildings** with rooftop solar PV[c]

By 2030: **Up to 11,400 buildings** with rooftop solar PV[c]

By 2050: **53,750 buildings** with rooftop solar PV[c]

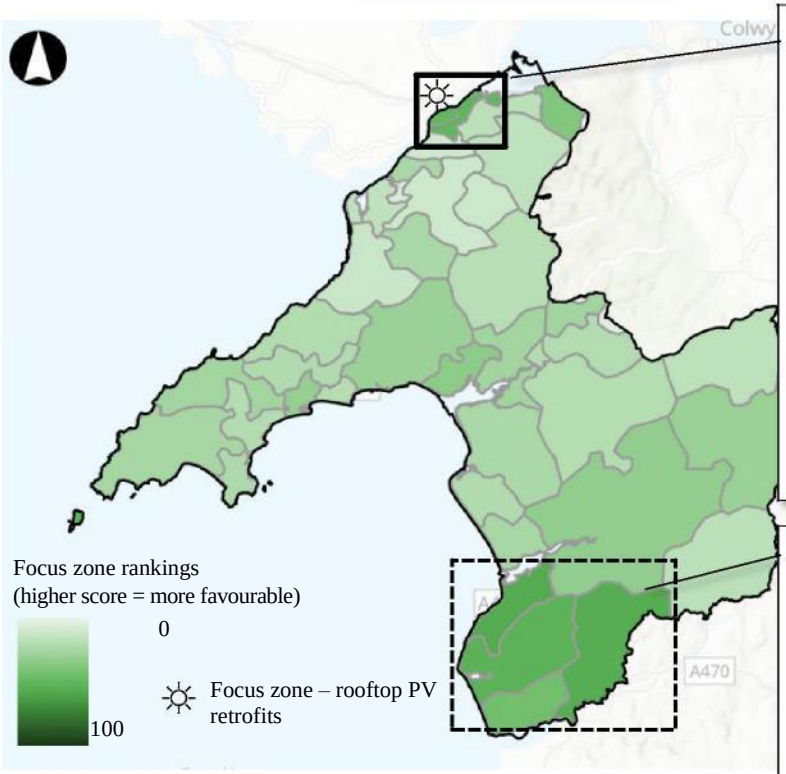


Figure 5.1.8: Focus zone rankings for rooftop solar PV in Gwynedd by modelling zone

Focus Zone A: Parc Menai
Our model projects rooftop PV installations across the Parc Menai zone (that serves Bangor) reaching 6 MW by 2050. This is predominantly due to the density of housing and larger amount of roof space identified in the area. The Parc Menai substation 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.

South of Gwynedd
Modelling zones also identified with the favourable conditions for rooftop solar PV are located in the south of Gwynedd, around towns and villages of Tywyn, Corris and Abergynolwyn where there is a higher density of housing than the rest of Eryri National Park and therefore potentially a greater capacity for rooftop solar PV installation.

5. Action planning
1. Transition to low carbon buildings

Investment requirements

The deployment model estimates the capital investment required for insulation retrofits and heat pumps.

Investment requirements for insulation retrofit

The upfront investment for insulation retrofit varies depending on the package of insulation measures appropriate for each archetype and the desired level of energy efficiency. In the High Demand scenario, the cost of retrofit can between £4,500 - £15,000 per household and £60,000 – £480,000 per commercial property. In the Low Demand scenario, the cost of retrofit is between £45,000 - £130,000 per household and £73,000 - £240,000 per commercial property.

Investment requirements for heat pumps and rooftop solar PV

The upfront cost for a heat pump and rooftop PV 4 kW system is estimated between £4,500[T42] and £4,400[T42] , 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. Similarly, the modelling does not assess the feasibility of installing rooftop PV systems, as it does not evaluate the structural integrity of rooftops, which could impact the ability to install such systems.

Funding Sources

There are different funding sources that could be explored to support delivery of these interventions:

- Social housing grants
- Interest-free loans for unoccupied housing
- 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
- The Great British Insulation Scheme (GBIS) is a government energy-efficiency initiative administered by Ofgem. Its primary goal is to enhance the energy efficiency of the least energy-efficient homes in Great Britain, thereby addressing fuel poverty and reducing carbon emissions. For owner-occupied housing – GBIS is limited, and uptake is low (throughout GB there were only 1,000 installations in November 2023).
- 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
- The Optimised Retrofit Programme (ORP) is a comprehensive approach to decarbonising existing homes. It considers factors such as building materials, energy sources, and infrastructure. Registered Social Landlords (RSLs) and local authorities can participate. ORP Phase 3 (2022-2025) focuses on affordable warmth and energy efficiency and aligns with the Welsh Housing Quality Standard 2023. The program aims to create a route to net zero for each home.

Energy system component(s)	Indicative (£millions) investment required high and low demand (range between scenarios)	
	2023-2030	2030-2050
Retrofit (domestic)	£100 - 1,700m	£150 - 2,400m
Retrofit (non-domestic)	£60 - 230m	£90 - 330m
Heat pumps	£25 - 37m	£130 -2 00m
Heat networks	£0.08 - 0.10m	£5.0 - 5.1m
Rooftop PV	£59m	£170m

Table 5.1.2: Investment costs for the transition to low carbon buildings to 2030 and 2050

5. Action planning
2. Decarbonise transport

Focus zones for public transport and EV chargepoints

The transport proposition for Gwynedd prioritises a reduction in car use as much as is possible through improved provision of active travel routes and public transport. Gwynedd is sparsely populated in most areas and rural in nature, which means that the private car is likely to play a role in the future of the local transport system, as is shown in our modelling. Therefore, the priority will also be to support the transition to electric vehicles through the provision of convenient, accessible chargepoint infrastructure, starting with opportunities on publicly-owned land.

Active travel and public transport

We used the transport hierarchy in our modelling which follows Welsh policy of 13% conversion to active travel. Most bus services are commercially operated in the County leaving limited influence for the Council to shape the service, such as setting fares and choosing vehicles. However, the Active Travel (Wales) Act 2013 places a duty on the Council to promote the use of active travel through means such as maintaining and expanding the active travel network and actively communicating information about the network.

The Council is currently developing a network of over a hundred charging points for electric vehicles across Gwynedd and work is in progress to install more charging points in locations in the areas of Aberdyfi, Barmouth, Bangor, Bethesda, Blaenau Ffestiniog, Caernarfon, Dolgellau, Harlech, Llanberis, Penygroes, Porthmadog, Pwllheli and Tywyn over the coming months.

5. Action planning
2. Decarbonise transport

Introduction

Predicted EV chargepoint deployment from Wales' EV Charging Strategy[T44] is that by 2030, there could be a total of 31,555 EV chargers in Gwynedd, of which:

- 115 are rapid
- 3,170 are fast
- 28,270 are slow chargers

Note that these numbers from Wales' EV Charging Strategy are likely to be amended imminently, reflecting a slower initial rate of deployment.

Our modelling indicates that by 2030, up to 5,700 chargers will need to be deployed to meet future transport demand (shown in Figure 5.1.9).

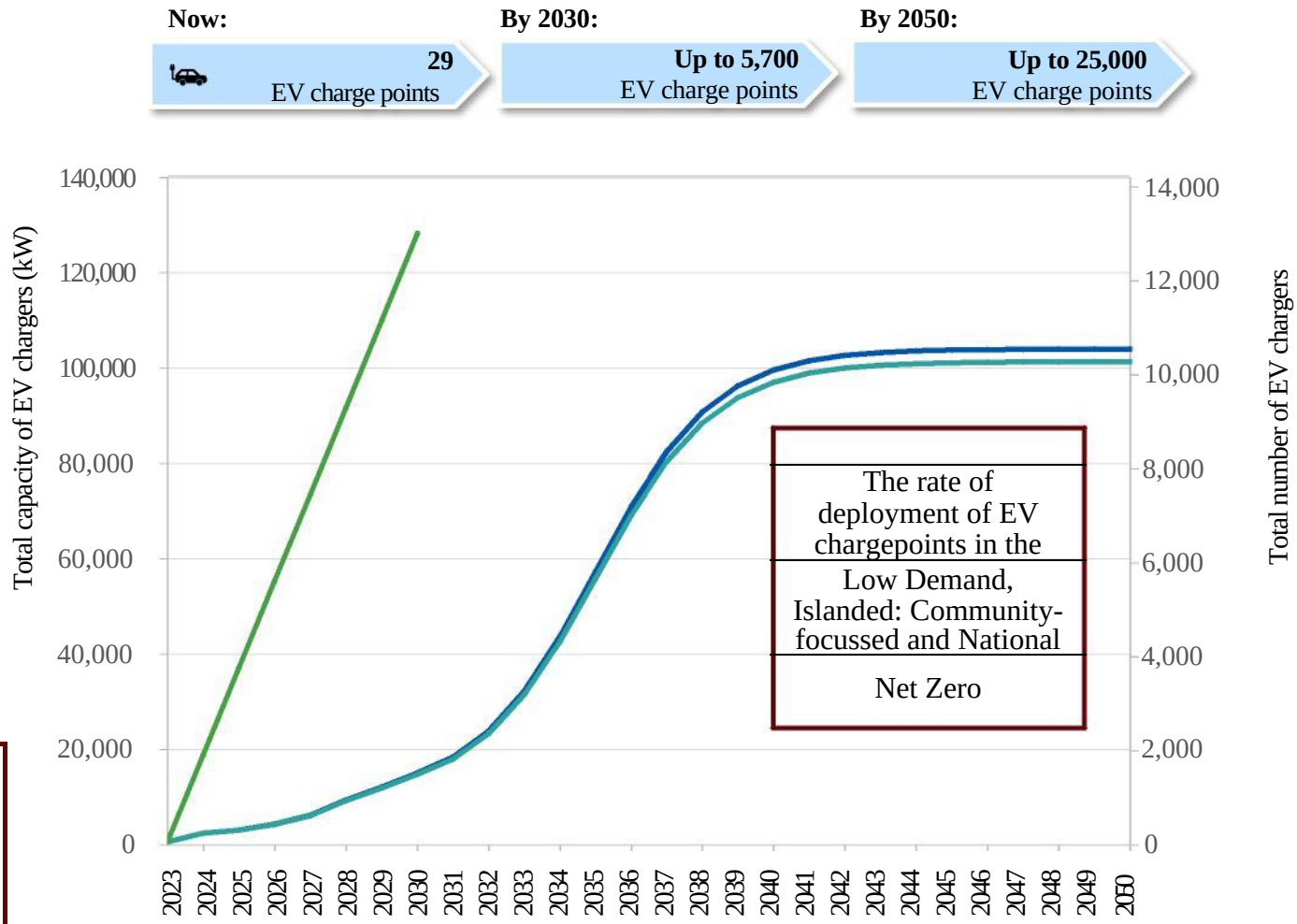


Figure 5.1.9: Capacity and EV chargepoint deployment over time

Key
- High Demand
- Low Demand
- Islanded: Community-focussed
- National Net Zero
- EV charging Strategy for Wales – requirements for chargers

5. Action planning
2. Decarbonise transport

Focus zones for public transport and 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 (see Chapter 3 for more detail) to compare each modelling zone's favourability for near-term installation of EV chargers. The highest-scoring zones are included in Figure 5.11 (overleaf) as priority focus areas.

Figure 5.1.11 shows one focus zone for EV chargepoints. These areas are the least likely to be able to afford an EV. Therefore, car clubs would also be suitable where affordability is low, this enables access and supports a modal shift.

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 will 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.

The maps shown in Figure 5.11 show focus zones and projected vehicle mileage to prioritise for public EV charging infrastructure.

Priority focus zones are identified by assessing electricity demand headroom (40% weighting), Welsh Index of Multiple Deprivation (30% weighting) and the deployment of EV charging capacity (30% weighting) from scenario analysis.

This shows strategic areas for the development of EV charging infrastructure.

Investment requirements

The investment required for EV chargers is about £100m by 2050. There are various UK government grants for renters, flat owners, houses with on-street parking, as well as workplace charging schemes.

Energy system component	Investment (£'millions) required, range between high and low demand scenarios	
	2023 - 2030	2030 - 2050
EV chargepoints	£12m	£70-72m

Table 5.1.3: Investment costs by energy system component

5. Action planning
2. Decarbonise transport

Focus zones for EV chargers

Development of EV charging infrastructure is a priority intervention area. Further analysis of off-street parking availability, transport patterns and locations of 'destinations' for destination public charging will be required to refine the strategic placement of EV chargers, particularly since a considerable proportion of residents do not have off-street parking.

The map in Figure 5.1.10 shows the projected vehicle miles in millions of miles by substation boundary.

Focus Zones B and C: Minffordd/Parc Bryn Cegin and Llanfairfechan
Substation zones around Bangor were identified as a priority focus zone for EV charging. The high population density and high projected vehicle mileage in 2050 in this area points to higher car dependency and/or the number of visitors to the area, which make conditions more favourable for EV charge points. However, it's likely that a lot of homes have limited off-street parking which means other options for providing charging facilities would need to be explored.

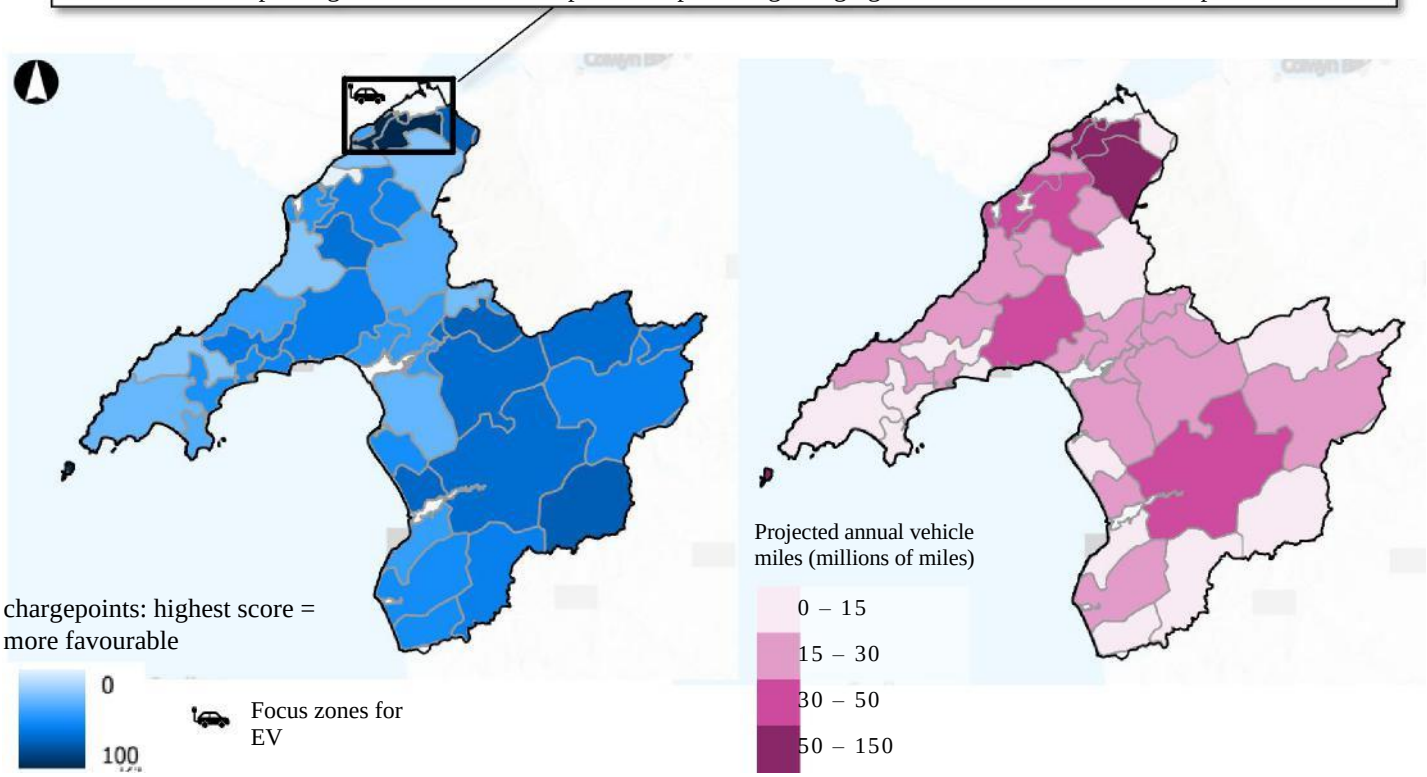


Figure 5.1.10: (Left) Priority focus zones for EV chargepoints by modelling zone and (right) projected vehicle miles (millions of miles) in 2050 by modelling zone across Gwynedd

5. Action planning
Proposition 3. Deployment of renewable energy generation

Onshore renewables

In the initial stages of the modelling process, the 'Scoping Renewable Energy Opportunities in Gwynedd' 2015 report was used to identify land suitable for onshore wind and ground-mounted photovoltaic (PV). As this report is now almost 10 years old, the modelling took a maximum theoretical amount of wind and solar energy from a Wales-wide study[T47]. We also accounted for the protection of good quality agricultural land (grades 1,2 and 3) and environmental (including the Eryri National Park) and historic designations (See Chapter 4) in the modelling process. For onshore wind, hub heights of 80m and outputs of 2MW were considered.

Figure 5.1.11 shows the locations of land that could be suitable for onshore wind (highlighted in green), ground-mounted solar PV (highlighted in orange) and areas suitable for both (highlighted in blue). The modelling indicates that up to 12 MW of onshore wind energy and 510 MW of ground mounted solar PV could be developed in the highlighted areas. For context, the most ambitious National Grid Future Energy Scenarios (FES) scenarios assume there could be another 77.2GW of solar and 30.8GW of onshore wind across the UK.

The areas identified for ground-mounted solar PV and onshore wind will need further investigation beyond the scope of this report, since there are many other factors to consider when assessing suitability and feasibility of renewable projects e.g. competition for other land uses, cumulative landscape impact, grid constraints and local policy considerations.

Figure 5.1.11 also shows available grid capacity in each modelling zone. Suitable locations where there is also spare capacity should be prioritised in the short-term, and this prioritisation is discussed further overleaf. Where there is little or no capacity in the grid for renewables, see the energy networks proposition (4. Reinforce and transition the energy networks) which goes into more details about the networks' plans for creating future-ready distribution networks. In constrained areas, opportunities to reduce peak demands through storage, and other flexibility options also become important, which are discussed in other propositions.

It will be for Gwynedd to decide what a realistic contribution to Wales' targets will be, so that it maximises local benefits and doesn't compromise other development priorities

Gwynedd's renewable energy opportunities report is now out of date and consideration should be given to updating it to inform the update of the Local Development Plan.

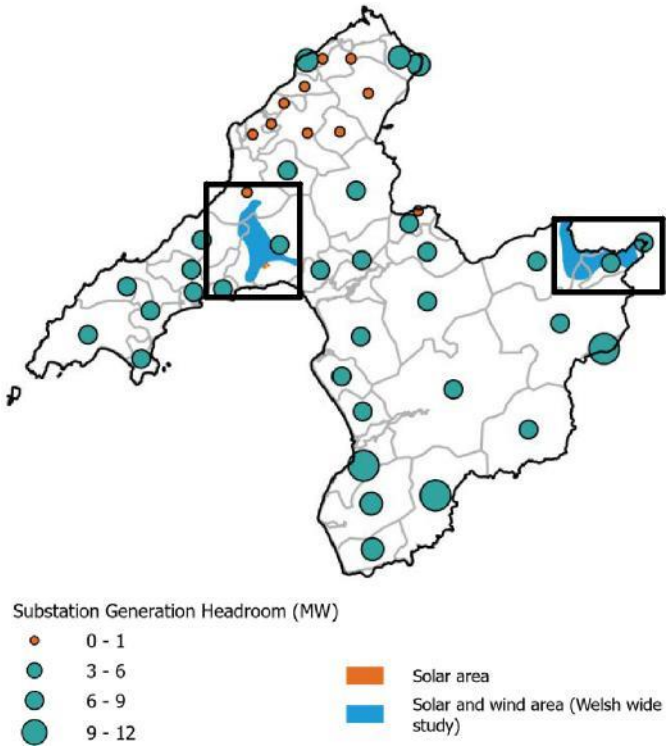


Figure 5.1.11: Areas suitable for wind and ground-mounted solar PV development in Gwynedd and substation generation headroom (MW)

5. Action planning
Proposition 3. Deployment of renewable energy generation

Focus zones for local electricity generation

We used several factors to compare each modelling zone's favourability for near-term installation of ground-mounted solar PV and onshore wind. Figure 5.1.12 illustrate the results; the focus zones with the highest rankings for favourability are included. Ground-mounted solar PV is focused on areas to the east of Gwynedd and north west of Eryri National Park (the highlighted areas in Figure 5.1.15). Due to the number of environmental and historic designations and additional constraints provided to the model, only a small amount of onshore wind was identified (8 MW) which is equivalent to 0.04% of the land area in Gwynedd.

Onshore wind and ground-mounted solar should still be considered in the other four zones not discussed below, especially since individual wind and solar projects may cross zone boundaries.

Note: Where substation capacity is limited, alternative delivery models could be explored. For instance, if a generator utilised a private wire connection, it would bypass the need for additional substation capacity, thereby eliminating headroom constraints.

Focus Zones E, G, I and J: Rhoslan, Tryweryn, Glan-Yr-Afon and Bala: In all focus zones there is suitable land identified for ground-mounted solar which means that the theoretical capacity for solar generation is greater in these areas. Zone I (around Glan-Yr-Afon) has the greatest amount of land suitable for onshore wind and more spare capacity compared to other areas in Gwynedd, which means less grid intervention may be required to accept new renewable generation connections here.

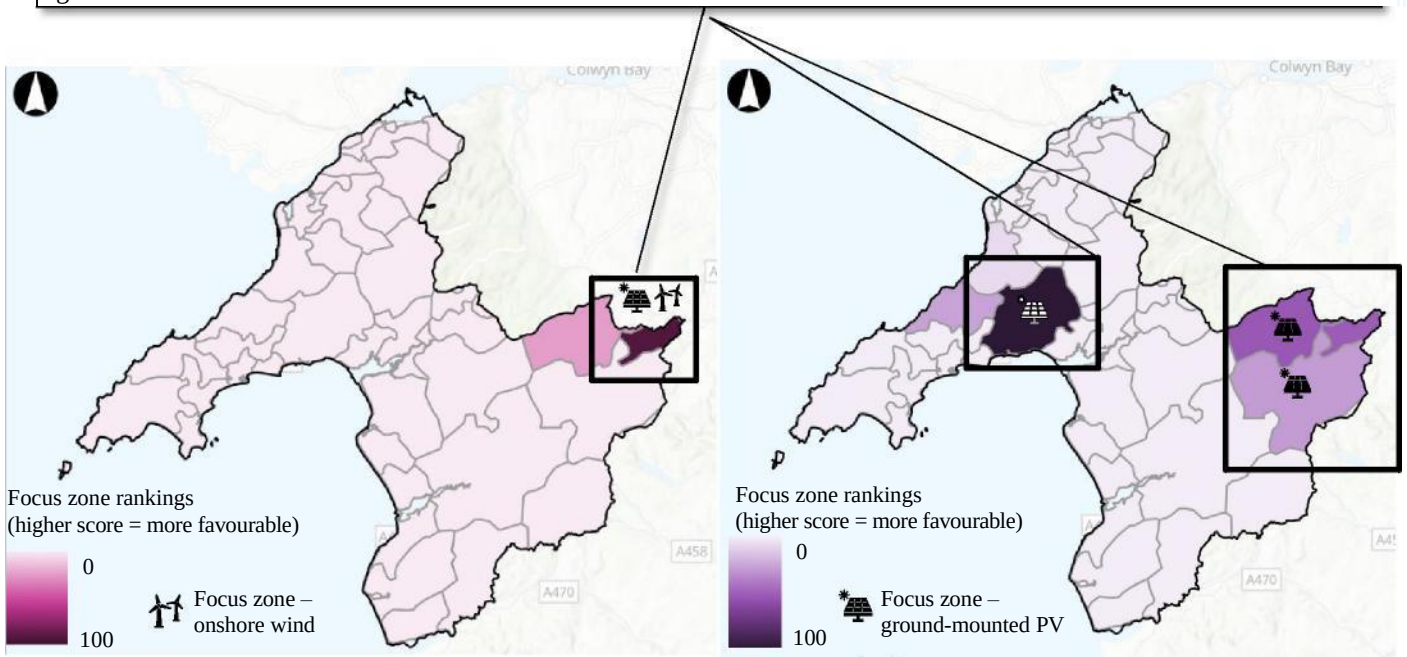


Figure 5.1.12: (left) Focus zone rankings for ground-mounted solar PV by modelling zone (right) focus zone rankings for ground-mounted solar PV by substation zone

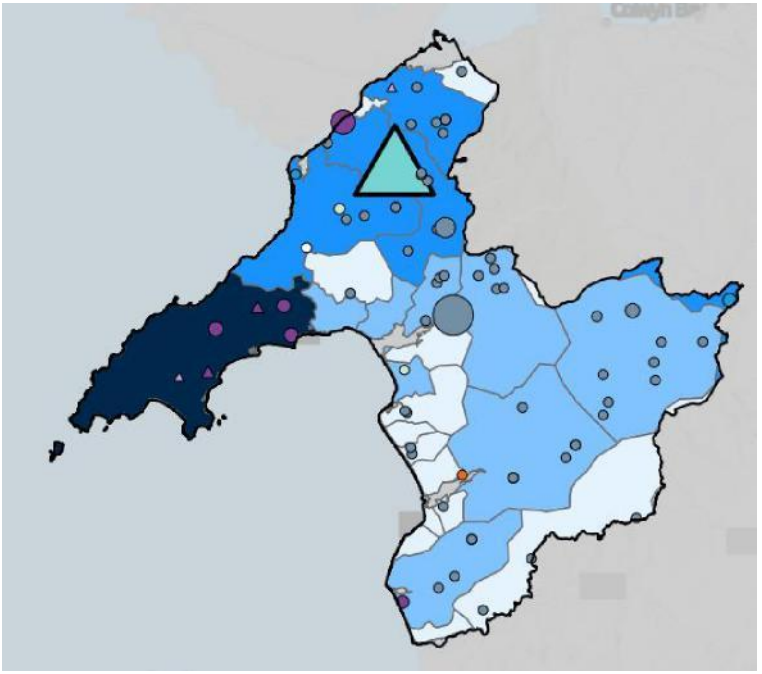
5. Action planning
Proposition 3. Deployment of renewable energy generation

Onshore renewables

Figure 5.1.13 shows all electricity generation projects in the baseline and the pipeline across Gwynedd.

Investment requirements

The deployment model estimates the capital investment required for ground-mounted solar and onshore wind. These are shown in Table 5.1.4.



Energy system component	Investment (£'millions) required, range between high and low demand scenarios	
	2023 - 2030	2030 - 2050
Ground-mounted solar PV	£52	£150
Onshore wind	~£0	£8.3

Table 5.1.4: Investment costs by energy system component

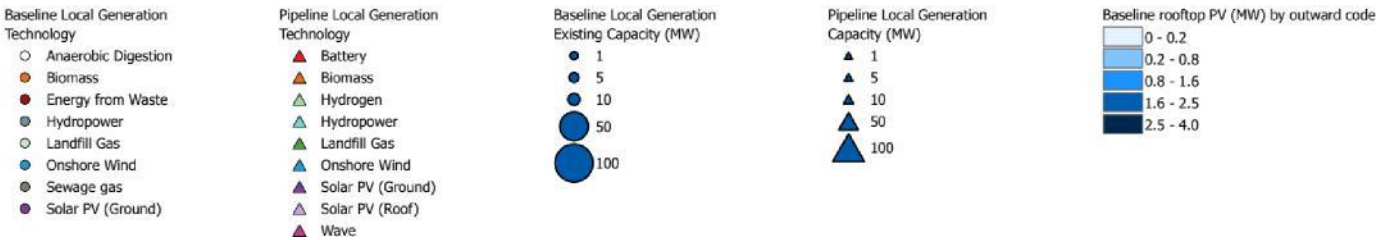


Figure 5.1.13: (from left to right) Electricity generation projects in the baseline and pipeline and baseline rooftop solar PV by outward code, investment requirements for priority focus zones for onshore wind and ground-mounted solar PV

5. Action planning
Proposition 3. Deployment of renewable energy generation

Introduction

Figure 5.1.15 shows the range of possible deployment of ground-mounted solar and onshore wind across the scenarios in Gwynedd, accounting for projects that are in the pipeline (see previous page) and national targets. The figure shows the minimum and maximum deployment rates across scenarios. In Gwynedd, the rate of installation is almost the same across all scenarios.

Now:

29.8 MW ground solar PV capacity

4.4 MW onshore wind capacity

By 2030:

Up to 150 MW ground solar PV capacity

Up to 4.5 MW onshore wind capacity

By 2050:

Up to 495 MW ground solar PV capacity

Up to 12 MW onshore wind capacity

Figure 5.1.14: Maximum deployment rates for ground-mounted solar PV and onshore wind in 2023, 2030 and 2050

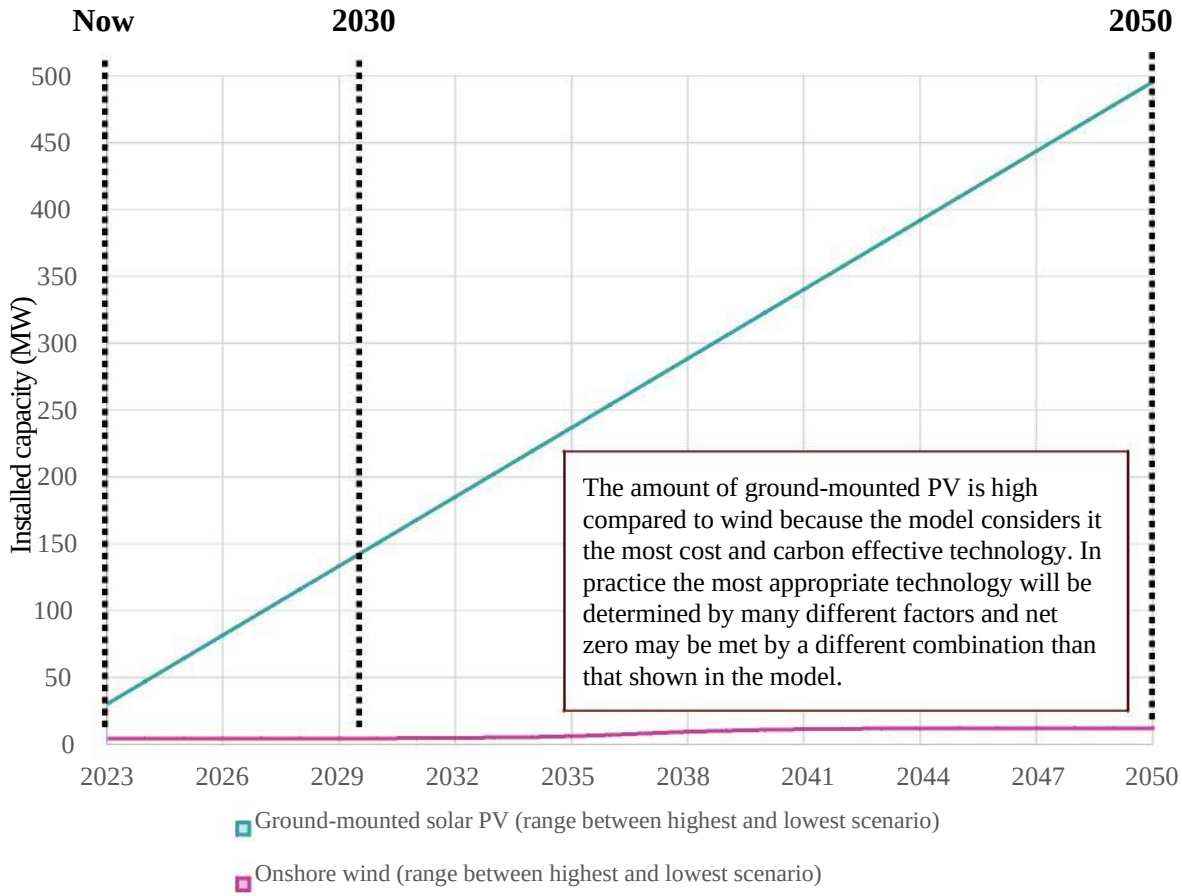


Figure 5.1.15: Summary of scale of renewables deployment across scenarios

5. Action planning

Proposition 4. Reinforce and transition the energy networks: electricity and gas networks

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. SPEN (electricity distribution network operator in North Wales, 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. Both networks undertaken annual planning through the process called DFES (Distribution Future Energy Scenarios), shown in Figure 5.1.16. DFES contains the underlying modelling that supports their business planning, which typically considers data for electricity and gas separately and doesn't link the changes in one system to the other, and as we know there are many interdependencies in the energy system. 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 is that the costs and timeframes of getting grid connections for renewable schemes and new development can make projects unviable.

As of 2023, the gas network provides natural gas to 50% of homes in Gwynedd. 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 5.1.16: SPEN's annual DFES process (credit: SPEN)

5. Action planning
Proposition 4. Reinforce and transition the energy networks: electricity and gas networks

Network transition planning

Gas distribution network

The gas network provided natural gas to 75% of homes in 2023.

£1.4 million is invested in the iron mains replacement programme every week, which will make the current gas network hydrogen-ready. 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.

Investment

The price control periods set out the allowances needed to complete the required mains replacement for that period, for GD2 due to end in 2026 this was already awarded. WWU are currently preparing our GD3 business plan which will set out the requirements needed to deliver the programme for the next price control period.

Most funding provided is through innovation funding. Ofgem provide WWU with Network Innovation Allowance funding (NIA) for innovative projects on our whole network. WWU looks for opportunities to deliver innovation that benefit the entire network and all local authorities within it, but also welcome any opportunities to collaborate with a specific local authority if there are relevant projects in their area.

There is additional funding available from Ofgem via re-openers (described earlier) which allow access to funding based on specific criteria.

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.

North Wales Conceptual Plan – Assess capability of existing infrastructure in North Wales for transporting hydrogen from Hynet Phase 3.

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

Cartrefi Hydrogen Homes – Demonstrate low-carbon heating alongside fabric retrofit, using different technologies.

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

5. Action planning
Proposition 4. Reinforce and transition the energy networks: electricity and gas networks

Network transition planning

The future position

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. The map in Figure 5.1.17 shows areas where substation upgrades are needed if the rest of LAEP is carried out.

The substation upgrade areas, are those that should be prioritised for investment from the electricity network, considered for hydrogen or "considered" as part of a smart local energy system (SLES).

Electricity networks

To undertake the level of change shown in Figure 5.1.17, which will be required if the uptake in EVs, renewables, heat pumps and electrolysis meets the modelled amounts, the number of substations that will need upgrading is 32 out of 44. This equates to a total of 200MW capacity.

Additional upgrades to the network may be required following comprehensive contingency analysis.

In the high demand scenario (worst case), the total cost of upgrades is £33m to 2050, which amounts to approximately £510 per home.

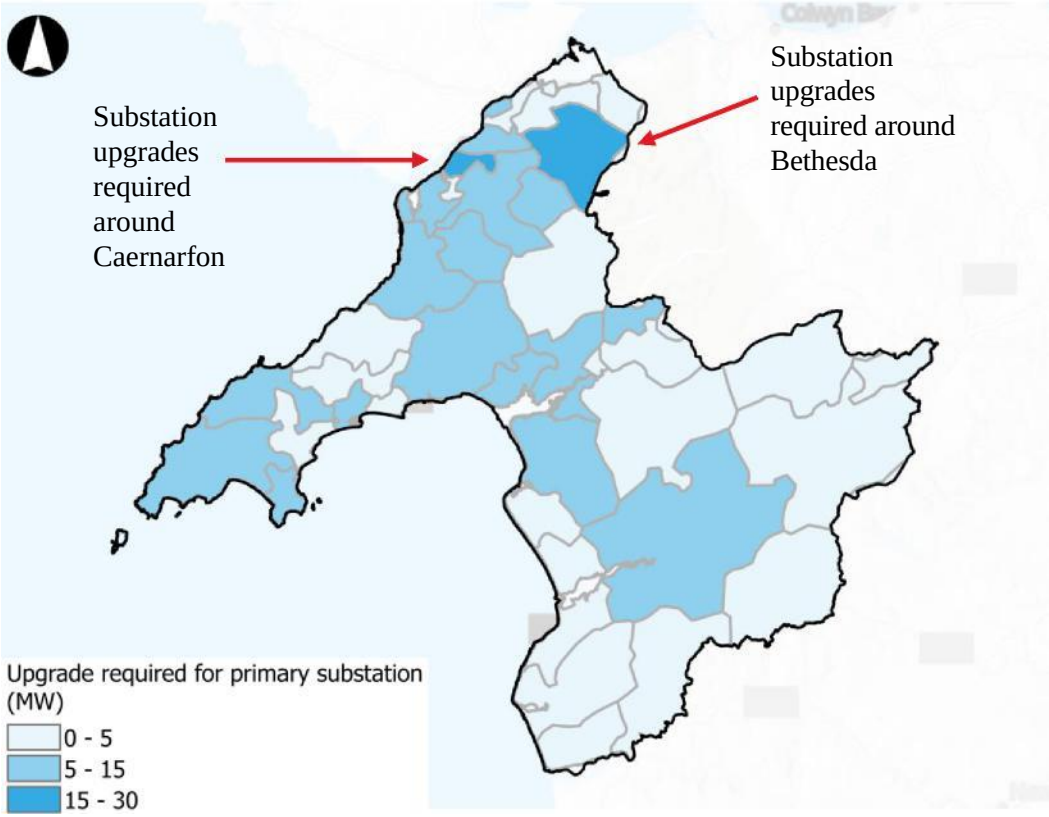


Figure 5.1.17: Map showing where substation interventions will be required by 2050 if the rest of the plan is followed (High Demand scenario)

5. Action planning

Proposition 4. Reinforce and transition the energy networks: electricity and gas networks

Network transition planning

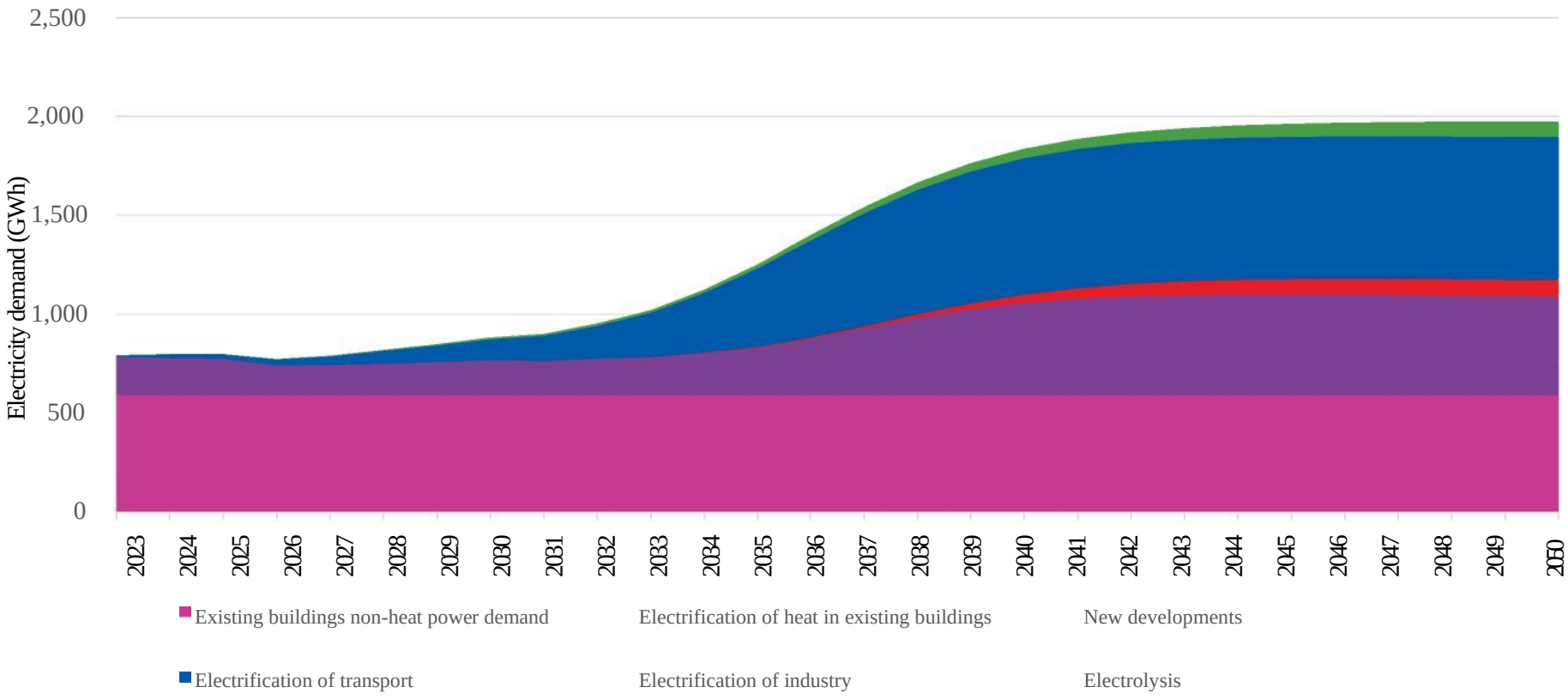


Figure 5.1.18: Projected power demand increase over time

5. Action planning

Proposition 4. Reinforce and transition the energy networks: electricity and gas networks

Network transitions

Hydrogen networks

There is more uncertainty around the changes needed to 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 100% 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. We know that the deployment levels required for heat pumps will be difficult to achieve and therefore need to keep alternative options open. 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 Gwynedd this is 77% complete.

Our modelling has shown a no demand for hydrogen in the future for industry, but a demand of 200GWh/year for transportation.

To test the sensitivity of hydrogen (see Chapter 4: The future energy system for sensitivity modelling outputs), we undertook some optimisation model runs incorporating 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 (see Chapter 4: The future energy system for an explanation of how our HeatNet tool operates). 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 have excluded this from the short-term road map and propositions, unless the local authority is already underway with pilot projects.

The model shows the hydrogen required for transportation is produced via electrolysis and imports. The capacity of electrolysers required in Gwynedd is 13-25MW. This is a small fraction (0.13-0.25%) of the UK 10GW[T51] target. 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.

The investment needed to meet the modelled scenarios for hydrogen in Gwynedd is £0.8-2 million until 2030, and £36-65 million until 2050.

Storage

Short term and seasonal storage also needs consideration. While our modelling does not show a lot of electrical storage, most 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. 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.

An approximate cost that would be available for national asset level production of electricity and storage would need to be commensurate to the OPEX costs for electricity imports in the model. Our model uses wholesale electricity costs; based on a cost of 6.3p/kWh for the 1040GWh/year of electricity imported in the high demand scenario, this equates to £66million/year.

5. Action planning
Proposition 4. Reinforce and transition the energy networks: electricity and gas 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 across all the LAEPs that we have developed. 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 and demand, the annual electricity use could be decreased

Areas to focus on would be those that need substation interventions (see Figure 5.1.18), liaising with the networks on the order of planned upgrade to the network will enable the local authority to prioritise where pilot programmes and roll-out of SLES would be most appropriate.

Investment in SLES can reduce the cost of upgrades needed in the electricity network. We haven't included specific costs for SLES because they should be undertaken in circumstances where it will reduce the cost to the electricity network and expediate the time that it takes to get a grid connection. Applying SLES 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.

Appendices

Section A

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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 Government – Decarbonising Transport – A Better, Greener Britain. Available at: https://www.gov.uk/government/publications/transport-decarbonisation-plan
No new gas boilers from 2035	UK Government – Net Zero Strategy: Build Back Greener. Available at: https://www.gov.uk/government/publications/net-zero-strategy
Phase out unabated coal by 2024	
UK Government committed to deploying CCUS at scale in 2030s	
UK Government 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 Government 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 Government – Energy efficiency: what you need to know. Available at: https://www.gov.uk/government/news/energy-efficiency-what-you-need-to-know

Appendix A1

Deployment modelling – National, regional and local policies applied

National (UK or Wales) proposed and committed policies	Source
Private rented homes EPC C by 2030, and EPC B for commercial units	UK Government – 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 Government – 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 Government Developments of national significance (DNS). Available at: https://www.gov.wales/developments-national-significance-dns-guidance
Welsh Government requirement to explore heat networks within Future Wales	Heat strategy for Wales. Available at: https://www.gov.wales/heat-strategy-wales

Appendix A1

Deployment modelling – National, regional and local policies applied

Local proposed and committed policies	Source
Hectares of new sites allocated: 55.1ha	Anglesey and Gwynedd Joint Local Development Plan March 2022/
642.9 hectares of existing employment land will be safeguarded	Anglesey and Gwynedd Joint Local Development Plan March 2022
Housing target for the Plan area is 7,184 units, taking into account vacancy rates.	Anglesey and Gwynedd Joint Local Development Plan March 2022
Land supply of 7,902 units	Anglesey and Gwynedd Joint Local Development Plan March 2022
53% of housing land is directed to Bangor and Urban Service Centres	Anglesey and Gwynedd Joint Local Development Plan March 2022
Projected electricity demand (2026): 937GWh	Anglesey and Gwynedd Joint Local Development Plan March 2022
Total potential for renewable energy delivered by 2026 (GWh) : 2,247GWh	Anglesey and Gwynedd Joint Local Development Plan March 2022
Projected gas demand 2026 (GWh): 647GWh	Anglesey and Gwynedd Joint Local Development Plan March 2022
55.1ha allocation of land for employment and business purposes	Anglesey and Gwynedd Joint Local Development Plan March 2022
New affordable homes for sale or letting to Gwynedd residents: 500	Anglesey and Gwynedd Joint Local Development Plan March 2022
Construction of 100 new affordable homes	Anglesey and Gwynedd Joint Local Development Plan March 2022
Construction of 280 new units for homeless and vulnerable people	Anglesey and Gwynedd Joint Local Development Plan March 2022
Projected population by 2036: 130,219	Anglesey and Gwynedd Joint Local Development Plan March 2022
Population increase from 2021-2036: 4	Anglesey and Gwynedd Joint Local Development Plan March 2022
Projected households by 2036: 58,340	Anglesey and Gwynedd Joint Local Development Plan March 2022
Affordable houses built during the planning period: 476	Anglesey and Gwynedd Joint Local Development Plan March 2022
Projection for installating renewable electricity capacity during planning period: 1,113GWh	Anglesey and Gwynedd Joint Local Development Plan March 2022
Projection for installating renewable heat capacity during planning period: 24GWh	Anglesey and Gwynedd Joint Local Development Plan March 2022
Capcity of Ryhd Y Groes Rhosgoch solar farm site: 50MW	Anglesey and Gwynedd Joint Local Development Plan March 2022
Growth level of 7,184 residential units between 2011-2026	Anglesey and Gwynedd Joint Local Development Plan March 2022

Appendix A1

Deployment modelling – National, regional and local policies applied

Local proposed and committed policies	Source
275 new residential units were granted permission in 2020/21	Annual Monitoring Report 2020-2021
2020-2021- 92 units designated as affordable housing	Annual Monitoring Report 2020-2021
360 homes were completed during the monitoring period,	Annual Monitoring Report 2020-2021
In 2020-21, 104 affordable housing units were completed, accounting for 29% of the total completions for the year.	Annual Monitoring Report 2020-2021
A total of 3,924 units were completed in the Plan area between 2011 and 2020/21, which is 12.3% lower than the trajectory projection of 4475 units.	Annual Monitoring Report 2020-2021
The average density of new housing permissions in the Plan area during the AMR period was 25.8 units per hectare.	Annual Monitoring Report 2020-2021
Three affordable housing exception sites were permitted during the AMR period, totaling 10 units.	Annual Monitoring Report 2020-2021
Planning permissions were granted for renewable schemes with the potential to contribute a total of 3.9MW within the JLDP area.	Annual Monitoring Report 2020-2021
The renewable energy target of achieving 50% of the potential capacity by 2021 was not met, with only 52.4 GWh for electricity and no GWh for heat achieved up to that year.	Annual Monitoring Report 2020-2021
Number of buildings scheduled for retrofit under REFIT IOA Phase 2: 36	REFIT IOA- IGP Phase 2
Number of buildings scheduled for retrofit under REFIT IOA Phase 1: 15	Larkfleet IGP- REFIT IOA Primary Schools Phase 1
Number of buildings scheduled for retrofit under REFIT IOA Phase 1: 2	Larkfleet IGP- REFIT IOA Corporate Sites Phase 1
Number of buildings scheduled for retrofit under REFIT IOA Phase 1: 4	Larkfleet IGP- REFIT IOA Leisure Facilities Phase 1
Number of buildings scheduled for retrofit under REFIT IOA Phase 1: 3	Larkfleet IGP- REFIT IOA Residential Phase 1
Number of buildings scheduled for retrofit under REFIT IOA Phase 1: 4	Larkfleet IGP- REFIT IOA Seondary Schools Phase 1
Gwynedd council fleet size: 543	Green Fleet Plan 2023-2029 (Gwynedd)

Appendix A1

Deployment modelling – National, regional and local policies applied

Local proposed and committed policies	Source
Planned reductions in emissions from 2015-2021: 30%	Carbon Management Plan 2015 (Gwynedd)
Gwynedd council energy consmption (2013/2014): 77,600MWh	Carbon Management Plan 2015 (Gwynedd)
Carbon footprint of Gwynedd Council's building portfolio : 9,207tCO_2e	Decarbonisation Oppurunity Screening Report (Gynedd)
% Energy spend on electricity for council building portfolio: 63%	Decarbonisation Oppurunity Screening Report (Gynedd)
Potential capacity (Mwe) [Electricity]: 310.8MWe	Gwynedd Renewable Energy Capacity Study
Potential generation (GWh) [Electricity]: 623.8GWh	Gwynedd Renewable Energy Capacity Study
Potential Capacity (MWt) [Heat]: 355.5MWt	Gwynedd Renewable Energy Capacity Study
Potential Generation (GWh) [Heat]: 192GWh	Gwynedd Renewable Energy Capacity Study
Gwynedd population (2011 census): 121,900	Gwynedd Renewable Energy Capacity Study
Planned EV charging locations in Gwynedd: 114	Lleoliadau EV chargers locations (Gwynedd)

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	The Cardiff Capital Region, that covers the 10 local authority areas covering South East Wales -Blaenau Gwent; Bridgend; Caerphilly; Cardiff; Merthyr Tydfil; Monmouthshire; Newport; Rhondda Cynon Taf; Torfaen; and 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 anything that can have a direct impact on energy demand and/or the way energy is supplied. E.g. installing retrofit measures can reduce overall heating demand, increasing solar PV capacity can change the supply mix and the way that the energy system operates.
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.
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.

Appendix A2
Glossary of terms

Term	Definition or meaning
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’ (Kooiman, 2003) which the state has at its disposal to direct, manage and shape change in public services.
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.

Appendix A2
Glossary of terms

Term	Definition or meaning
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 used in the reports referring to the electricity network serving Wales, including both the transmission and distribution networks and facilitating the flow of electricity between neighbouring areas or regions. *May also be called generically "grid" in the reports.*
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 RCT.

Appendix A2
Glossary of terms

Term	Definition or meaning
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 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).

Appendix A2
Glossary of terms

Term	Definition or meaning
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 .
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.
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 .
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.

Appendix A2
Glossary of terms

Term	Definition or meaning
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.
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).
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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Appendix A5
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

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Section B

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Appendix B1
Emissions sources in scope

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

Appendix B1
Emissions sources in scope

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

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	Notes
Biomass	0.0119	kgCO2e/kWh	DESNZ, 2023 (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 (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	FES 23 (average

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

Appendix B3
Buildings – non-domestic archetypes

Archetype	Description	Age	Wall	Roof	Floor	Window	Heat demand (kWh/m^2)	Electricity demand (kWh/m^2)	Cooling demand (kWh/m^2)
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

Appendix B3
Buildings – non-domestic archetypes

Archetype	Description	Age	Wall	Roof	Floor	Window	Heat demand (kWh/m^2)	Electricity demand (kWh/m^2)	Cooling demand (kWh/m^2)
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 hear demand (kWh/m²)	Cost £
12	73.8									■						■				66.5	£1,517 +£82/m²
13	95.8										■	■				■				94.8	£1,250 +£0/m²
14	120.9										■							■		118.5	£11,250 +£0/m²
15	72.4										■							■		70.9	£26,000 +£0/m²
16	127.7				■							■			■					110.0	£27,295 +£32/m²
17	107.3					■									■		■			88.5	£49,620 +£45/m²
18	141.0	■												■		■				132.7	£5,120 +£10/m²
19	113.3								■									■		108.4	£11,250 +£22/m²
20	177.8											■		■		■				173.7	£5,120 +£0/m²
21	162.6						■								■			■		157.8	£83,076 +£69/m²

22-27 not modelled, Industry modelled separately

Sponsors: *Delivery partners:*

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 (de-centralised)	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 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 Flintshire: 1.09 Isle of Anglesey: 1.08 Gwynedd: 1.02 Wrexham: 1.01 Denbighshire: 1.00

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
Gwynedd	No
Cardiff	Yes
Merthyr Tydfil	Yes
Monmouthshire	No
Torfaen	No
Rhondda Cynon Taf	No
Vale of Glamorgan	No
Gwynedd	Yes
Flintshire	Yes
Isle of Anglesey	Yes
Gwynedd	Yes
Wrexham	Yes

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 building heat	Assumed to be higher than 10% heat network figure due to less thermal storage at building level
Ambient air temperature	5	^{o}C	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Elec boiler efficiency	100	%	Taken from calliope inputs
ASHP carnot cycle efficiency	50	%	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Electricity unit cost	0.13 0 4	£/kWhe	HMT Green Book central commercial/public sector price
ASHP source ΔT	10	^{o}C	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	^{o}C	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Building supply temperature	65	^{o}C	Typical building supply temperature – inputs give equivalent COP to calliope

Appendix B6

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

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	^{o}C	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	^{o}C	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	^{o}C	Typical technology assumption– same as counterfactual	Heat network supply temperature	65	^{o}C	Consistency in supply temperature

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*	^{o}C	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	^{o}C	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	^{o}C	Typical technology assumption	Ancillary electricity usage (e.g., for pumps)	3	% of EC annual heat	Used in Arup HNDU feasibility studies

Appendix B6
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	^{o}C	LSBU waste heat research
Heat capture ΔT	5	^{o}C	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

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: 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	$_{o}$C	LSBU waste heat research
Heat capture ΔT	5	$_{o}$C	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

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: 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	^{o}C	LSBU waste heat research
Heat capture ΔT	5	^{o}C	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

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: 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	$_{o}$C	LSBU waste heat research
Heat capture ΔT	5	$_{o}$C	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

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: 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	^{o}C	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: 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	^{o}C	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 – 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	$_{o}$C	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	^{o}C	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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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). Available at: 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). Available at: 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). Available at: 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). Available at: 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. Available at: 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 93% (BEIS hydrogen production costs) multiplied by the carbon emissions per kWh of hydrogen produced.
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)	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	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 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

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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	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.

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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 c ost	0	kgCO2e / kWh	n/a	Hydrogen for export only produced via electrolysis so assumed zero emissions .

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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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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: prospects 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	Setting	Value	Units	Reference	Notes
Biogas CUP	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 CUP	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: 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	Settin	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 efficiency to electricity	Energy	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/	
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.

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Technology parameters for future energy system scenario modelling

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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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	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) Saving Energy with Electric Resistance Heating. Available at: https://www.nrel.gov/docs/legosti/fy97/6987.pdf	All incoming electricicty 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	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)	£/kW	Energy CAPEX		NGED charging statements - CDCM model for South Wales 625.54 (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	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. NREL/TP-6A40-85332. Available at: 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	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). Available at: 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
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	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	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).	

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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:

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

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

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

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	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
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	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

Appendix B8
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.