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Denbighshire County Council

Local Area Energy Plan (LAEP) Technical Report

Denbighshire

August 2024

This Local Area Energy Plan was prepared by Arup, The Carbon Trust and Afallen on behalf of Denbighshire County Council 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.

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Abbreviations

Acronym	Definition or meaning
ANW	Ambition North Wales.
AONB	Area of Outstanding Natural Beauty.
BEIS	Business, Energy and Industrial Strategy.
CAPEX	Capital Expenditure.
CCGT	Combined Cycle Gas Turbine.
CCR	Cardiff Capital Region
DESNZ	Department for Energy Security and Net Zero.
DFES	Distribution Future Energy Scenarios.
DNO	Distribution Network Operator.
ECOFLEX	Flexible Eligibility Energy Company Obligation.
ECR	Embedded Capacity Register.
EfW	Energy from Waste.
EGW	Energy Generation in Wales.
EPC	Energy performance certificate.
ESC	Energy Systems Catapult.

Acronym	Definition or meaning
EV	Electric Vehicle.
EVCI	Electric Vehicle Charging Infrastructure.
FES	Future Energy Scenarios.
GDN	Gas Distribution Network.
GHG	Greenhouse Gas.
HGV	Heavy Goods Vehicles.
HVO	Hydrotreated Vegetable Oil.
LAEP	Local area energy planning or Local area energy plan.
LDP	Local Development Plan.
LGV	Light Goods Vehicles.
LPG	Liquid Petroleum Gas.
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.
MSOA	Middle super output area, a medium-sized area classification in the UK designed to have a comparable population.

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.
PEDW	Planning and Environment Decisions Wales.
PSB	Public Services Board.
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.

Acronym	Definition or meaning
RIIO-ED2	See above. The current price control period for electricity distributors (ED) that runs from 2023-2028.
RIIO-GD3	See above. The next price control period for gas distributors (GD) that runs from 2026-2031.
RLCEA	Renewable and Low Carbon Energy Assessment.
RSP	Regional Skills Partnership.
RTP	Regional Transport Plan.
SAP	Standard Assessment Procedure.
SDP	Strategic Development Plan.
SLES	Smart Local Energy System.
SMR	Steam Methane Reformation.
SPEN	SP Energy Networks.
TEC	Transmission Embedded Capacity.
TfW	Transport for Wales.
WHQS	Welsh Housing Quality Standards.
WIMD	Welsh Index of Multiple Deprivation.
WWU	Wales and West Utilities.

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Navigating this Report

Navigating this report

Home icon

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Navigation to Sections

Readers can navigate to every section of the report my clicking on the desired section from this contents page.

Navigation within the report

Throughout this document, clicking on underlined text with take the reader to the page referred to. Clicking on the backward and forward icon will take you to the previous chapter or the beginning of the next chapter of the report.

Chapter 1: Introduction (stage 1)

Figure 1.1.1: Solar panels at Ysgol Dinas Bran, Llangollen

Introduction to Technical Report

Denbighshire's Local Area Energy Plan (LAEP) provides an evidence-based plan of action that identifies the most effective route to a net zero local energy system for the county. 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 aims to avoid the duplication of efforts, save money, and realise additional social benefits that might otherwise have been over-looked.

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.

These two documents are the:

- Local Area Energy Plan contains the overarching plan, focusing on Denbighshire's area-wide energy plan and actions.
- Technical Report (this document) which contains the graphs, charts, maps and supporting data for the results published in the LAEP. It also provides more detail about the modelling and scenario analyses that we completed.

The report is structured so that it follows the seven-staged development process outlined in ESC's National LAEP Guidance[T01]. It includes additional supporting information related to stages 1-7, which are categorised into the introduction (Stage 1-2), the current energy system (Stage 3), The future energy system (Stages 4-5) and action planning (Stages 6-7). The table overleaf summarises what is included in this report and the Local Area Energy Plan in more detail.

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.

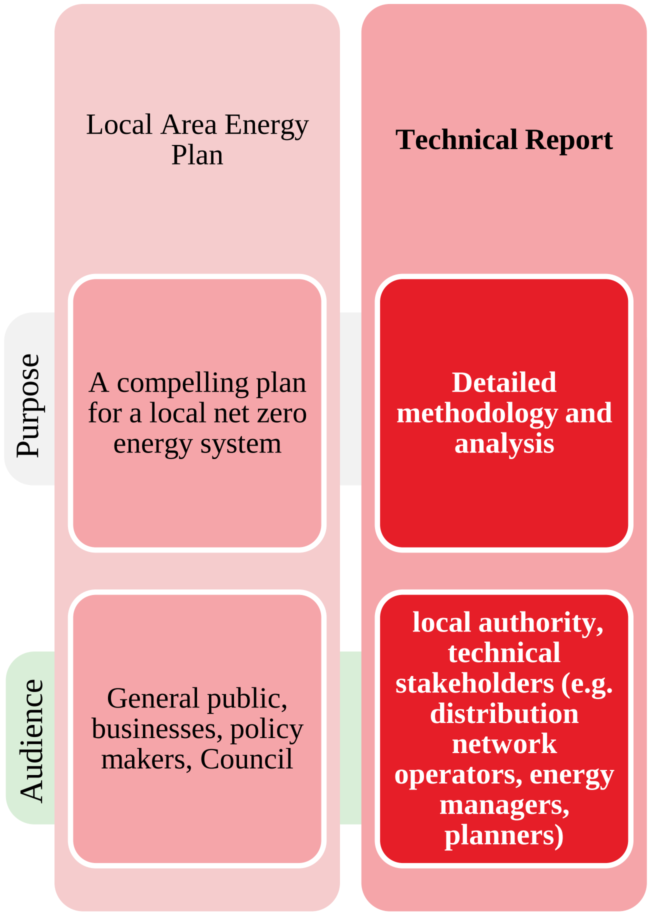

Figure 1.1.2: Summary of LAEP reports' purpose and audience

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1. Introduction

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 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	• Summary of energy system baseline • Summary of local, regional and national policy drivers for LAEP
The future 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

Table 1.1.1: Summary of content in Local Area Energy Plan and Technical Report

1. Introduction

The energy transition across Wales

Overview

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. The rationale for taking this approach was because there are efficiencies on data collection and management, as well as reinforcing the links between the regional and local plans to maximise opportunities across local authority areas and between regions. Several suppliers have been selected to produce the LAEPs for each region, as detailed in the map to the right.

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

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

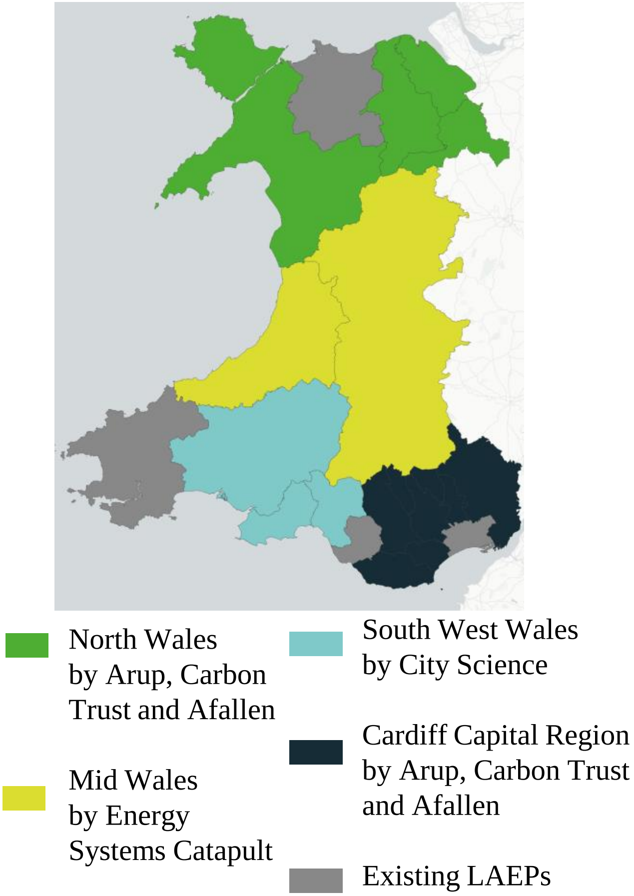

Figure 1.1.3: Progress made in the development of LAEPs across Wales

1. Introduction
The local energy system

A LAEP considers energy use, supply and generation within Denbighshire'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 is required for the energy system to operate.

Fuel for transport, heat and power in buildings and heat and power for industrial processes (where applicable), and other energy needs are considered together in the LAEP 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.

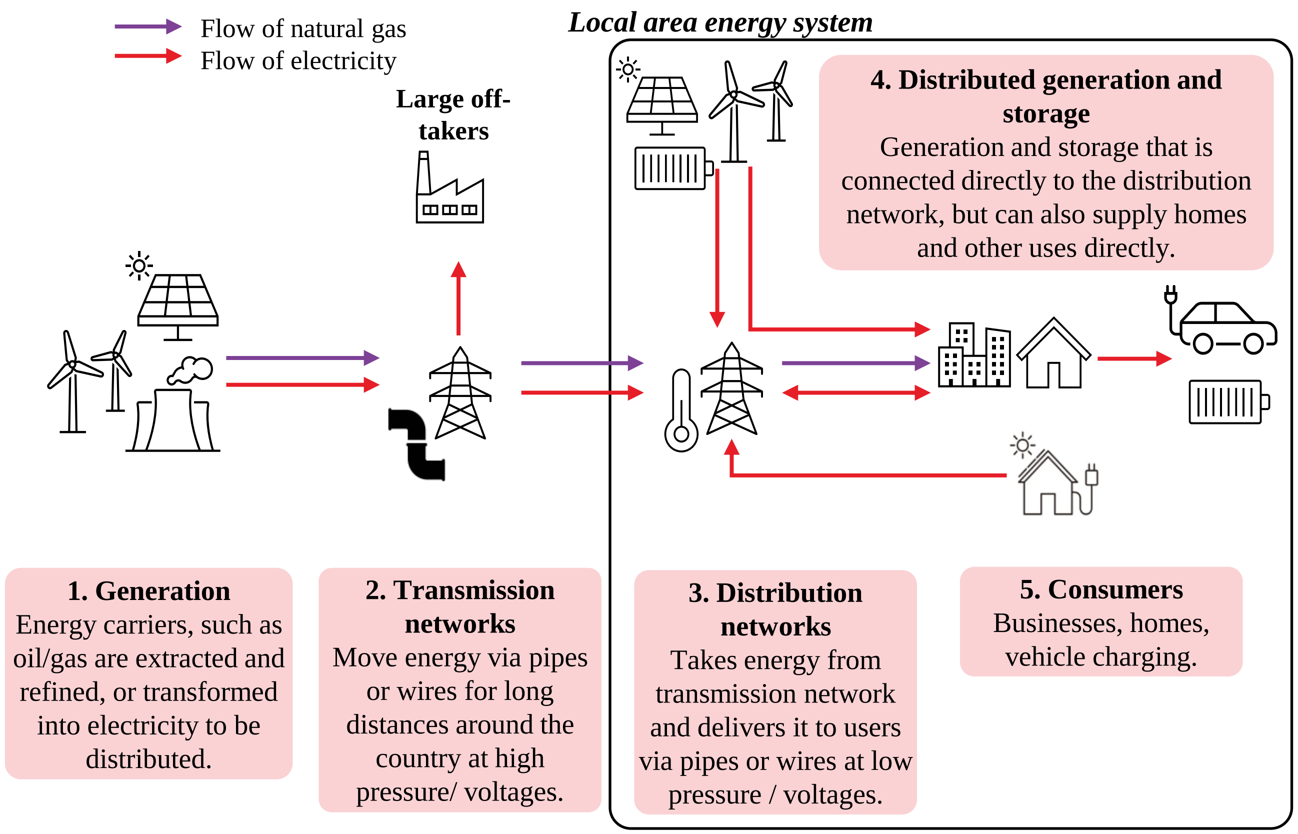

Figure 1.1.4: Illustration of transmission and distribution of gas and electricity from supply to consumer, and what parts of this system are included in the system boundary for LAEP

1. Introduction

The local energy system

Boundary

We used the geographic boundary of Denbighshire County 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 off the north coast of Wales 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 the LAEP focuses 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.

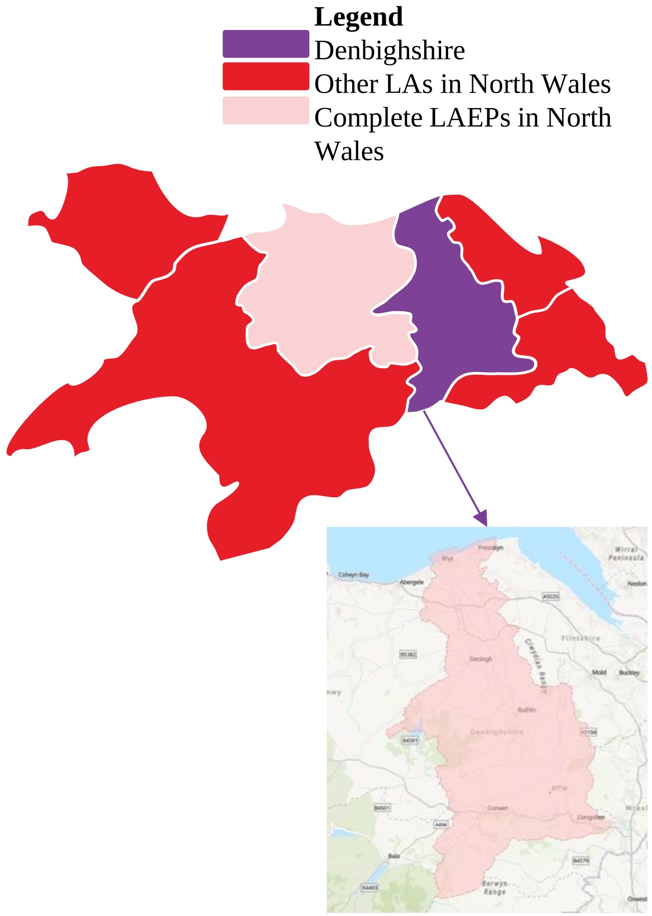

Figure 1.1.5: Location of the North Wales economic region (red) and the LAEP system boundary for Denbighshire (purple)

1. Introduction

The local energy system

Scope of the LAEP

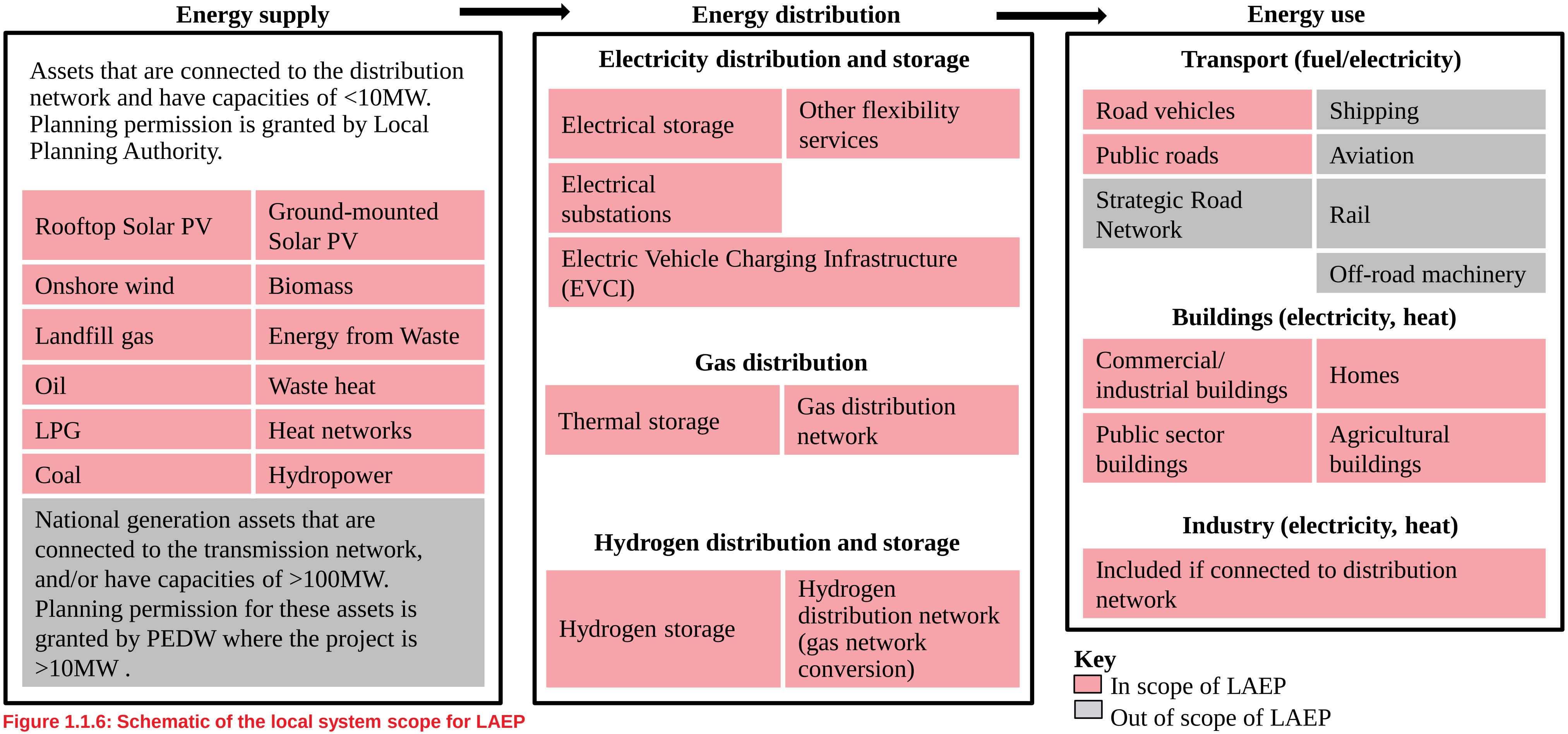

Figure 1.1.6: Schematic of the local system scope for LAEP

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Chapter 2: Stakeholder engagement (stage 2)

Figure 2.1.1: Two council-owned electric vans and charge points, Denbighshire

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 authorities.

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 with each Local Authority and ANW and using the results from analysis completed in stage 3, 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. making sure that industry was local authorities understanding the importance of industry stakeholders to a local authority. The aim of this review and confirmation process was to ensure that the identified stakeholders represented all aspects of the local energy system.

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 individual(s). Mitigated by networking with participants, continuous improvement, promotion of LAEPs locally.
3. 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.

Stakeholder identification process

Stakeholder group	Organisations	Role in LAEP development	Method of engagement
Primary stakeholders	Local authority officers, council member(s), Welsh Government, energy network operators i.e. Distribution Network Operators, (DNOs), Gas Distribution Networks (GDNs), Ambition North Wales.	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 project 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 project leads, as well as bi-weekly meetings with the local authority project 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.

3. 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.

4. 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 using chat, and facilitation introducing chat comments on participants behalf, and the opportunity to contribute for an extended period after the workshop by email.

2. Stakeholder engagement

Overview of stakeholder engagement plan

LAEP stages>>	1	2	3	4	5	6	7
Objectives / Purposes Regional Local	Governance set-up. Identify relevant regional policy and strategic drivers for work and create objectives Review stakeholder mapping	Review constituents of the local energy system Review the local energy system baseline. Review potential scenarios	Agree regional scenarios to be used in the LAEP modelling Identify local scenarios for each LA Review regionally consistent assumptions for LAEP modelling	Review potential futures for the local energy system Determine 'low regrets' near-term propositions Understand local barriers and enablers	Review near-term, low regrets propositions Share deployment pathways to net zero. Identify local and regional actions and responsibilities	Identify opportunities for regional collaboration and focus from local discussions	Presentation of 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 propositions.	Agree collective action to address barriers to delivering energy propositions locally	Agree regional actions and responsibilities to support the delivery of the local propositions	Final comments
Technical advisor							
Primary							
Regional							
Secondary							

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

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Chapter 3: The current energy system (stage 3)

Methodology


Figure 3.1.1: Rooftop solar PV

Methodology overview

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

1. Data collection

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

We collected baseline data for 2023 to include the most up to date data for housing stock and renewable generation installations. The exception to 2023 datasets was for transport (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.

2. Data validation

We cross-referenced the calculated results with existing datasets to evaluate their accuracy. This validation process was essential to understand any discrepancies between datasets and ensure the overall precision of our reporting. The Department for Energy Security and 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

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

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

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Methodology – electricity and gas network infrastructure

Electricity

We combined capacity[a] data 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.

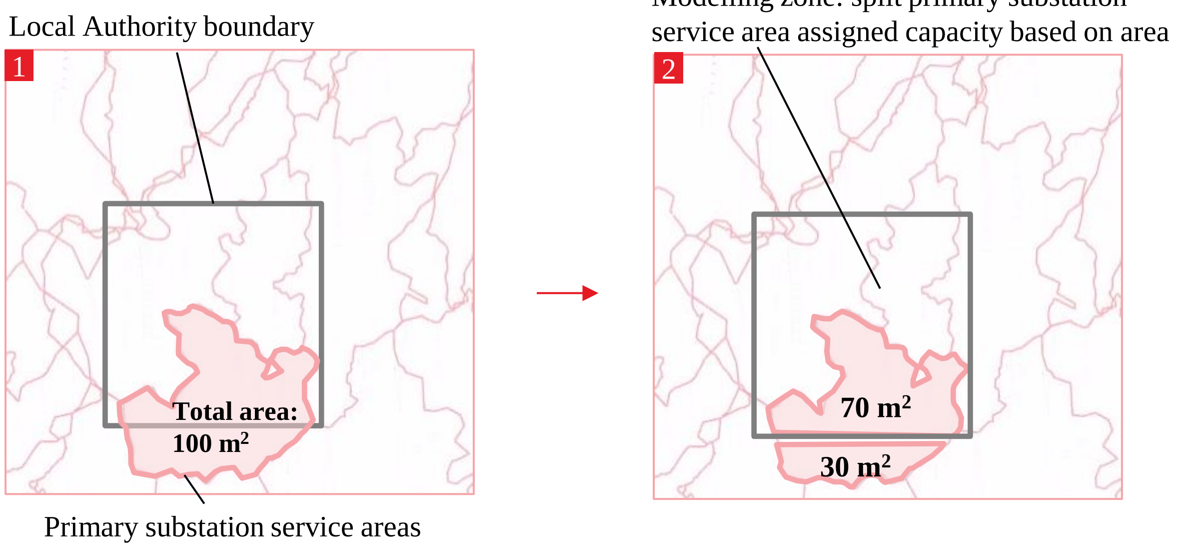
For five small areas in the North Wales region, there was no data provided. These areas with data gaps were referred to as modelling zones, with an unlimited capacity for modelling purposes.

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.



Note: areas shown here are theoretical values.

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

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Methodology – electricity and gas network infrastructure

Data input	Data source	Data type	Data quality
Primary substation service areas and headroom	SP Energy Networks (SPEN) – Open Data Portal[TN06]	Primary	Five small areas in the North Wales region were not included within any SPEN substation zones.
Off-gas grid homes	Domestic EPC database[T07]	Primary	Heating-type data available for ~60% of homes

Table 3.1.1: Electricity and gas network infrastructure – data sources

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Methodology – electricity and gas network infrastructure

Figure 3.1.3 shows the geographic boundary of Denbighshire (black) which is also the boundary used for Denbighshire's LAEP. The primary substation service areas that serve consumers (e.g. businesses, homes) within the geographic boundary are shown in red. Where primary substation service areas intersected one or more Local Authority boundaries, they were divided into **smaller modelling zones**. Most of the analysis, results, and maps in this report are presented in terms of these smaller modelling zones, which may also be called "substation zones" or simply "zones."

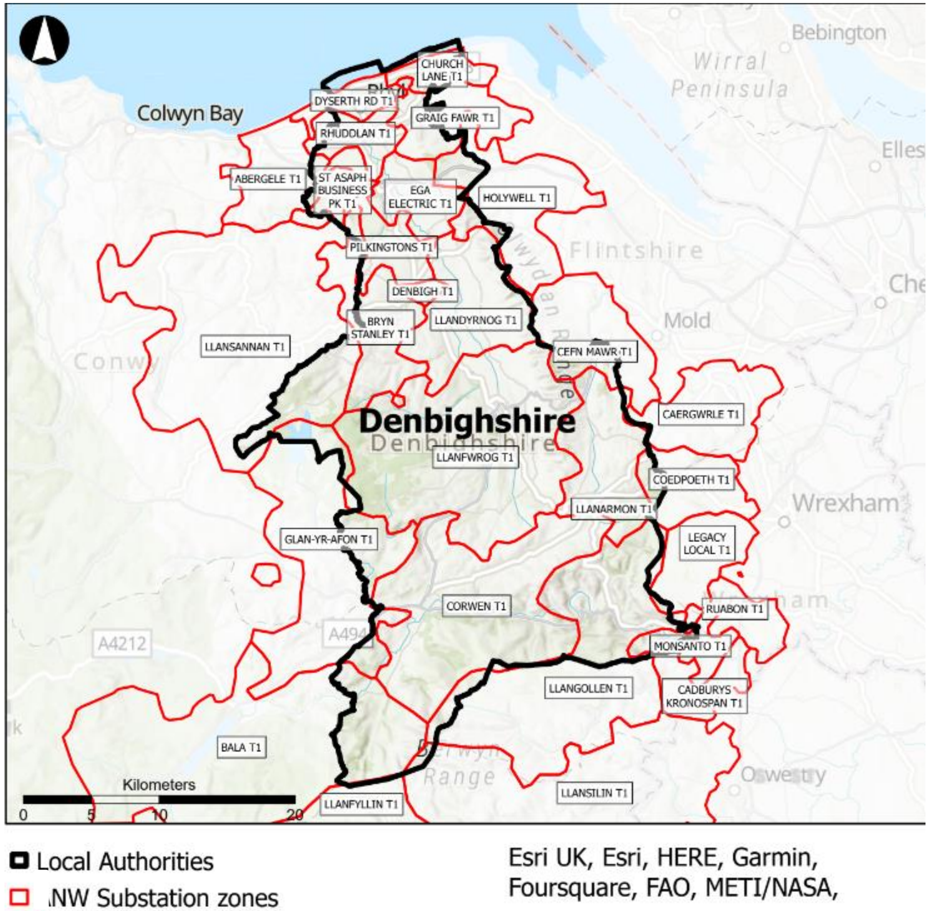

Figure 3.1.3: Geographic boundary of Denbighshire used to define the boundary for this LAEP and the associated modelling zones within the LAEP boundary

Methodology – buildings energy demand

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

We created an address-level database for this assessment by combining energy performance certificate (EPC) 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)

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Methodology – buildings energy demand

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

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

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

Data validation

We generated building profiles at the archetype level and aggregated to local authority area to compare the annual consumption with DESNZ's (formerly BEIS) sub-national energy consumption statistics (referred to as DESNZ's sub-national statistics from herein)[T05]. Differences are expected between this dataset and this approach 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 significant.

Domestic electricity consumption taken from DESNZ sub-national statistics[T05] is 1% higher 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.

Denbighshire County Council	Difference
Domestic electricity demand difference	1%
Domestic heat demand difference[a]	-18%
Non-domestic electricity demand difference	-20%
Non-domestic heat demand difference	-30%
Un-occupancy (Census 2021)[T11]	16%
% non-domestic properties with no archetype	23%

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

Table 3.1.3: Demand differences between DESNZ's statistics and building profiles

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 Government 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

Sponsors:

Delivery partners:

Methodology – transport energy demand

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

We used data from Transport for Wales (TfW) transport models[TN12] to estimate annual road mileage data between different parts of a local area. TfW's data provided the number of trips between two different transport zones (defined by TfW) on an average day according to vehicle type. In this data, a trip is defined by the transport zone where a vehicle's journey starts and the transport zone where it ends. Therefore, vehicles which pass through a transport zone without stopping are not counted. We estimated the route distance to be 130% longer than the distance between each area's centre point. This 'route indirectness' factor was based on Arup work from a previous local area energy plan in Wales. We then scaled up that daily mileage value to an annual mileage value.

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

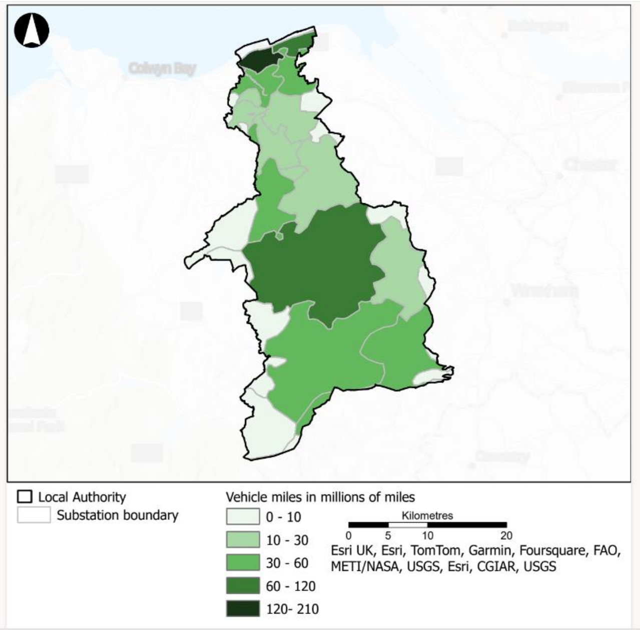


Figure 3.1.4: Estimated annual mileage (million miles per year) for all vehicles for by substation zone (2019)

Sponsors: Delivery partners:

Methodology – transport energy demand

Data validation

We compared our baseline results against two datasets: the Department for Transport (DfT) road traffic statistics[T13], and the energy consumption values were compared against the DESNZ's sub-national road transport fuel consumption statistics[T14]. The road traffic statistics provide junction to junction data for motorways, 'A' road network and some minor roads across the UK.

The mileage comparison is shown on the right, which compares total mileage for all vehicles to this reference. We found our estimates to be broadly consistent with the DfT dataset. In some cases, our results were above or below the reference, likely due to differing levels of route directness in different local authorities.

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

Please see the energy consumption comparison on the next page.

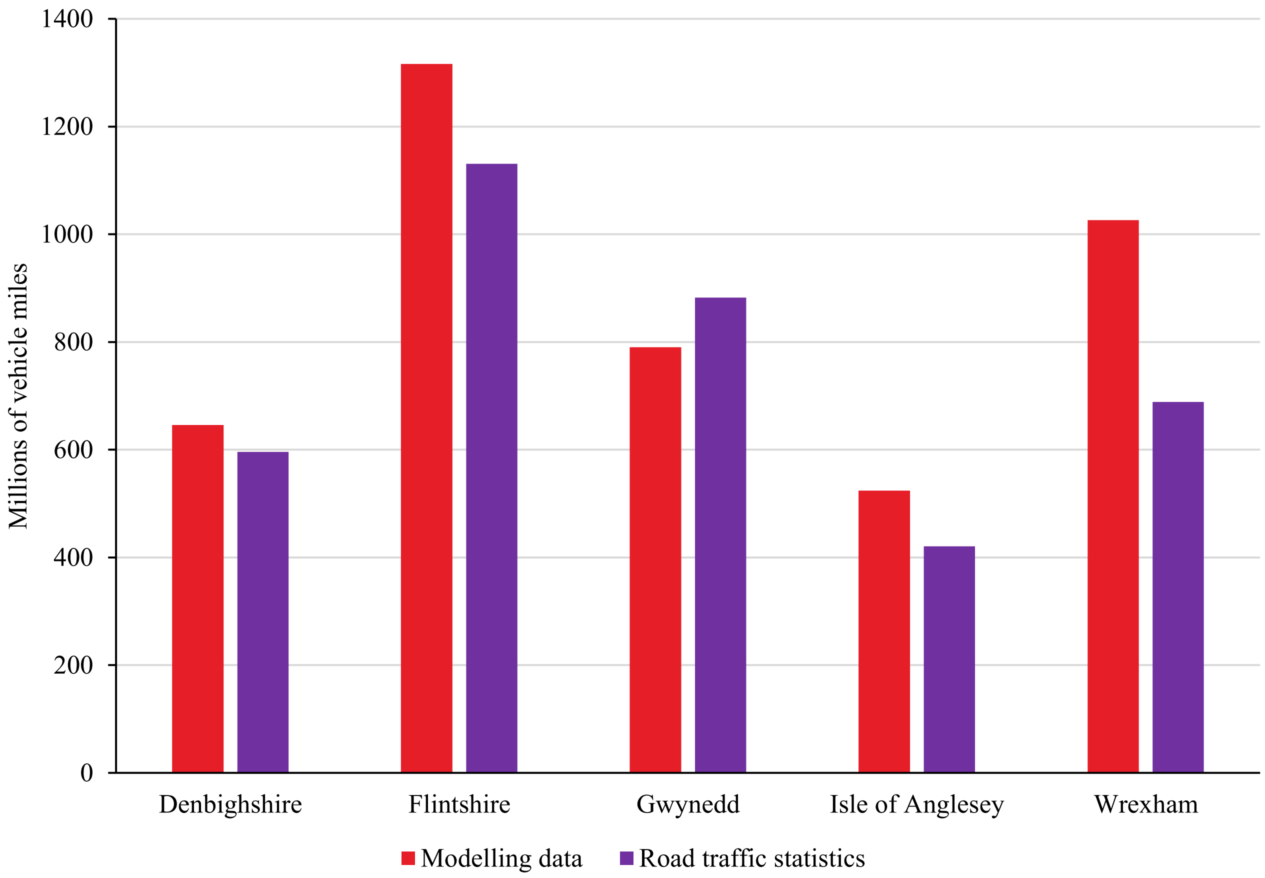


Figure 3.1.5: Comparison of modelling data to DfT road traffic statistics[T13]

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 (formerly BEIS) sub-national fuel consumption statistics[T14].

In our estimates, we calculate the energy consumption of Heavy Goods Vehicles (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 chargepoints according to the postcodes supplied in the National Chargepoint Registry[T15] and, where provided, local authority records. For Denbighshire'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 Denbighshire County Council wasn't included in Figure 3.1.6 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.

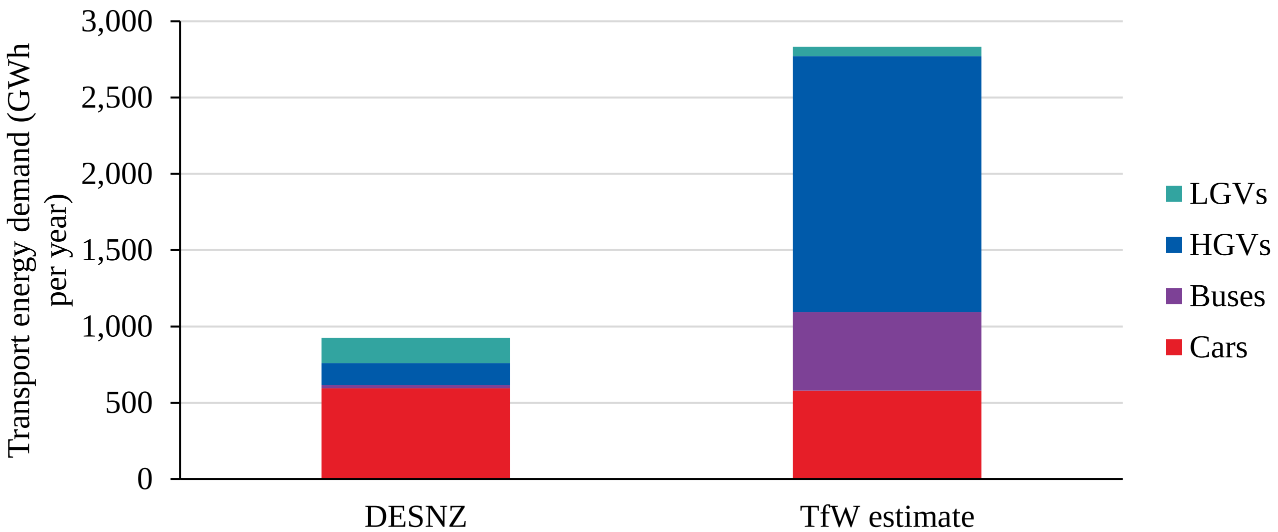


Figure 3.1.6: Annual transport energy consumption; our analysis based on TfW data compared to DESNZ sub-national fuel consumption statistics

Methodology – transport energy demand

Data input	Data source	Data type	Data quality
Demand tables	North Wales Transport Model (NWTM)[TN12]	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 Light Goods Vehicles (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 in less urban parts of Wales.
Number of diesel vehicles and total number of vehicles	Vehicle licensing statistics data tables (veh0105)[T19]	Secondary	All non-diesel vehicles assumed to be petrol.
Postcodes of charge points	National Chargepoint Registry (NCR)[T15] (May 2023)	Primary	Relies on updates by contributors.

Table 3.1.5: Baseline data sources (transport)

Sponsors: Delivery partners:

Methodology – industry energy demand

We identified industrial energy demands in Denbighshire using the National Atmospheric Emissions Inventory (NAEI) large point sources database[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 (CO_2) emissions.

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

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

Where industrial organisations with large energy demands in Denbighshire did not respond to this information request, we used the carbon (CO_2) emissions data from the NAEI database to calculate 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	NAEI large point sources database 2020[T20]	Primary	Only carbon dioxide emissions were considered. Other emission types were excluded.

Table 3.1.6: Baseline data sources (industry)

Methodology – local energy generation

We mapped generators identified in the renewable energy planning database (REPD)[T22] to primary substation 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 (REPD) or SPEN's embedded capacity registers (ECR)[TN24]. This was the latest available report 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 entry capacity register (TEC)[T25] to ensure we only captured generators connected to the distribution network.

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 excluded.

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] Energy generation for Wales (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[a] (MWth)	Energy generation for Wales (2021)[T23]	Secondary	Generators listed by outward code (first half of postcode) as no full postcode available.
Domestic rooftop solar PV	Energy generation for Wales (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.

[a]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)

Methodology – greenhouse gas (GHG) emissions

Generation-based emission factors are factors that measure 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.

Technology	Value	Units	Source
Biomass	0.0119	kgCO_2e per kWh	DESNZ, 2023 (Average of 4 biomass fuels: wood logs, wood chips, wood pellets, grass/straw)[T21]
Coal	0.3226		DESNZ, 2023 (Coal - Industrial, Gross CV)[T21]
Diesel	0.2391		DESNZ, 2023 (Liquid fuels - Diesel (average biofuel blend), Gross CV)[T21]
Electricity grid	0.045		National Grid FES 2023 (averaged scenario, without BECCS). Also includes projections to 2050.[T31]
Landfill gas	0.0002		DESNZ, 2023 (Biogas - Landfill gas)[T21]
Natural gas	0.1843		DESNZ, 2023 (Gaseous fuels - natural gas, Gross CV)[T21]
Oil/LPG	0.2413		DESNZ, 2023 (Average of LPG and Fuel Oil, Gross CV)[T21]
Organic matter	0.0002		DESNZ, 2023 (Biogas - Biogas)[T21]
Petrol	0.2217		DESNZ, 2023 (Liquid fuels - Petrol (average biofuel blend), Gross CV)[T21]
Sewage gas	0.0002		DESNZ, 2023 (Biogas - Biogas)[T21]
Waste incineration	0.038		DESNZ, 2023; Tolvik, 2021[T26]

Table 3.1.8: Baseline emission factors

Technical Report

Chapter 3: The current energy system (stage 3)

Analysis

Figure 3.2.1: Ysgol Tir Morfa rooftop solar PV, Rhyl, Denbighshire

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

Delivery partners: ARUP; Carbon Trust

Analysis - local context

Denbighshire is in the north-eastern part of Wales, and borders the Irish sea to the north, Conwy County Borough, Powys and Wrexham County Borough.

Economics

The area is mainly rural, and historically, agriculture has been a significant part of Denbighshire's economy due to the expanse of land suitable for farming activities. Scenic landscapes such as the Clwydian Range and Dee Valley National Landscape historical towns such as Denbigh, Rhyl and Prestatyn, and other cultural attractions attract many visitors to the area annually. Whilst Denbighshire is not as industrialised as some other parts of Wales and neighbouring Flintshire and Wrexham, there is some light industry mainly located in around St. Asaph and the other market towns.

Renewable energy

Due to its coastal location, there is potential for wind power to play a significant role in Denbighshire's future energy mix. There are already some major wind projects in operation such as those located in the Clocaenog forest. Due to significant area of designated landscapes and privately-owned farmland, the development of ground-mounted renewable energy projects is more challenging. However, farming activities in the area also present an opportunity to capture energy from agricultural waste using anaerobic digestion and other technologies.

Transport

Denbighshire County Council's Transport Strategy 2022, recognises that dependence on cars will be greater in rural areas, but statistics show there are opportunities to convert shorter journeys being made by car to other more sustainable forms of transport.

Bus services in Denbighshire are commercially-operated, which means they are outside the council's control. Denbighshire County Council is partnering with Transport for Wales (TfW) and regional partners to develop suitable, better integrated bus networks for the local communities, looking at flexibility, interchange and connectivity with other transport modes, and simpler ticketing options.

There is also an opportunity for Denbighshire to encourage active travel in and around its scenic landscapes to encourage more sustainable travel options for visitors.

Figure 3.2.2: Map showing the boundary of Denbighshire

Analysis – socio-economic context

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. The most deprived small area in Wales in WIMD 2019 was Rhyl West 2 (around Rhyl high street).[T28]

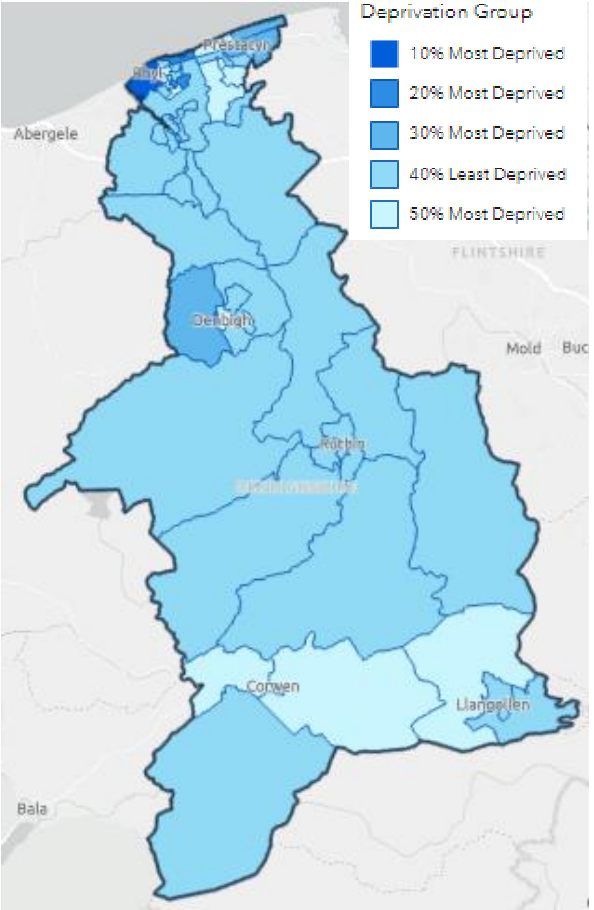


Figure 3.2.3: Welsh Index of Multiple Deprivation (WIMD) by LSOA in Denbighshire (2019)

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 2021, 14% of households in Denbighshire were identified to be in fuel poverty 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.

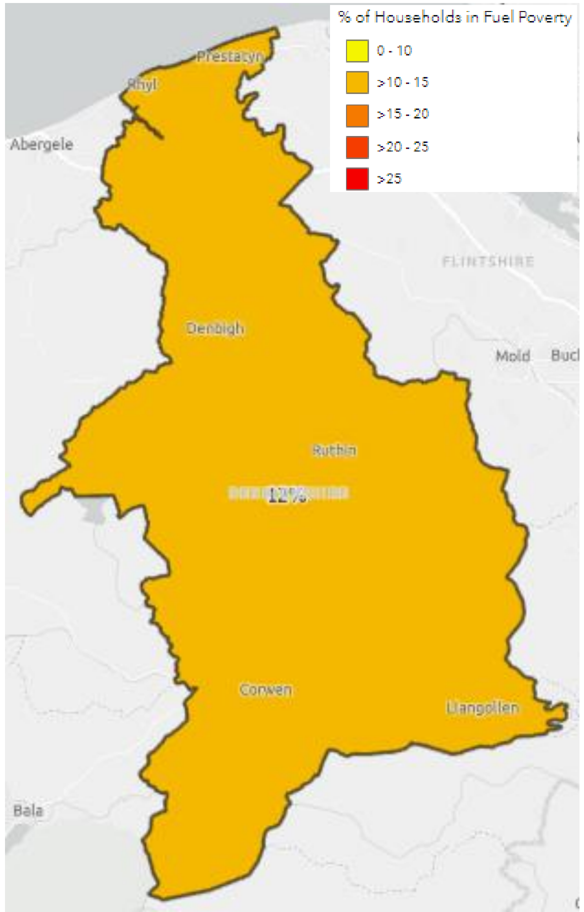


Figure 3.2.4: Fuel poverty in Denbighshire (2019). Data is only available at the Local Authority level

Analysis – greenhouse gas (GHG) emissions

The figures presented here are GHG emissions produced by the local energy system, which is defined in Chapter 2: The current energy system.

The emissions shown in Figure 3.2.5 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 large point sources database.[T20]

Greenhouse gas (GHG) emissions in Denbighshire in 2023 were 506ktCO_2e. GHG emissions per capita were 5tCO_2e per capita.

The largest contributors were:

- **Road vehicles (62%)**
  - 62% of total GHG emissions are from the use of petrol and diesel in road vehicles.
- **Energy used in buildings (37%)**
  - 27% of total GHG emissions are from the use of natural gas in buildings.

NB: The emissions in Figure 3.2.5 exclude emissions from waste and land use, land use change and forestry (LULUCF).

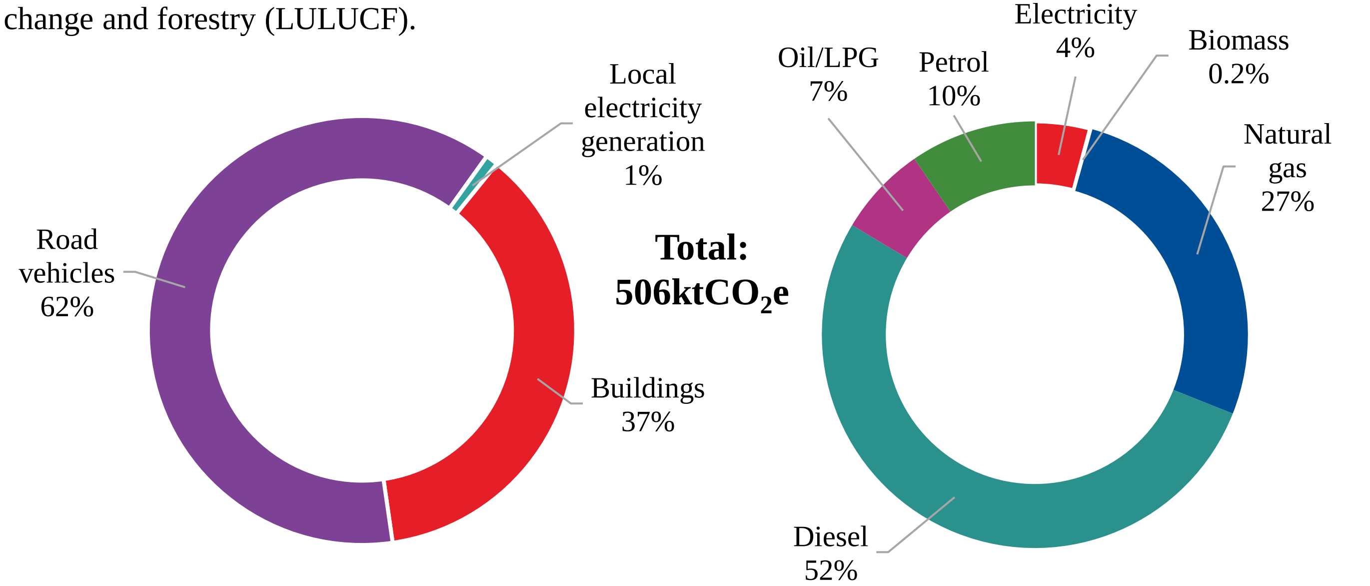


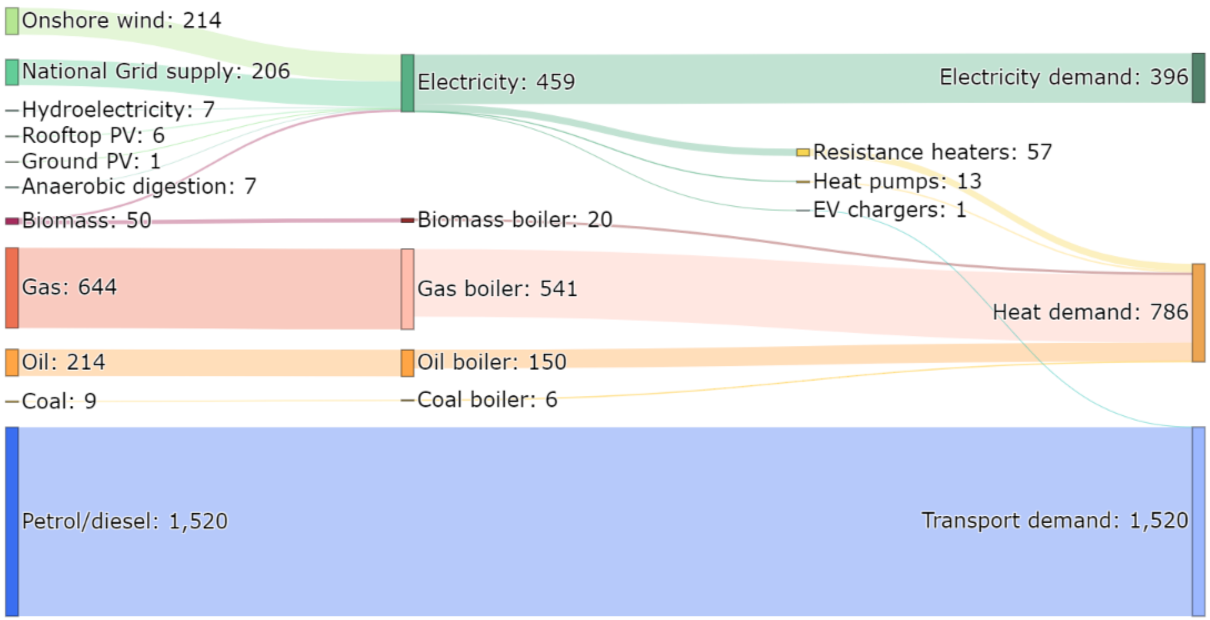
Figure 3.2.5: (Left) Denbighshire County's GHG emissions (ktCO_2e per year) by sector (2023) (right) Denbighshire County's GHG emissions (ktCO_2e per year) by fuel type (2023)

Sponsors:

Delivery partners:

How to read a 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 Denbighshire 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 3.2.6: How to read a Sankey diagram (units are GWh per year)

Annual energy flows (GWh per year)

This Sankey diagram shows how energy is supplied, converted and used in the local energy system. This Sankey diagram represents energy flows in Denbighshire's local energy system as totals for one year, using 2023 as the baseline year.

55% of the **electricity** supplied to the local energy system is from local renewable energy sources.
Onshore wind generates the most energy annually on average compared to other local resources.
Almost all electricity generated is used to fulfil electricity demand from buildings (i.e. not heat or transport).

Heating accounts for 29% of total energy demand across Denbighshire.
75% of properties are connected to the gas grid, so most properties are heated using gas boilers.
The remaining heat demand is provided by other fuels such as oil, biomass, coal and solid fuels.

Almost all **vehicles** in Denbighshire have internal combustion engines (ICEs), with relatively low uptake of electric vehicles (EVs).

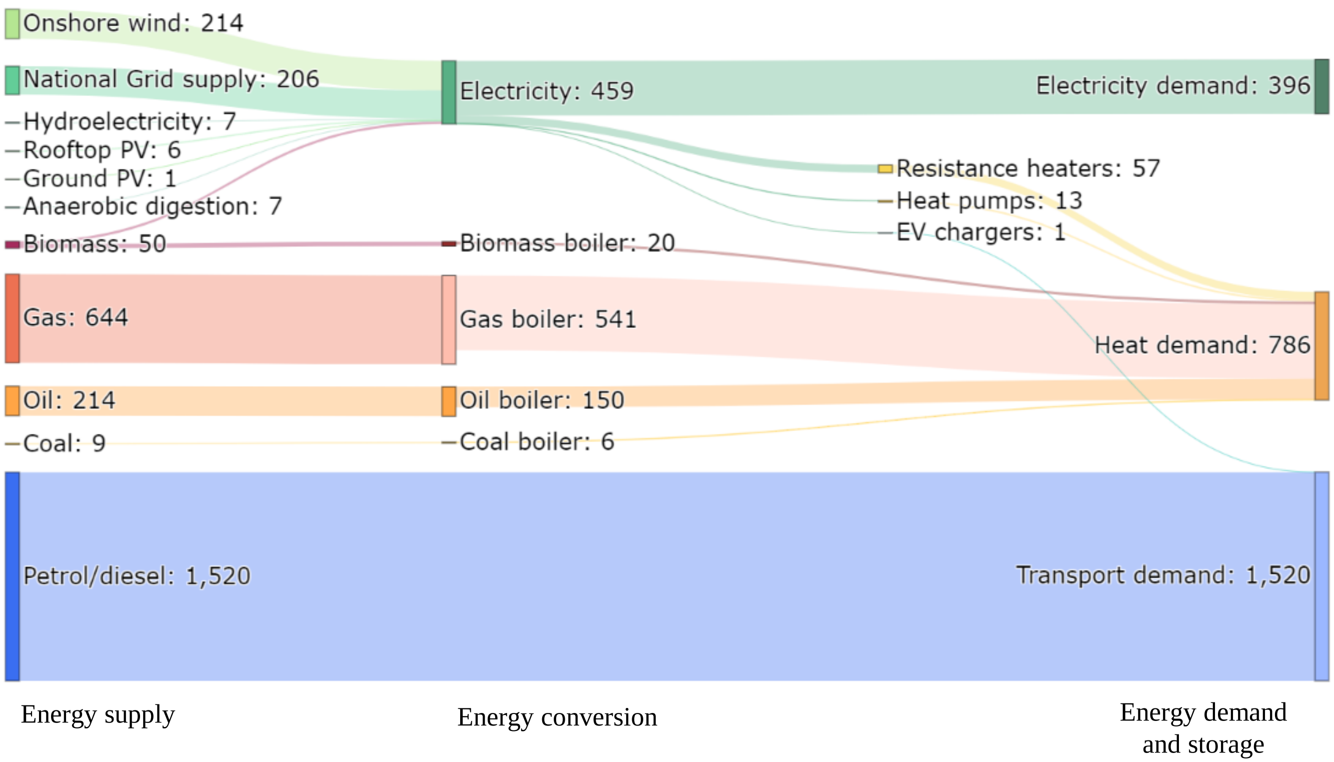


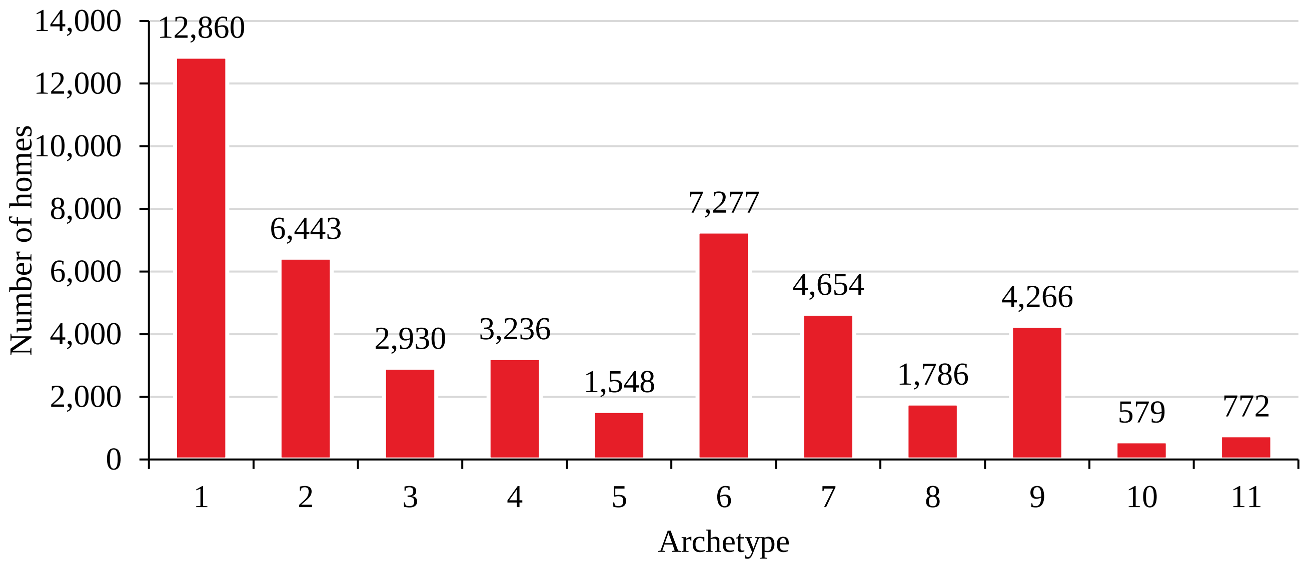
Figure 3.2.7: Baseline Sankey diagram, representing energy flows in Denbighshire in GWh per year (2023)

Analysis – buildings energy demand

Heat in buildings constituted 32% of total energy demand in 2023 and domestic heating was responsible for 76% of total heat demand from buildings.

In total, there were 46,000 domestic properties. 75% of homes were semi-detached or detached. Unoccupied homes in Denbighshire accounted for 16% of the total stock, this is above the Welsh average of 7%.[T11]

75% of homes were connected to the gas grid. This figure was above the regional average for Wales, of 72%[T07]. Homes that are not connected to the gas network mostly use oil (10%), electricity (6%), LPG (3%) or a combination for heating.



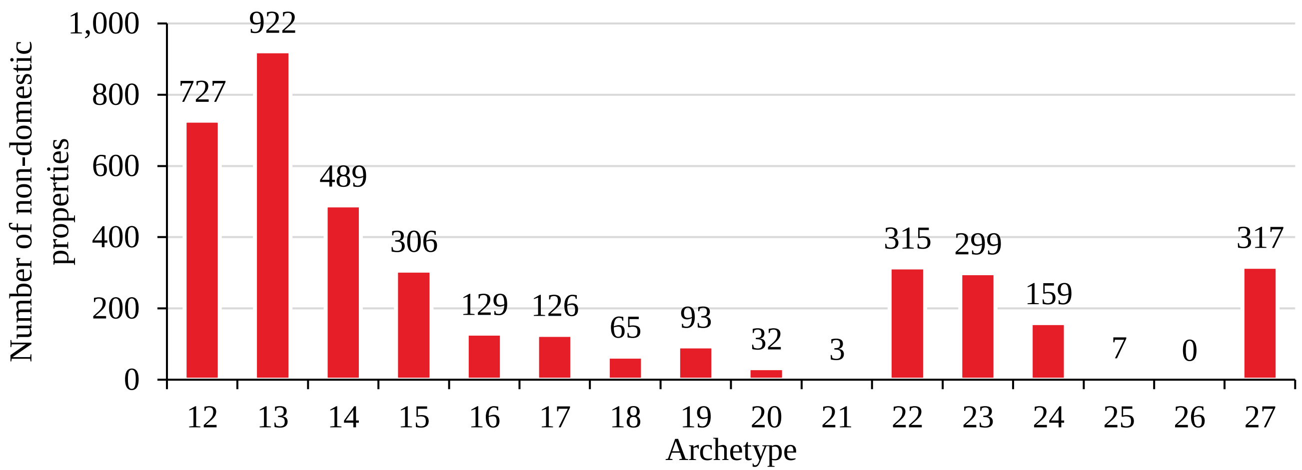
No.	Description	No.	Description
1	Detached - after 1930 - medium/high efficiency	7	Semi-detached - before 1930 - low efficiency
2	Detached - low efficiency	8	Semi-detached - before 1930 - high efficiency
3	Terrace - medium efficiency	9	Flat - high efficiency
4	Terrace - before 1930 - low efficiency	10	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 3.2.8: Distribution of domestic properties by archetype (2023)

Analysis – buildings energy demand

24% of heat demand in buildings was for non-domestic properties in 2023.

There were a total of 4,000 non-domestic properties with retail being the dominant type, accounting for 23% of non-domestic buildings. 18% of non-domestic properties are health centres/clinics.



No.	Description	No.	Description
12	Office	20	Emergency services, local Government 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 3.2.9: Distribution of non-domestic properties by archetype (2023)

Analysis – monthly buildings energy demand profile (GWh)

Energy demand has been presented on an annual basis in this report, but it's 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 3.2.10 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).

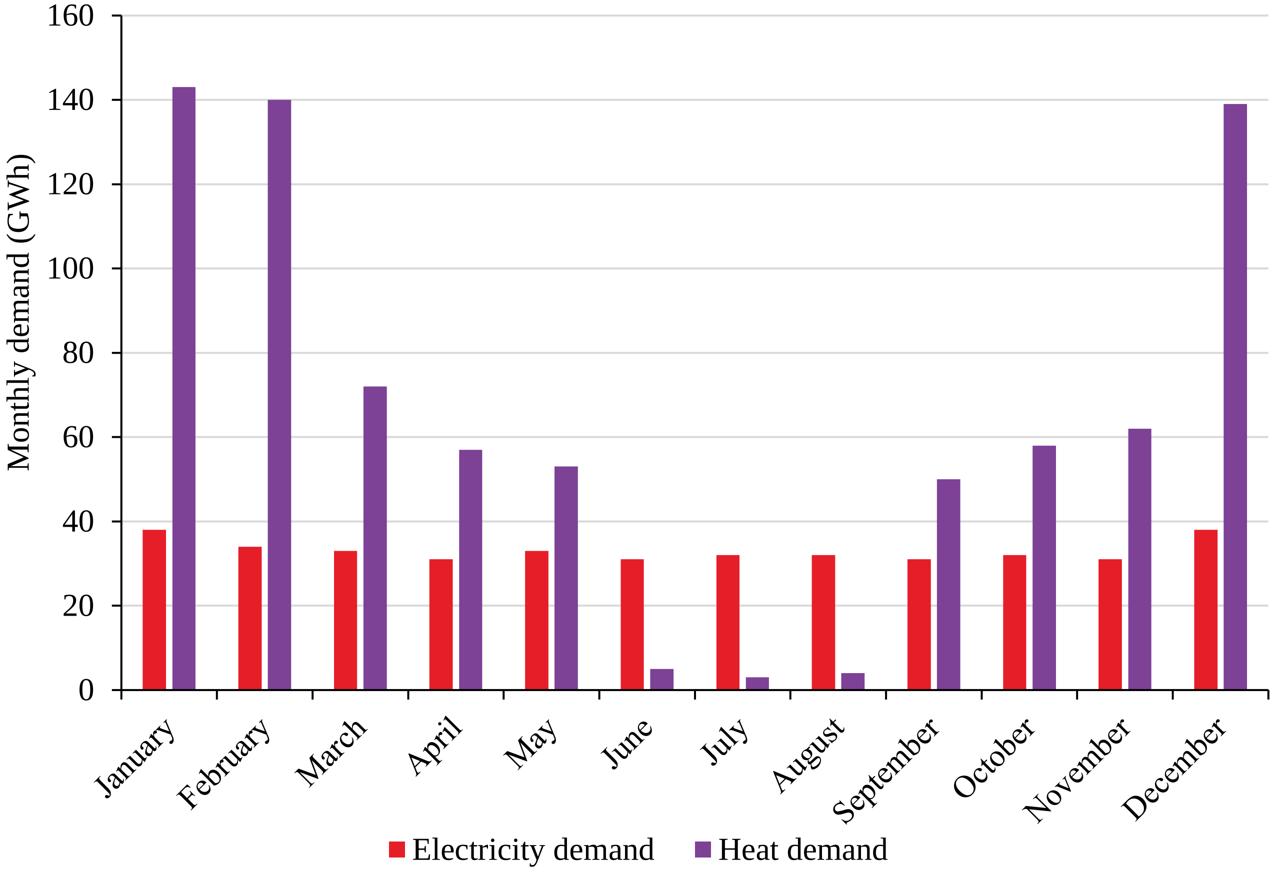


Figure 3.2.10: Monthly buildings energy demand profile for Denbighshire, showing heat and electricity demand (in GWh per month) (2023)

Analysis – electricity consumption in buildings (MWh per year)

Electricity consumption (total domestic and non-domestic) varies across the area, with slightly higher electricity consumption in more densely populated areas such as along the A55 corridor in the north. Electricity consumption is much lower in areas such as the Clwydian Range and Dee Valley National Landscape to the east.

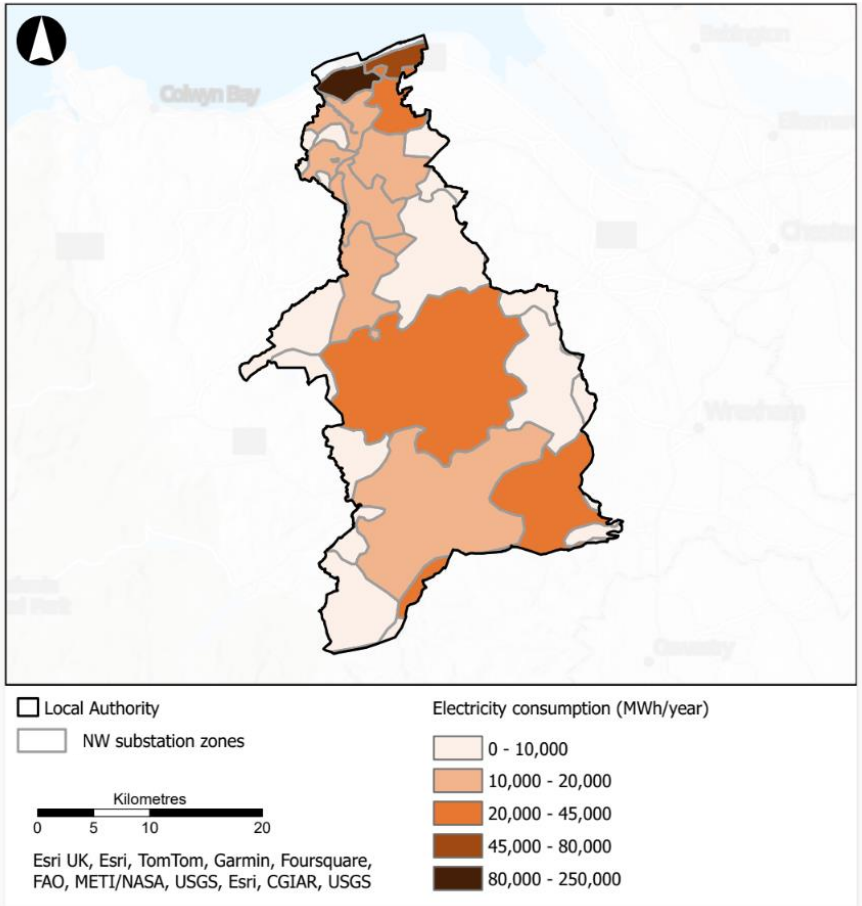


Figure 3.2.11: Electricity consumption (MWh per year) (domestic and non-domestic properties) by substation zone across Denbighshire (2023). Data is based on meter level electricity consumption data

Analysis – heat demand in buildings and industrial energy demand (MWh per year)

Heat demand is generally higher in more densely populated locations like Rhyl, Prestatyn and in and around Ruthin. These locations are also where most businesses are located, with most people employed in health and social care, retail, public services and construction.

Denbighshire is not heavily industrialised, but some parts are more commercialised than others. As a result, there are no businesses that meet the threshold for industrial loads defined in the NAEI large point sources database[T20] which has been used for this baseline.

Larger businesses are mainly based in St Asaph which is located near the north coast and is accessible from the A55 North Wales expressway.

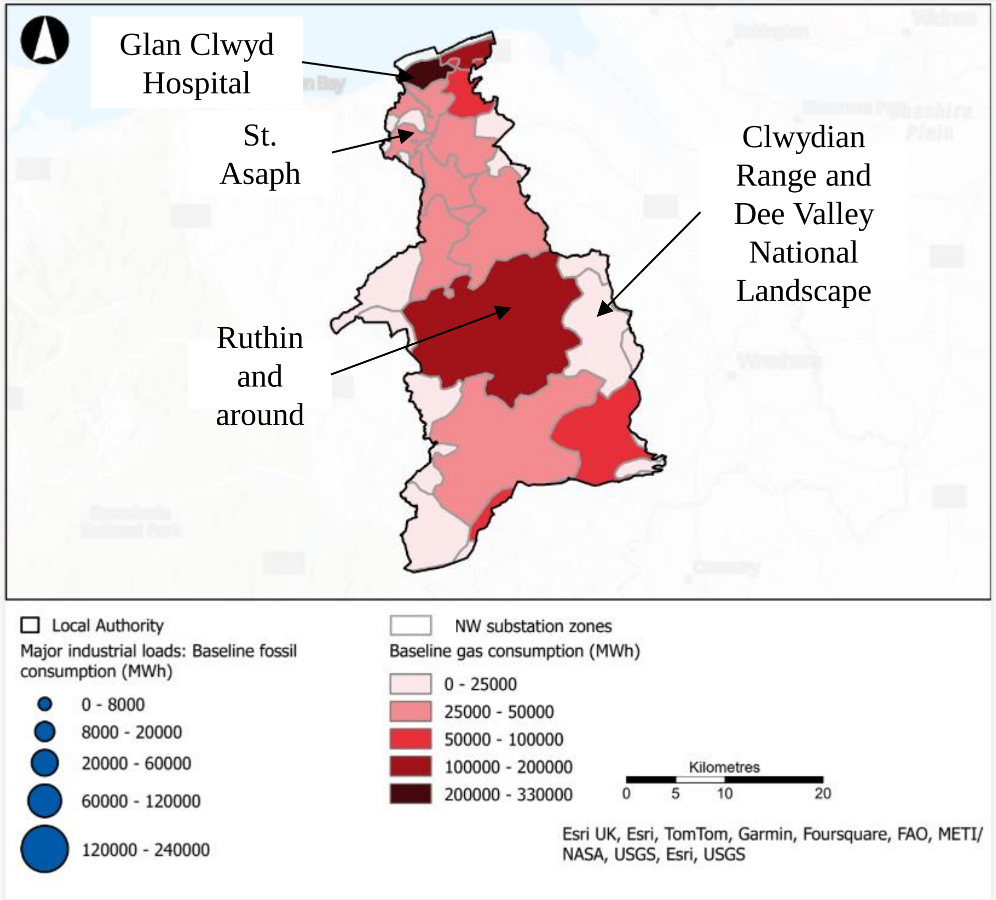


Figure 3.2.12: Heat demand (GWh per year) across all buildings (2023) and fossil fuel consumption from major industrial loads (2019) in Denbighshire by substation zone

Analysis – buildings (domestic) energy efficiency

The energy efficiency of Denbighshire's housing stock varied considerably. On average, properties have below average levels of insulation (e.g. 30% of homes have <100mm loft insulation and 17% had unfilled cavity walls), influencing their overall energy performance. These distinctions are shown in the EPC ratings, with only 31% of properties achieving A-C ratings, relatively high compared to other local authorities in North Wales. There are a higher proportion of homes in Ruthin, Denbigh and parts of Prestatyn with EPC A-C ratings. And there are a lower proportion of homes with EPC A-C ratings in and around St. Asaph in the Clwydian Range and Dee Valley National Landscape.

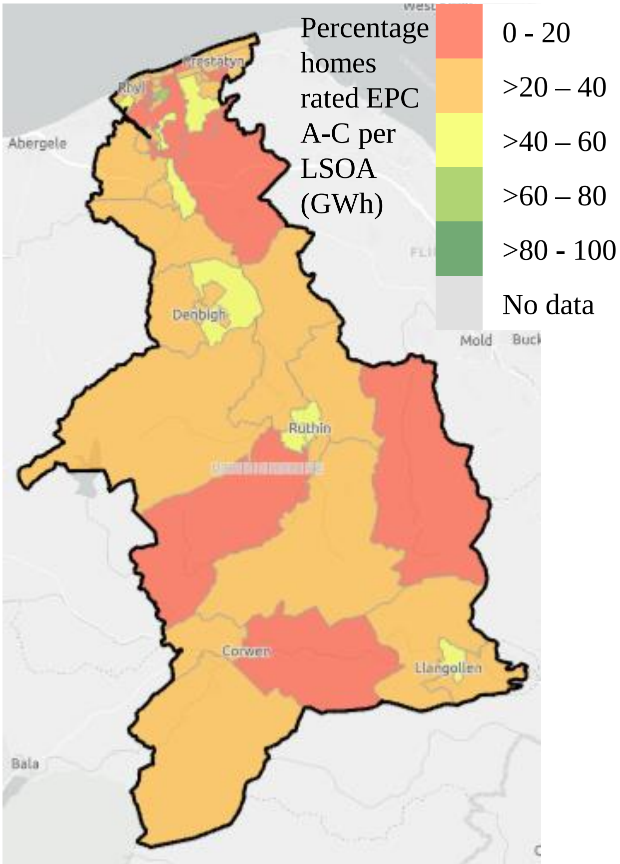


Figure 3.2.13: Proportion of domestic homes by EPC rating in Denbighshire by LSOA (2023)

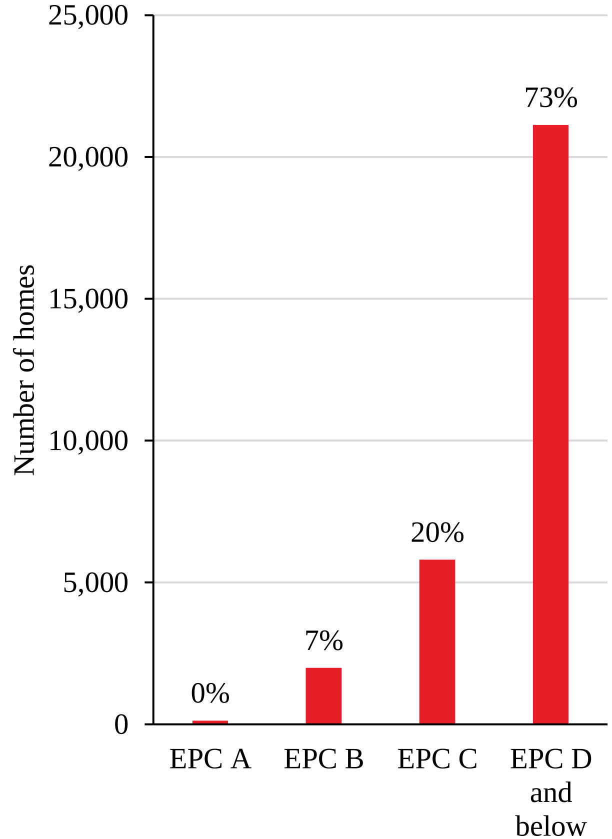


Figure 3.2.14: Energy efficiency of domestic properties across Denbighshire, rated EPC A-C and EPC D and below (2023)

Analysis – transport energy demand

In 2023:

- Road transport contributed 292ktCO_2e or 62% to county-wide GHG emissions.
- <1% of vehicles were electric or hybrid, about the average across Wales[T40].

Road infrastructure

Denbighshire is mostly rural, with most transport infrastructure concentrated on the following transport corridors:

- A525 connecting north to south.
- A494 connecting west to east through Corwen and Ruthin to Mold.
- A547 connecting the north of Denbighshire to the Deeside Valley and Isle of Anglesey.
- A5 connecting Corwen and Llangollen in the South of Denbighshire.
- A55 (part of the Strategic Road Network) connecting north Denbighshire to the rest of North Wales and Cheshire.

This network has a significant impact on local employment, fostering economic growth and job opportunities.

Car ownership

Transport behaviour in Denbighshire 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. The North Wales expressway (passing through Rhyl and Prestatyn) provides limited access to rail services for the communities living in the north of Denbighshire, but most of the communities rely either on bus services or private vehicles.

77% of households in the area owned cars, with an average of 1 car per household[T41], which is in line with the average in Wales[T41].

Electric Vehicle Charging Infrastructure (EVCI)

According to the National chargepoint Registry, there were 72 public EV chargepoints in Denbighshire in May 2023[T15]. The council owned 45 chargepoints (public and workplace) as of 2021. These chargepoints are distributed along major transportation routes and in towns to facilitate convenient charging for residents and visitors. To support the growing EV fleet, the council has invested in EV charging infrastructure across depots and council car parks. The Rhyl charging hub is the largest with 36 electric vehicle (EV) charging stations.

Public transport and active travel

Most public bus services are commercially operated, so the local authority has little control over them. However, the local authority has made investments to showcase electric buses, such as the Ruthin electric bus.

Denbighshire County Council is also working to improve active travel infrastructure to offer residents efficient and sustainable commuting alternatives, reducing reliance on private vehicles for shorter journeys where possible.

Finally, Denbighshire also offers an electric taxi scheme, a 30-day free trial for licensed drivers to encourage the uptake of electric taxis for use in the local area.

Analysis – transport energy demand

63% of total vehicle miles are covered in cars, 20% are covered in Heavy Goods Vehicles (HGVs).

HGVs were the main source of transport emissions, accounting for 48% of total transport emissions and 139ktCO_2e, despite only accounting for 27% of mileage due to their higher emissions intensity (gCO_2e per km).

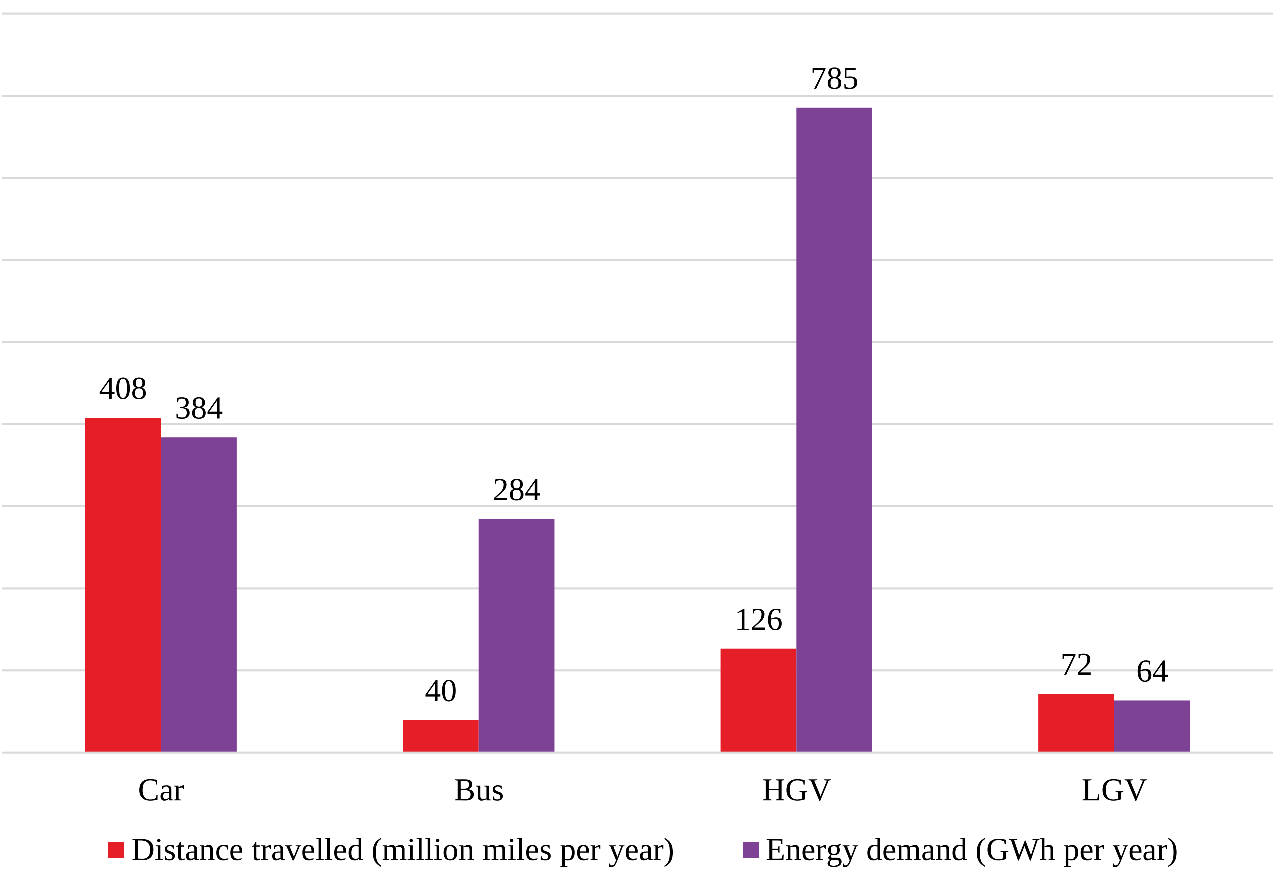


Figure 3.2.15: Total mileage (million miles per year) and energy demand (GWh per year) by vehicle type (2019)

Analysis – transport energy demand (kWh)

Energy demand from travel in Denbighshire is highest in and around larger settlements and where businesses are located (Rhyl, Prestatyn, Ruthin). 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.

Denbighshire is mostly rural, with most transport infrastructure concentrated on the following transport corridors:

- A525 connecting north to south
- A494 connecting west to east through Corwen and Ruthin to Mold
- A547 connecting the north of Denbighshire to the Deeside Valley and Isle of Anglesey
- A5 connecting Corwen and Llangollen in the South of Denbighshire.
- A55 (part of the Strategic Road Network) connecting north Denbighshire to the rest of North Wales and Cheshire.

This network has a significant impact on local employment, fostering economic growth and job opportunities.

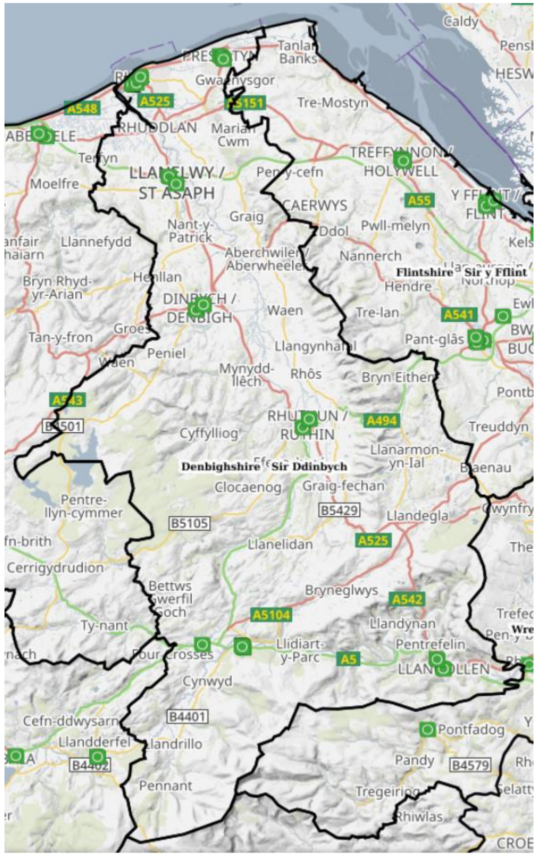


Figure 3.2.16: Map showing major and minor roads in Denbighshire

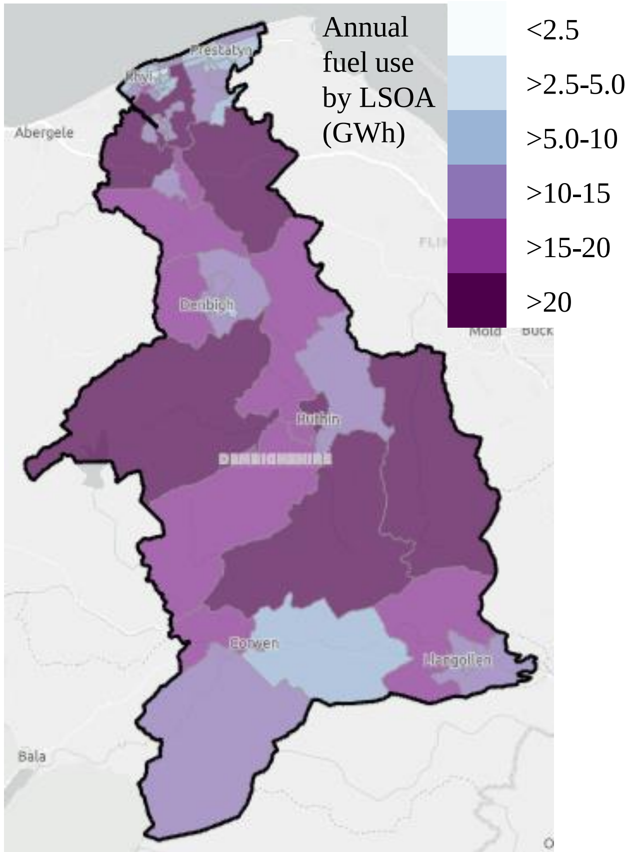


Figure 3.2.17: Transport energy demand (combined total across cars, light goods vehicles (LGV) and heavy goods vehicles (HGV) by LSOA (2019) (GWh per year)

Analysis – energy generation in 2023

Denbighshire has the potential to generate an average of 285GWh electricity annually (based on 2023 figures). This electricity generation capacity[a] plays a pivotal 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 (refer to Chapter 1:Introduction for details on the boundary and scope of this assessment).

Onshore wind power is a prominent renewable energy source harnessed within Denbighshire. In 2023, the region had a total wind capacity of 69MW. Wind energy continues to grow as a reliable and sustainable power source, contributing significantly to reducing carbon emissions. Significant projects are the Brenig and Tir Mostyn and Foel Goch wind farms in the Clocaenog Forest as well as Wern Ddu near Llangwm.

Solar power also plays a vital role in the local energy mix. Solar PV capacity amounted to 1MW of ground-mounted solar PV and 7MW of rooftop solar PV in 2023. Rhug solar farm is Denbighshire's only solar farm.

Renewable energy was generated locally from other sources such as hydroelectricity (2MW) along the River Dee near Corwen and Afon Ceidiog, biomass (3MW) near St. Asaph and Bodelwyddan, and anaerobic digestion (1MW) facilities. These sources further diversify the energy mix, ensuring reliability and sustainability.

In addition to these renewable sources of generation, Denbighshire generated some of its electricity from non-renewable sources. In 2023, two gas-fired generators were connected to the network within the boundary, with a combined capacity of 3MW. See Figure 3.2.19 (overleaf) for a map of larger generators.

While Denbighshire 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 206GWh in 2023. This import ensures a reliable and continuous supply of power.

See overleaf for a map of existing renewable electricity generators in Denbighshire.

Due to a lack of centralised data for existing district heating systems, heat demand met by heat networks in 2023 was not calculated. In 2023, Denbighshire didn't have any heat networks in operation although the council is currently undergoing feasibility assessments for a district heat network in Betws Gwerfil Goch village.

Figure 3.2.18: Heat pump system, Denbighshire

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Analysis – energy generation in 2023

Rooftop solar PV

In 2023, there was a total of 7MW of rooftop solar PV capacity[a] across Denbighshire, roughly equivalent to 3% of buildings (if we estimate that there are 58,000 buildings and rooftop solar PV systems are on average, 4kWp).

This map (Figure 3.2.19) shows the total capacity of rooftop solar PV by outward code, as well as some larger energy generators. Across Denbighshire, the density of rooftop solar PV per substation is roughly consistent, with an average of 0.6-1.6MW connected at each substation. Interestingly, there is slightly more capacity reported in east Denbighshire (properties with outwards codes CH7 and LL11) compared to the west.

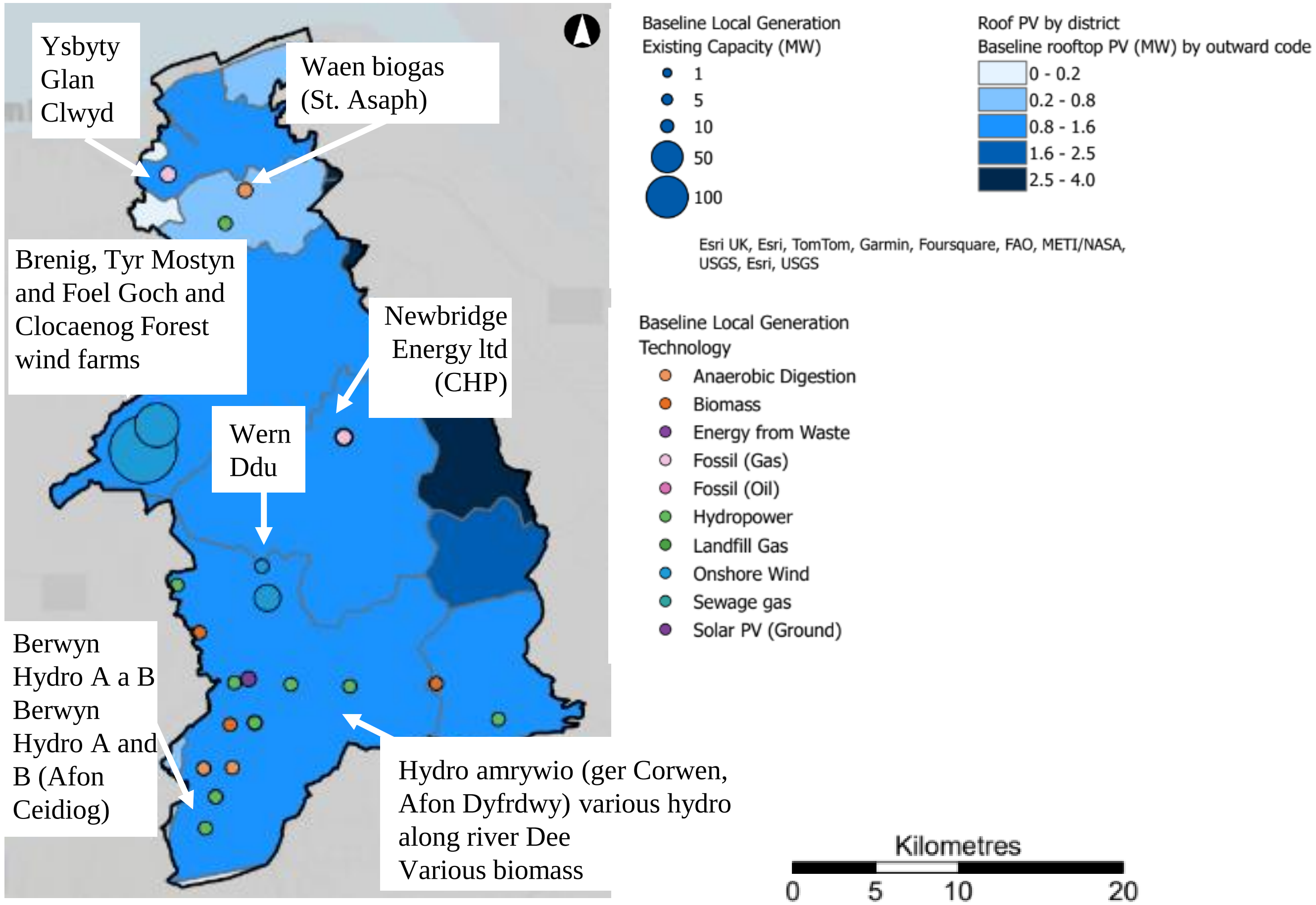


Figure 3.2.19: Local energy generators and their respective capacities (MW) and domestic and non-domestic rooftop solar PV (MW) by outward code (2023)

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Analysis – electricity distribution network

- Presently, Denbighshire faces challenges with existing grid limitations, often leading to new connection delays and substantial expenses. These constraints impact the ability to develop new energy generation and infrastructure, highlighting the need for grid intervention. In simple terms, generation headroom is the amount of new generation that can be supported by an existing substation. For a more technical definition, refer to the Glossary.
- Generation headroom is relatively high in the Clwydian Range and Dee Valley National Landscape. This is likely because this area has low housing density and therefore lower energy demands from housing, and there is only a small capacity being used by local renewable energy generators.
- Demand headroom is the amount of energy demand that a substation can serve at a given point in time. For a more technical definition, refer to the Glossary.
- Demand headroom in Denbighshire varies across the region, from near zero to 8MW per substation zone (median of 0-2MW).

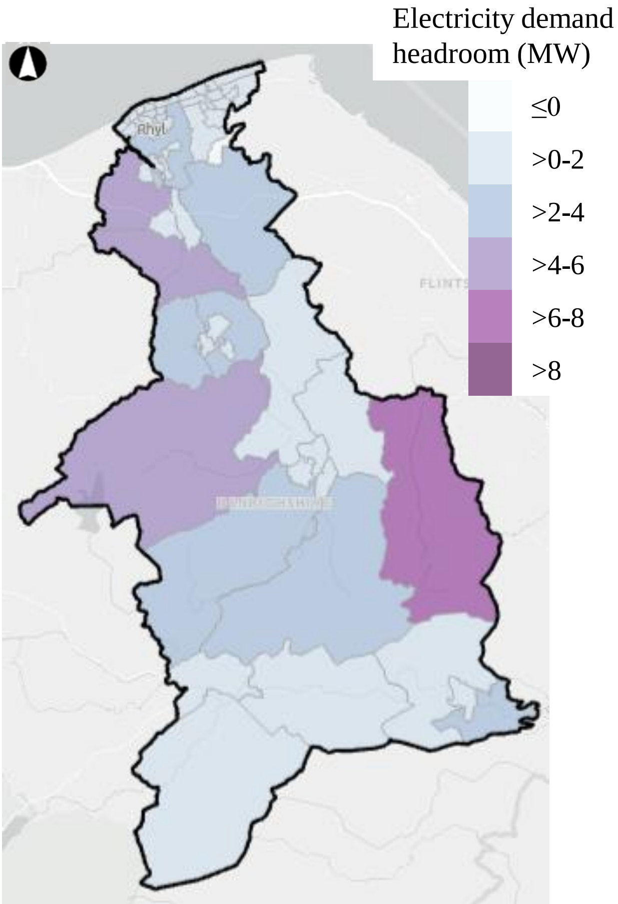


Figure 3.2.20: Electricity demand headroom (MW) by substation zone (2023)

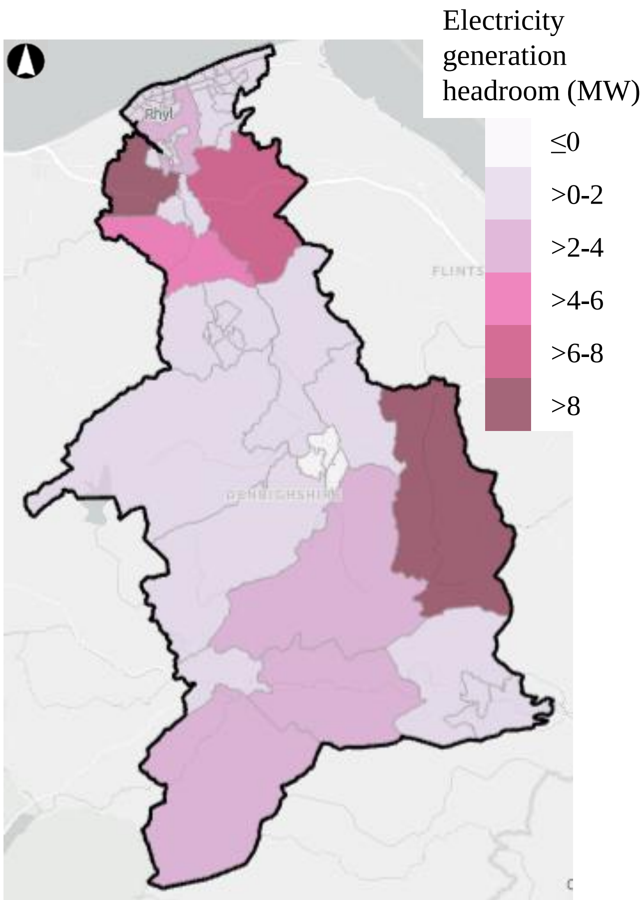


Figure 3.2.21: Electricity generation headroom (MW) by substation zone (2023)

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

25% of homes are not connected to the gas network. This is most prominent in the areas south of Prestatyn, in and around the Clwydian Range and Dee Valley National Landscape and south of Ruthin.

13% of all properties use oil or LPG and 3% use direct electric heating systems. The remaining 9% use biomass, other solid fuels (e.g. coal) or a combination of different fuels. This trend is consistent across the whole county.

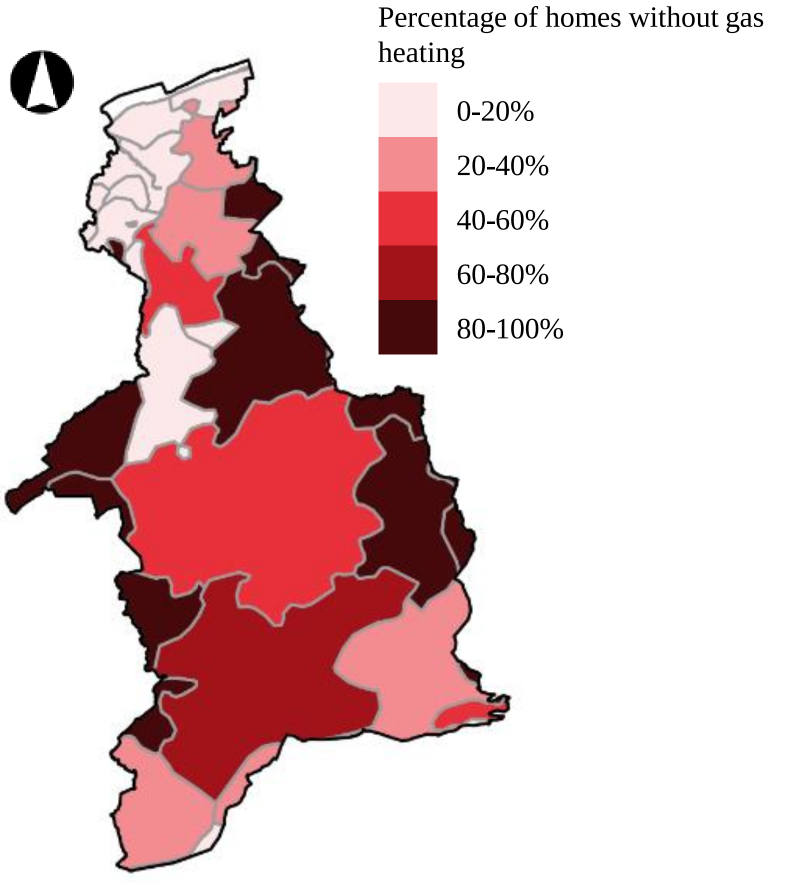


Figure 3.2.22: Percentage of properties that are not connected to the gas distribution network (2023)

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Technical Report

Chapter 4: The future energy system (stage 4-5)

Methodology

Figure 4.1.1: Ysgol Betws Gwerfil Goch solar PV array, Corwen, Denbighshire

4. The future energy system
Methodology overview

This section is structured as follows:

Scenario analysis

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

Deployment modelling

Scenario analysis highlighted energy system components that played a role in all future energy scenarios and could therefore be defined as “low-regret, 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 a net zero energy system, and to set a level of ambition from which the action plan could be based

Chapter 3: The current energy system

Chapter 4: The future energy system

Scenario analysis

- We defined modelling parameters such as the maximum amount of solar and wind which can be installed in Denbighshire.
- We modelled four future energy scenarios scenarios and explored the most cost- and carbon- effective mix of technologies to generate energy to meet future demand.
- We compared the results to identify common energy system components to consider as high priorities for near-term action.

Deployment modelling

- We modelled the rate of deployment for key energy system components, helping us understand by how much we need to ramp up adoption of different technologies over time.
- We estimated the wide benefits of each scenario, looking at the impact of greenhouse gas (GHG) emissions, air quality and employment in the local area.

Chapter 5: Action planning

4. The future energy system
Scenario analysis

Methodology - overview

What is the purpose of scenario analysis?

The process of creating scenarios involves considering different versions of possible futures. Some of these may seem unlikely or even surprising, yet they could still be possible. Other scenarios explore the possible outcomes of choices the world already appears to be making. By exploring multiple scenarios, we can reveal patterns in supply trends, energy sources and renewable technologies that play a part in multiple energy futures and use this to inform Denbighshire'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 of Denbighshire's local energy system consists of many different dependencies, making it challenging to predict how it might look in the future. Therefore, we used scenarios to explore how different potential energy futures might influence how a net zero local energy system is achieved. It's important to note that at this stage of LAEP development, 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 now, and to make informed decisions on a suitable, credible approach to achieving a net zero energy system.

We presented this analysis to stakeholders in workshops to support a decision about what energy propositions Denbighshire would focus on as "low-regret, near-term energy propositions" and those that had a higher risk and uncertainty associated with them based on the modelling results. This information was then taken forwards for further consideration alongside broader plan objectives and local and regional strategic priorities to inform Denbighshire'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"), future energy scenarios and their associated assumptions were agreed with the primary stakeholders, representatives from Ambition North Wales 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 4.1.2 for a description of each scenario and its scope. The final scenario was put forward by Denbighshire County Council and was informed by the council's existing principles, strategic objectives and energy priorities. The local authority Lead sought approval for this alongside the other regionally and nationally-consistent scenarios at the Greener Denbighshire Board.

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Methodology - overview

Level	Scenario	Description
National	Do Nothing	•A scenario for comparison which considers committed activities and assumes that current and consulted upon policy goes forward and remains consistent. •This scenario provides a cost counterfactual. •There is no decarbonisation target for this scenario, and we do not use it in optimisation modelling.
National	National Net Zero	•Uses the lowest lifetime cost and carbon combination of technologies to meet Wales' 2050 net zero target. •Explores impact of energy-reducing initiatives such as home fabric improvements and uptake of active travel and public transport use and high reduction in car use. •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 combined gas cycle turbine (CCGT), grid-level battery storage, nuclear (these are considered as national assets and outside the scope of the LAEP).
Regional	Low Demand	•Considers the lowest plausible future energy demand across different sectors. •Considers a moderate roll-out of home fabric improvements. •Considers a significant shift to active travel and public transport and a reduction in car use. •Model finds the lowest lifetime cost and carbon combination of technologies to meet predicted future energy demand. •Import and export of electricity as National Net Zero.
Regional	High Demand	•Considers the highest plausible future energy demand across all sectors. •Considers significant roll-out of home fabric improvements. •Considers a moderate shift to active travel and public transport and a reduction in car 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.
Local	Maximising Our Potential	•Considers the highest plausible future energy demand across different sectors. •Explores impact of low deployment of energy-reducing initiatives such as home fabric improvements •Explores impact of a significant shift to active travel and public transport use. •Explores impact of restricting electricity imports and increasing reliance on local renewable generation. •Considers hydrogen for heavy goods vehicles but not for home heating. •Uses a lifetime cost- and carbon-optimal range of technologies to meet predicted future energy demand.

Figure 4.1.2: Summary of future energy scenarios

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Methodology – modelling parameters

We developed a set of modelling parameters that describe certain characteristics of The future 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[a], 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), 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. A 3-hr run was also completed, and insights from this more granular time resolution is presented in the analysis section of this report. Please see Uncertainties and sensitivities which discusses modelling sensitivities in more detail, including how timestep impacted the results.

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Methodology – optimisation modelling

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

The results 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 with 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.

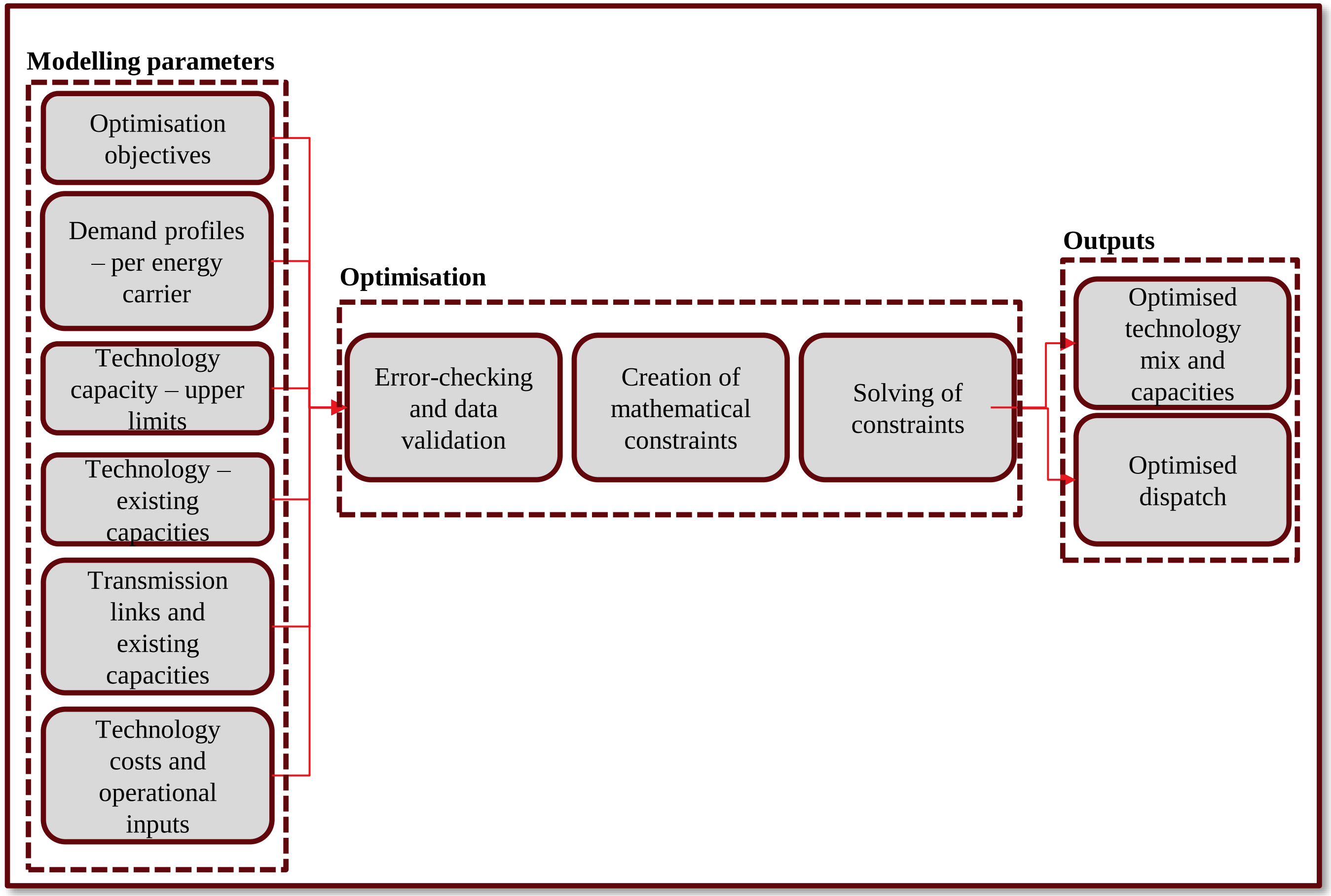

Figure 4.1.3: Optimisation modelling input data and desired outputs

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Methodology - technologies considered

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

Figure 4.1.4 overleaf shows the technologies and carriers (energy vectors) that were modelled for Denbighshire's LAEP.

For each technology we collected key information defining costs, greenhouse gas (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 (£ per kW capacity) • Opex (£ per kWh output)
Technology emissions • Operational carbon emissions (tCO_2e per 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 energy system
Scenario analysis

Methodology - technologies considered

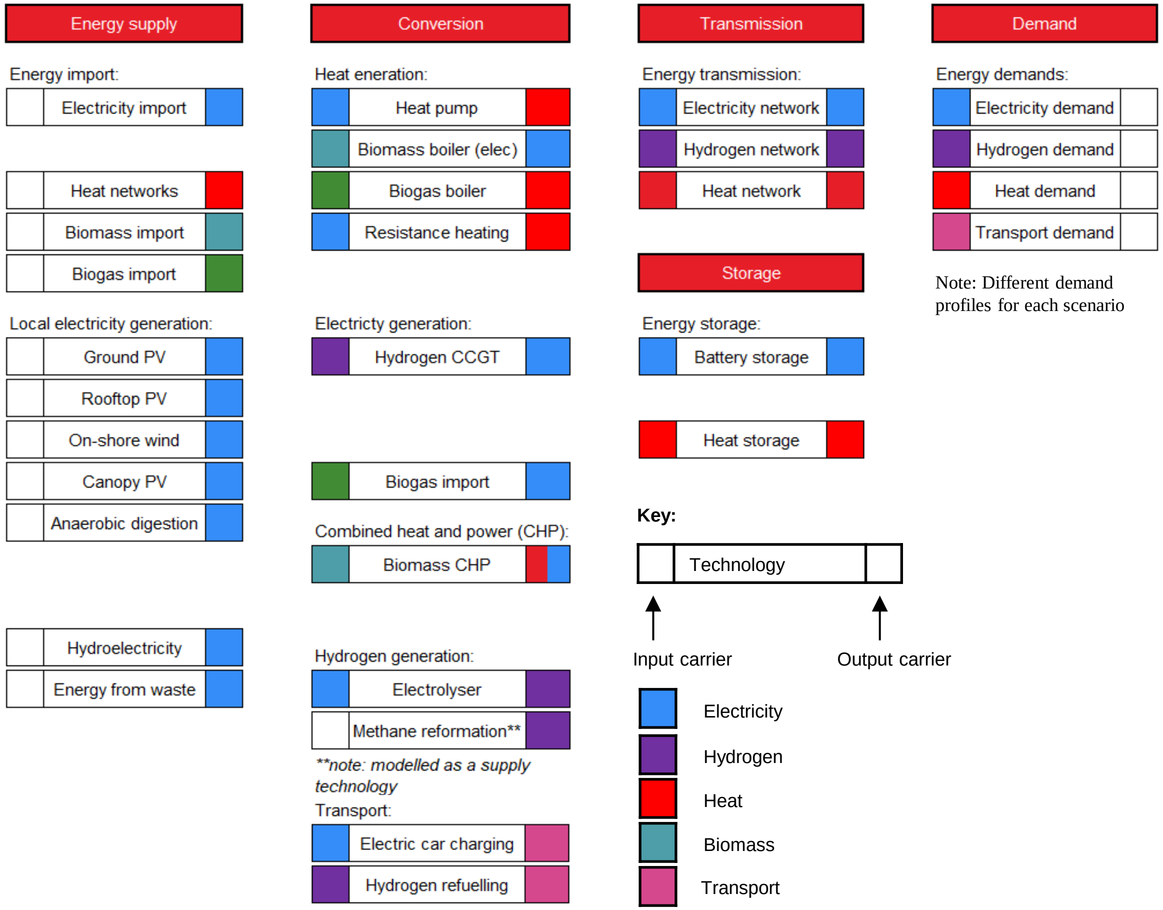

Figure 4.1.4: Technologies included in optimisation modelling

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. See Appendix B3 for more details on the retrofit package applied to each archetype. Electricity and heat profiles, generated at the archetype level, were reduced in line with RdSAP-modelled changes to building thermal properties and aggregated to substation areas.

		High demand	Low demand
	Scenarios that this applies to	**National Net Zero, High Demand, Maximising Our Potential**	**Low Demand**
DOMESTIC	**Electricity demand**	No change from baseline	5% reduction from smart appliances
DOMESTIC	**Heat demand**	Cost-optimal fabric measures applied to upgrade all buildings with a rating of EPC C and below with insulation measures associated with EPC C-rated homes. 17,200 separate retrofits measures installed by 2050.	All buildings below EPC A upgraded with insulation measures associated with EPC A-rated homes. 42,500 separate retrofit measures installed by 2050.
DOMESTIC	**New development build rate**	Average historic build rate applied to 2050. 16% increase in number of homes by 2050	LDP housing targets extrapolated to 2050. 8% increase in number of homes by 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

4. The future energy system
Scenario analysis

Methodology - future energy demand for buildings (continued)

To upgrade buildings to EPC C, the most cost-effective combination of measures was selected e.g., prioritising loft and cavity wall insulations. 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 Local Development Plan (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 (more than 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 (approximately 60% of buildings) and the archetype approach of grouping similar buildings that may have slightly different levels of insulation.

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

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

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Methodology - future energy demand for buildings (continued)

		High Demand	Low Demand
	Other scenarios this applies to	**National Net Zero, High Demand, Maximising Our Potential**	**Low Demand**
NON-DOMESTIC	**Electricity demand**	No change from baseline.	5% reduction from smart appliances.
NON-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 properties. 1,075 separate retrofit measures installed by 2050.	All buildings below EPC A upgraded with insulation measures associated with EPC A-rated properties. 6,146 separate retrofit measures installed by 2050.
NON-DOMESTIC	**Employment site allocation**	LDP employment land allocations/jobs projection (proxy) extrapolated to 2050. 55% increase in commercial floorspace from 2023 to 2050.	LDP employment land allocations/jobs projection (proxy) extrapolated to 2050. 32% increase in commercial floorspace from 2023 to 2050.
NON-DOMESTIC	**Weather profile**	4 days with temperature profiles equivalent to the 'Beast from the East' (extreme weather event in 2018 with -7°C lowest temp).	2 days with Beast from the East (-7°C lowest temp) temperature profiles.
NON-DOMESTIC	**Interventions for retrofit considered**	**Same as domestic**, plus MEV/MVHR ventilation	**Same as domestic**, plus MEV/MVHR ventilation

Table 4.2.2: Assumptions for non-domestic buildings in each future energy scenario

4. The future energy system
Scenario analysis

Methodology – future energy demand for transport

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

Like the baseline analysis, we used the North Wales Transport Model (NWTM)[TN12] to determine transport demand across Denbighshire. 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 proportions from National Grid's "Leading the Way" 2050 future energy scenario (FES)[T31] percentages to the annual mileage for the baseline. Refer to Table 4.2.3 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[TN12] to account for modal shifts. The selection of growth factors varied based on the specific scenario considered. Table 4.2.4 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/ Light Goods Vehicles (LGVs)	100	0
Heavy Goods Vehicles (HGVs)	86	14

Table 4.2.3: Assumptions for the proportion of mileage covered by vehicle type and fuel in the High Demand and Low Demand future energy scenarios

Methodology – future energy demand for transport (continued)

	High demand	Low demand
Applies to:	**High Demand**	**National Net Zero, Low Demand, Maximising Our Potential**
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% (National Grid's FES (2022) Leading the Way scenario[T31]). **LGVs** – Increase by 15% (National Grid's FES (2022) Leading the Way scenario[T31]).

Table 4.3.4: Assumptions for future transport energy demand in each future energy scenario

Methodology– future energy demand for industry

The NAEI (National Atmospheric Emission Inventory) large point sources database[T20] was used as the primary source of information to identify large emissions sources from the industrial sector, at a known location. The sites in this database were subsequently categorised as using high-grade heat or low-grade heat processes.

Limitations

The NAEI database[T20] doesn't include all large point sources as some information is deemed disclosive. Therefore, companies that owned industrial sites in Denbighshire 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 in Denbighshire, 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 greenhouse gas (GHG) emissions) in the future energy scenarios that we modelled.

4. The future energy system
Scenario analysis

Methodology – maximum potential capacities for solar PV and onshore wind

The maximum theoretical amount of renewable resource (onshore wind, ground-mounted solar PV, and rooftop solar PV) was included in the energy model as the sum of the baseline capacity[a] (discussed previously in Chapter 2) and the 2050 renewable resource (discussed below) for each technology.

2050 renewable resource – onshore wind and ground-mounted solar PV

The maximum theoretical resource was calculated using local authority-specific renewable and low carbon energy assessments (RLCEA) and/or local development plans (LDP). These areas, along with an estimate of the equivalent land requirement land area are shown in Table 4.3.5. A full breakdown of sources 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 per area) were used to estimate available capacity (MW) at the LA- and substation-level.

2050 renewable resource – rooftop solar PV

Maximum available new resource for rooftop solar 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 that 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, discussed further in the Chapter 4: Deployment modelling.

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[T54] atmospheric model. For solar irradiance, the hourly profile assumed an optimal slope and azimuth, and used the PVGIS-SARAH2[T55] radiation database.

	Maximum theoretical capacity (MW)	Equivalent land area (km^2)
Ground-mounted solar PV	1,070	20 (2% total land area)
Onshore wind	156	19 (2% total land area)

Table 4.3.5: Maximum theoretical capacities (inc. operational sites) and total area suitable (inc. operational sites) for ground-mounted solar PV and onshore wind

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

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

Figure 4.1.5 shows the location of different land packages that could be suitable for ground-mounted solar PV, onshore wind or both, and the generation capacity[a] 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 Denbighshire that are ranked highly based on defined criteria for different low carbon technologies, including ground-mounted solar PV and onshore wind.

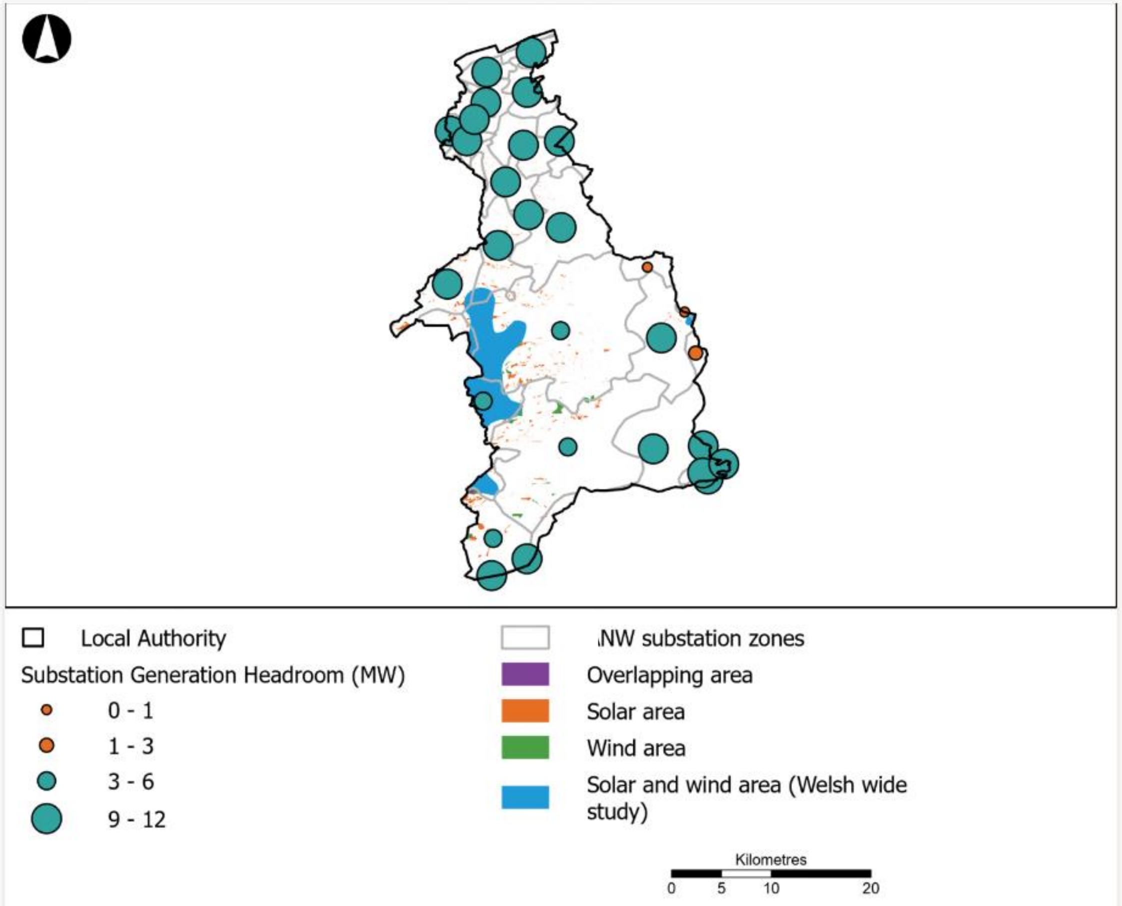

Figure 4.1.5: Map showing areas suitable for wind and ground-mounted solar PV development in Denbighshire, based on a Wales-wide study completed by Arup in 2019[T47] and substation generation headroom (MW) by substation

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

4. The future energy system
Scenario analysis

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

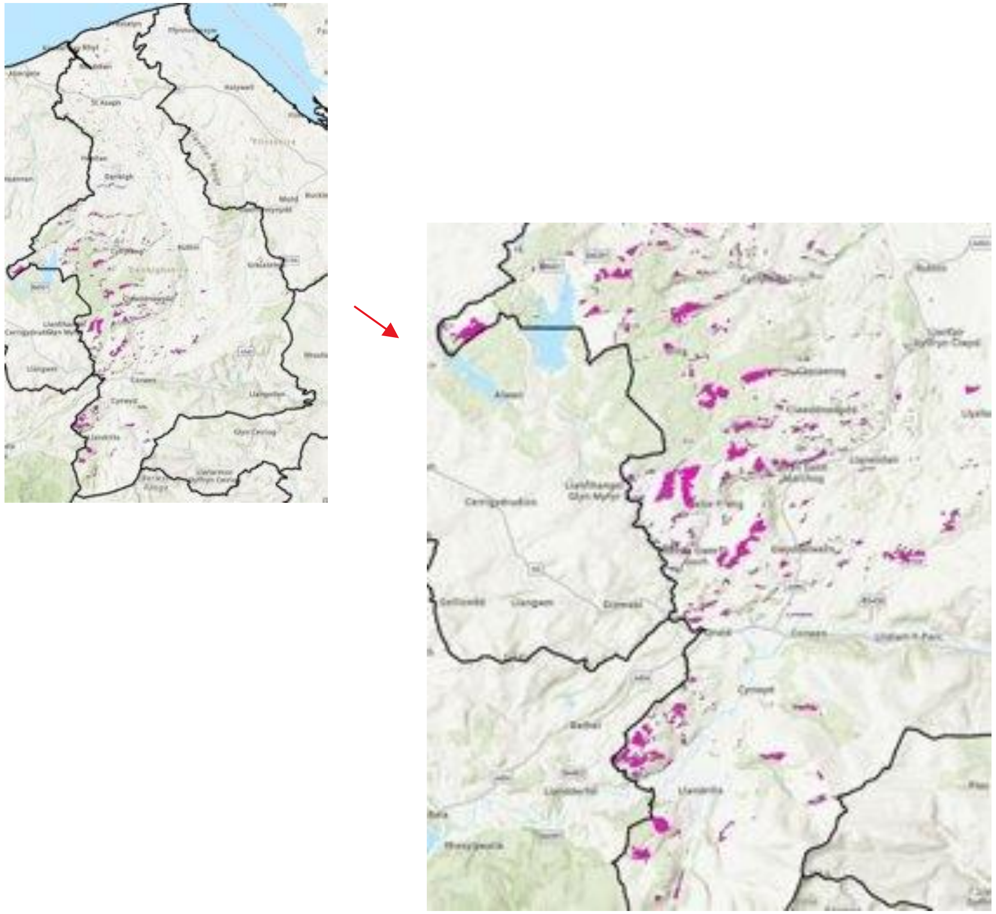

Figure 4.1.6: Map showing areas suitable for onshore wind development in Denbighshire, based on a Wales-wide study completed by Arup in 2019 and substation generation headroom (MW) by substation

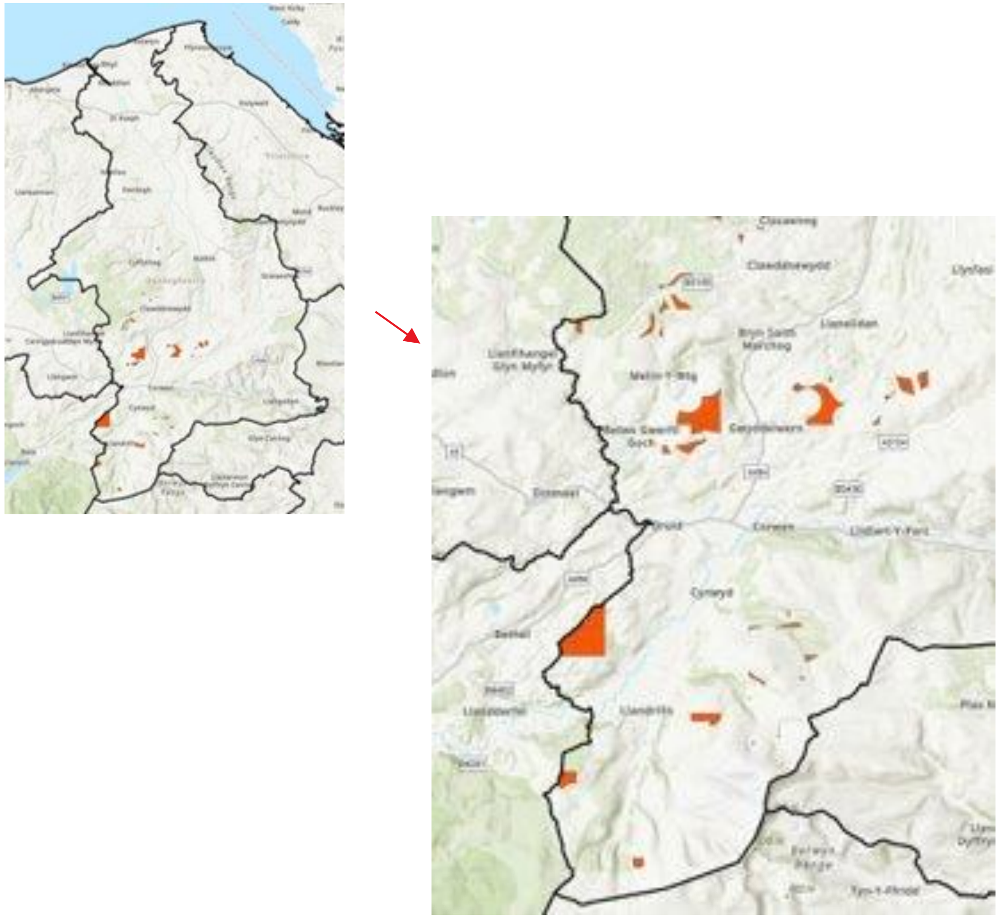

Figure 4.1.7: Map showing areas suitable for ground-mounted solar PV development in Denbighshire, based on a Wales-wide study completed by Arup in 2019 and substation generation headroom (MW) by substation

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[a] 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.

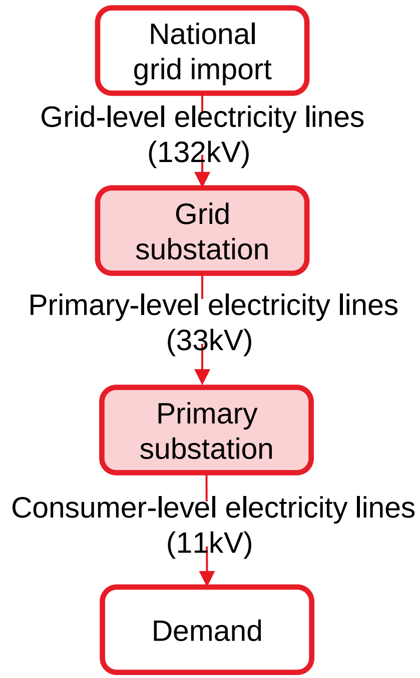

Figure 4.1.8: Modelled electricity flow for each zone

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

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[a].

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.

We tested the sensitivity of hydrogen for home heating, and the result was an additional amount of peaking capacity for systems but no hydrogen boilers chosen as the primary system for heating in homes. This was also the case when evaluating potential for future heat networks (see overleaf). Based on this evidence, we have not considered hydrogen for heating homes in the future energy scenarios modelled.

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 £1,000 per household[T33] to £2,300 per household[T34] - it is still an area of great cost uncertainty[T33], especially since the data available is not specific to Denbighshire or Wales.

	Low hydrogen
Scenario application	**National Net Zero, Low Demand, High Demand, Maximising Our Potential**
Industry	*No processes classified as "industrial" in Denbighshire.*
Transport	A proportion of vans and HGVs use hydrogen.
Domestic / commercial heat	Hydrogen is not considered for domestic/commercial heat.

Table 4.3.5: Summary of assumptions related to hydrogen demand applied to future energy scenarios

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Methodology – heat networks

Heat networks are an option for supplying heat to buildings in our scenario modelling. Heat networks supply heat to buildings through hot water pipes in the ground from a centralised heat source. Centralised heat sources in low carbon heat networks may be heat pumps (boosting heat from sources like air, ground, water, or waste heat), or hydrogen boilers.

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

How were heat networks modelled?

To determine which buildings should be supplied by heat networks rather than decentralised heat pumps in a future, optimised energy system, Arup used its proprietary HeatNet tool to assess where networks could offer a lower levelised cost of heat (LCoH) than decentralised heat pumps. The tool builds a digital representation of the local road network and uses a specialised algorithm to evaluate the combination of pipework routes and connected heat loads that maximises the amount of connected demand while minimising pipework length and maintaining a LCoH lower than the value for decentralised ASHPs. The LCoH is evaluated through a built-in discounted cashflow model. See Appendix B7 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[a] of heat pumps selected by the Calliope[T30] 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.

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Methodology – heat networks

To capture the full potential of heat networks, known, location-specific waste heat sources (for example, substations, water and sewage treatment works, mine water treatment works, industrial sites, data centres, cold stores), their temperature and their supply potential were mapped across Denbighshire to include in the model. This includes waste heat generated by national assets, since the waste heat is a locally available resource. The modelling doesn't consider waste heat sources that are known but show no extraction potential because it would be challenging to assign a location for these sources, and therefore the potential to act as an energy source for a heat network. Hydrogen boilers were considered in 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 Air Source Heat Pumps (ASHPs)) with lower COPs were made available without requiring networks to route to specific locations. **There were no potential heat networks identified in Denbighshire within the scope of this assessment.**

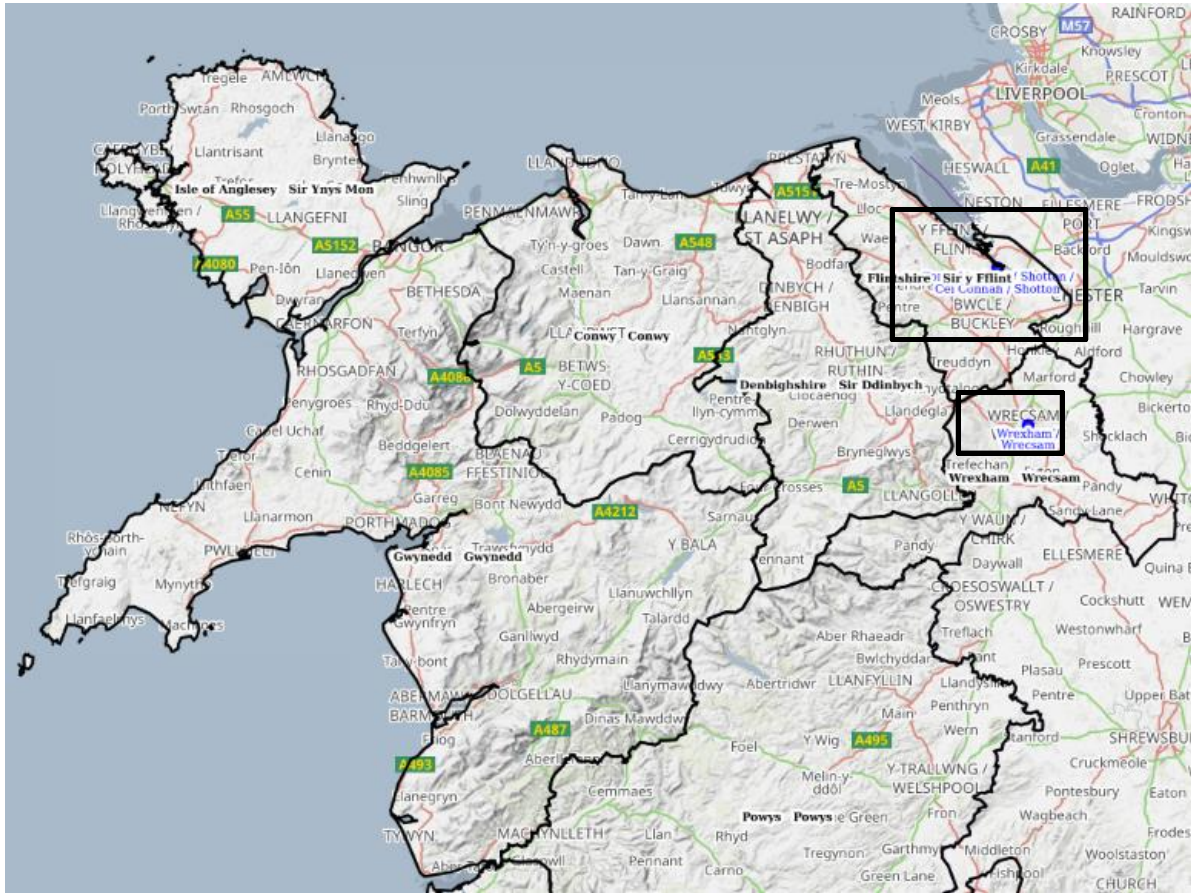

Figure 4.1.9: Map showing priority areas for heat networks in North Wales according to Policy 16 in Net Zero Wales[T02]

Sponsors: Delivery partners:

Technical Report

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

Analysis

Figure 4.2.1: Cysgod Y Gaer, Corwen, Denbighshire

4. The future energy system
Analysis

We have explored several future energy scenarios to help us create a strategic plan of action for decarbonising the local energy system. The following Sankey diagrams are an output from our modelling and show four potential future energy systems for Denbighshire. 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 Denbighshire's near-term action plan.

Sponsors:

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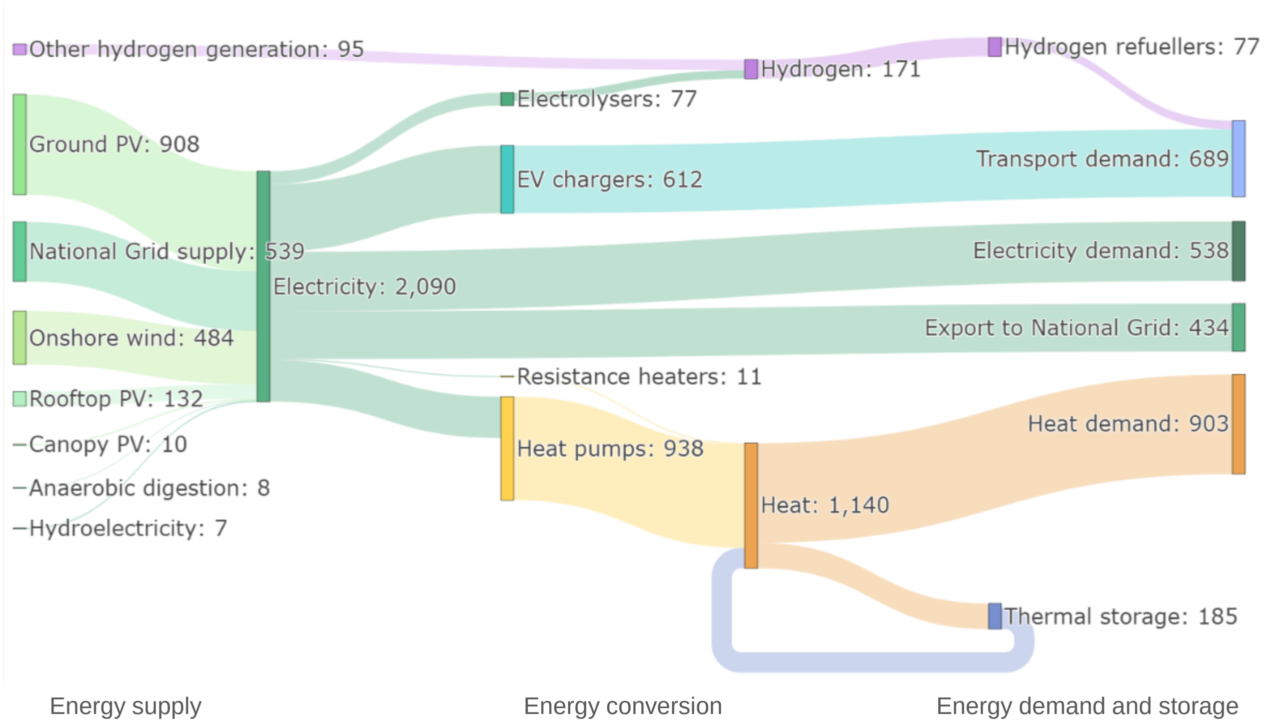
National Net Zero scenario – annual energy flows (GWh)

There could be a significant increase in renewable energy generation, especially ground-mounted solar PV (900 times higher than baseline) and onshore wind (1.7 times higher than baseline).

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

Electricity could be supplied by the National Grid and could increase by 2.7 times compared to the baseline.

There could be smaller contributions from anaerobic digestion and hydroelectricity, which stay consistent to the baseline.



Annual electricity generation could be 4.6 times larger than the baseline.

Heat could be generated mostly by heat pumps (82%), with smaller contributions from resistance heaters (2%) and thermal storage (16%).

Thermal storage could help to meet heat demand when renewable sources are not available at time of demand (16% of heat generation).

21% of generated electricity could be exported when it's not required to meet local demand.

Electricity could meet 89% of transport demand and hydrogen could meet 11% of transport demand.

Figure 4.2.2: Sankey diagram for a potential future 2050 energy system – National Net Zero scenario (GWh). Based on a 3-hour timestep

4. The future energy system
Analysis

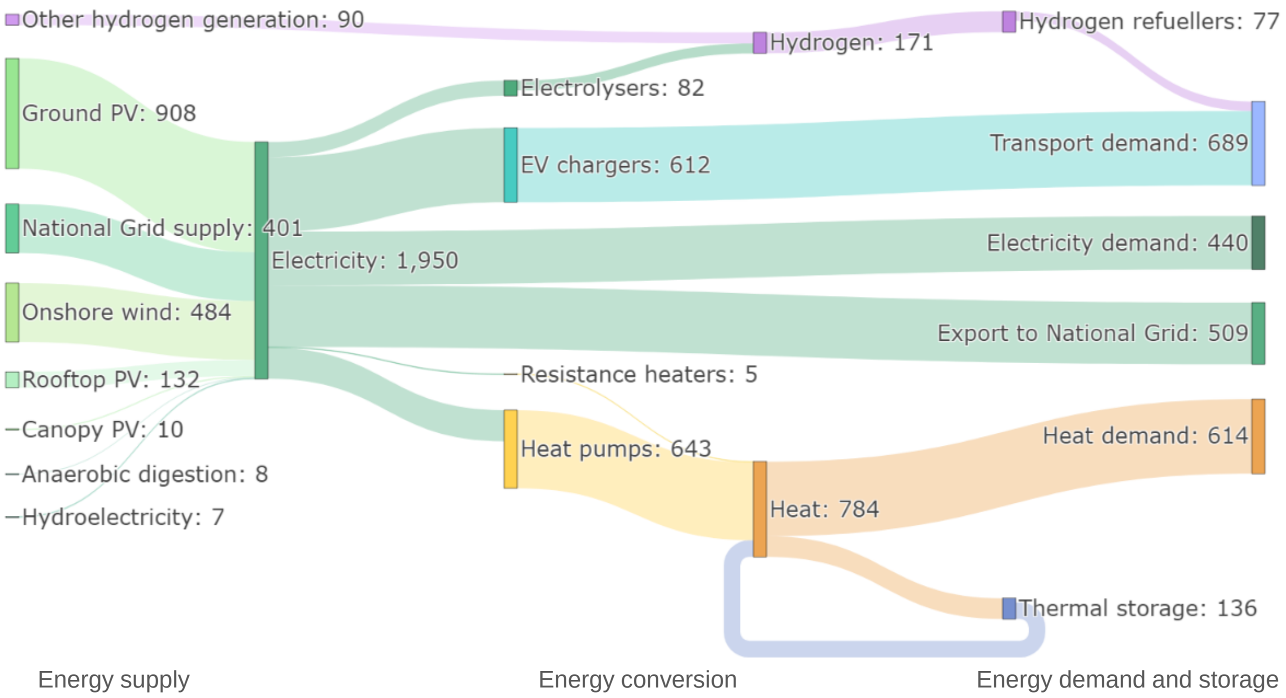
Low Demand – annual energy flows (GWh)

There could be a significant increase in renewable energy generation, especially ground-mounted solar PV (900 times higher than baseline) and onshore wind (1.7 times higher than baseline).

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

Electricity could be supplied by the National Grid and could increase by 2 times compared to the baseline.

There could be smaller contributions from anaerobic digestion and hydroelectricity, which stay approximately consistent to the baseline.



Annual electricity generation could be 4.2 times larger than the baseline.

Heat could be generated mostly by heat pumps (82%), with smaller contributions from resistance heaters (1%) and thermal storage (17%).

Thermal storage could help to meet heat demand when renewable sources are not available at time of demand (17% of heat generation).

26% of generated electricity could be exported when it's not required to meet local demand.

Electricity could meet 89% of transport demand and hydrogen could meet 11% of transport demand.

Figure 4.2.3: Sankey diagram for a potential future 2050 energy system – Low Demand scenario (GWh). Based on a 3-hour timestep

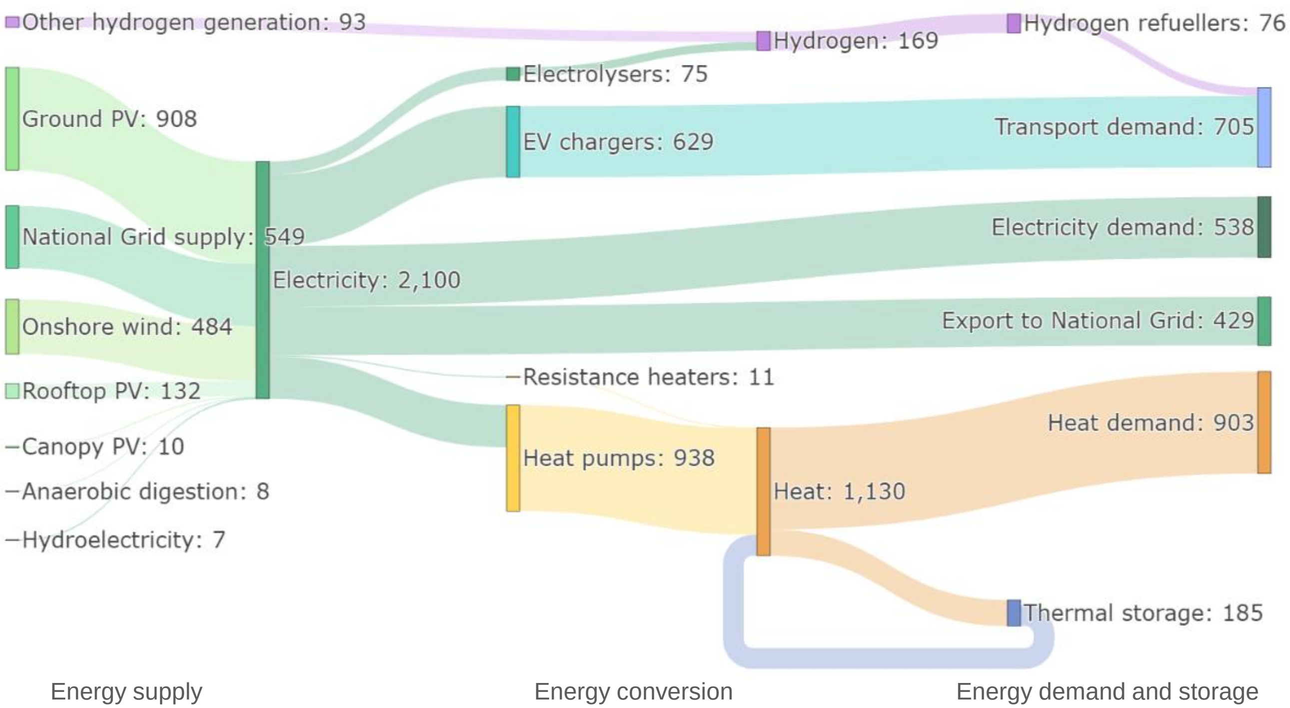
High Demand – annual energy flows (GWh)

There could be a significant increase in renewable energy generation, especially ground-mounted solar PV (900 times higher than baseline) and onshore wind (1.7 times higher than baseline).

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

Electricity could be supplied by the National Grid and could increase by 2.7 times compared to the baseline.

There could be smaller contributions from anaerobic digestion and hydroelectricity, which stay approximately consistent to the baseline.



Annual electricity generation could be 4.8 times larger than the baseline.

Heat could be generated mostly by heat pumps (83%), with smaller contributions from resistance heaters (1%) and thermal storage (16%).

Thermal storage could help to meet heat demand when renewable sources are not available at time of demand (16% of heat generation).

20% of generated electricity could be exported when it's not required to meet local demand.

Electricity could meet 89% of transport demand and hydrogen could meet 11% of transport demand.

Figure 4.2.4: Sankey diagram for a potential future 2050 energy system – High Demand scenario (GWh). Based on a 3-hour timestep

4. The future energy system
Analysis

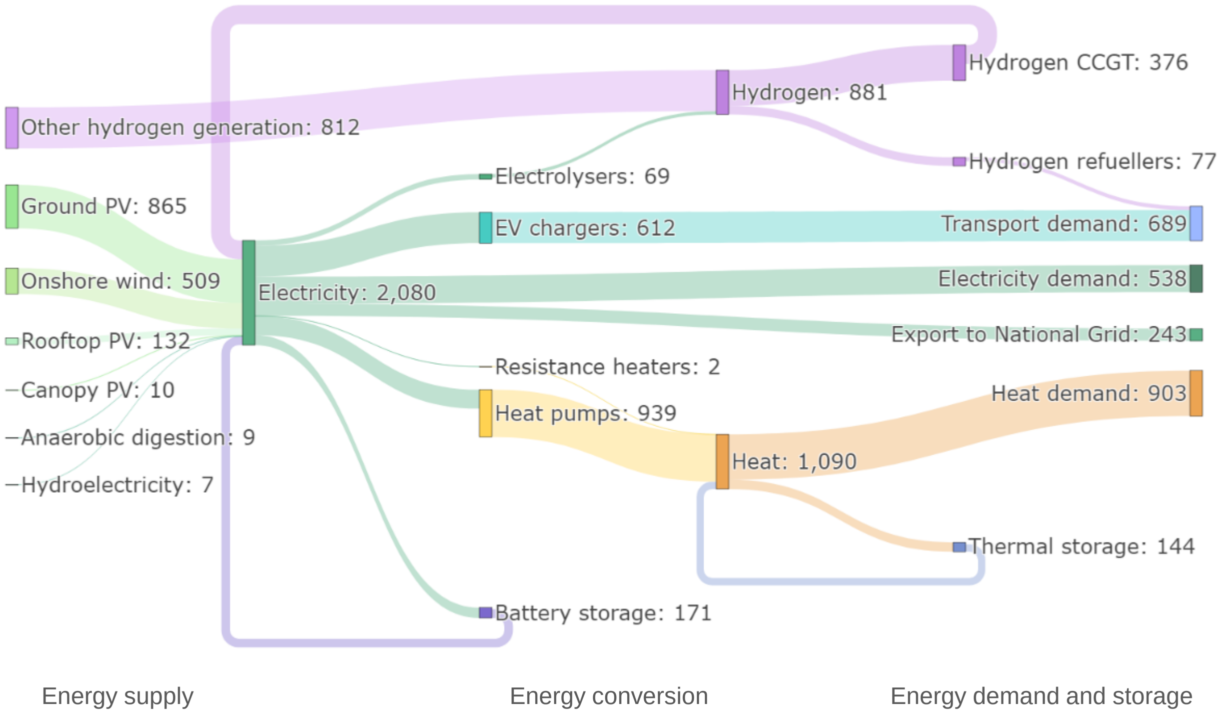
Maximising Our Potential – annual energy flows (GWh)

There could be a significant increase in renewable energy generation, especially ground-mounted solar PV (900 times higher than baseline) and onshore wind (1.8 times higher than baseline).

Annual electricity generation could be 4.5 times larger than the baseline.

Hydrogen could be imported or generated from electrolysis to supply Heavy Goods Vehicles and to be converted to electricity at times where renewable sources are not available to meet demand.

There could be smaller contributions from anaerobic digestion and hydroelectricity, which are slightly higher than the baseline.



In this scenario, no electricity is imported from National Grid.

Battery storage could be needed to store electricity when it is not needed at the time of generation

Heat could be generated mostly by heat pumps (86%), with smaller contributions from resistance heaters (1%) and thermal storage (13%).

Thermal storage could help to meet heat demand when renewable sources are not available at time of demand (13% of heat generation).

12% of generated electricity could be exported when it’s not required to meet local demand.

Electricity could meet 89% of transport demand and hydrogen could meet 11% of transport demand.

Figure 4.2.5: Sankey diagram for a potential future 2050 energy system – Maximising Our Potential scenario (GWh). Based on a 3-hour timestep

Comparing future energy scenarios – annual energy flows (GWh)

Scenario analysis helped identify energy system components that the model selected in all scenarios. These components were defined as "low-regret, near-term components" and formed the basis of Denbighshire's energy propositions. The system components that weren't selected in every scenario were considered in the longer-term, and in conjunction with broader policy decisions. Table 4.2.1 and Table 4.2.2 (overleaf) show what system components are recommended in each future energy scenario and on average, the amount of energy generated/converted/transferred by the energy system in one year, alongside Denbighshire's energy baseline for 2023.

All scenarios suggest a transition to renewable energy sources, especially ground-mounted and rooftop solar PV and onshore wind. In contrast, the modelling indicates that electricity generated using biomass decreases across all scenarios, likely due to there being less need as renewable capacity[a] from solar PV and wind increases.

Modelling indicates that hydrogen could be incorporated into the energy mix in all scenarios to meet transport demand. It's only in the Maximising Our Potential scenario that hydrogen could act as a "dispatchable" energy source to produce electricity at short notice and at times where intermittent forms of energy (solar, wind) are not available to meet demand.

Energy system components	Baseline (GWh)	National Net Zero (GWh)	High Demand (GWh)	Low Demand (GWh)	Maximising Our Potential (GWh)
Biomass	50	0	0	0	0
Coal	9	0	0	0	0
Hydroelectricity	7	7	7	7	7
Other hydrogen generation	0	95	93	90	812
Natural gas	644	0	0	0	0
Oil	214	0	0	0	0
Onshore wind	214	484	484	484	509
Rooftop/Canopy solar PV	6	142	142	142	142
Ground-mounted solar PV	1	908	908	908	865
Petrol/diesel	1,520	0	0	0	0

Table 4.2.1: Comparison of energy sources across the scenarios

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Sponsors:

Delivery partners:

Comparing future energy scenarios – annual energy flows (GWh)

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.

Hydrogen Combined Cycle Gas Turbine (CCGT) is only used in the Maximising Our Potential scenario where grid import is restricted. It is used to convert hydrogen into electricity to meet electricity demand when renewable generation is not available. Thermal storage is used to store excess heat generated and discharge it when it is needed.

In all scenarios, battery storage was allowed as a technology that the model could choose to optimise the future energy system to meet demand. This can happen simultaneously with grid export (i.e. it is not a true alternative). In most scenarios, building batteries is more expensive than grid import, and thus the model does not choose to build batteries. However, in the maximising our potential scenario, grid import is not allowed, so the model instead chooses to build batteries to meet the electricity demand. The balance between technologies (including the interaction between batteries and grid export, as discussed here) is determined in the optimisation model based on the carbon / cost inputs.

Energy system components	Type	Baseline (GWh)	National Net Zero (GWh)	High Demand (GWh)	Low Demand (GWh)	Maximising Our Potential (GWh)
Anaerobic digestor (plant)	C	7	6	8	8	9
Electrolyser	C	0	77	75	82	69
Heat pumps	C	0	938	938	643	939
Hydrogen CCGT[a]	C	0	0	0	0	376
Resistance heaters	C	0	11	11	5	2
Biomass boiler	C	20	0	0	0	0
Coal/solid fuel/oil boiler	C	156	0	0	0	0
Battery storage	S	0	0	0	0	171
Thermal storage	S	0	185	185	136	144
EV chargers	T	0	612	629	612	612
Export to National Grid	T	0	434	429	509	243
Hydrogen refuellers	T	0	77	76	77	77
National Grid supply	T	206	539	549	401	0

[a]Combined Gas Cycle Turbine

Table 4.2.2: Comparison of energy conversion (C), transfer (T) and storage (S) technologies and transfer systems across the scenarios

Balancing future energy systems – monthly electricity generation and consumption (GWh)

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

Electrification of transport could make up a significant amount of the final electricity demand. 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 February and October.

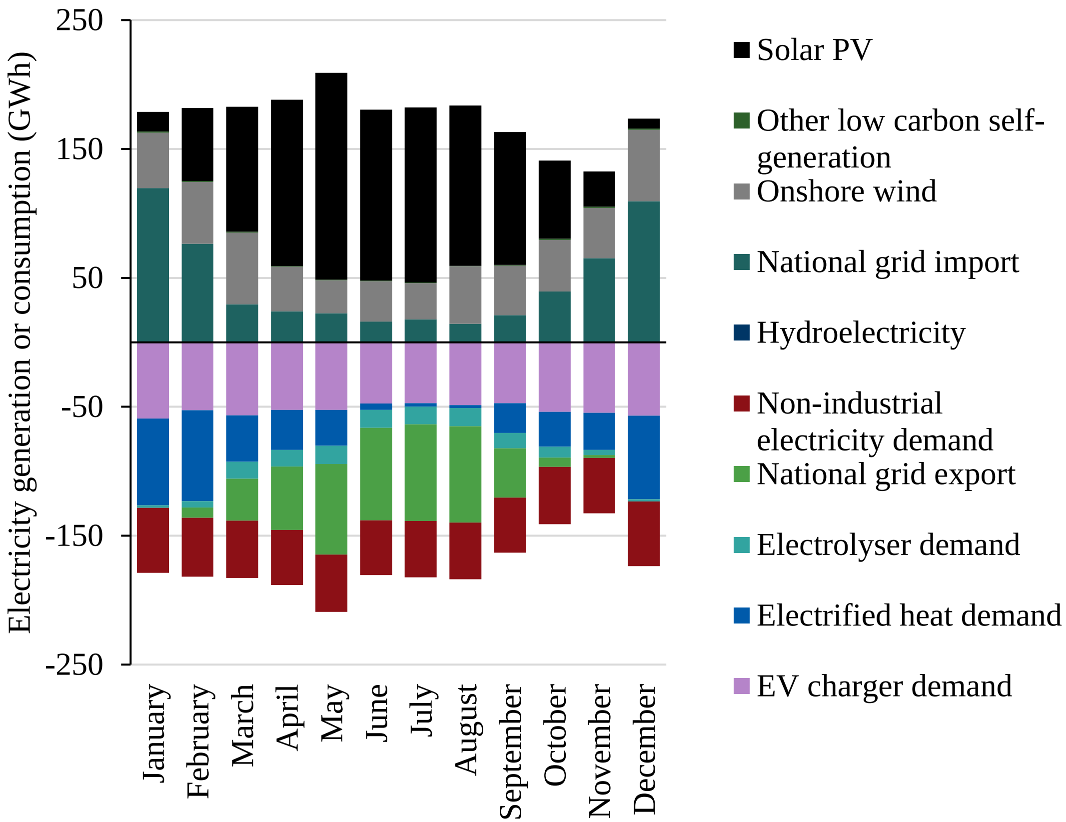


Figure 4.2.6: Monthly electricity generation and consumption in the High Demand scenario

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. In the summer months, the amount of energy exported to the grid increases where it is not used locally.

Electrified heat demand is not 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.

Sponsors: Cyngor Sir Ddinbych Denbighshire County Council; Llywodraeth Cymru Welsh Government; Uchelgais Gogledd Cymru Ambition North Wales
Delivery partners: ARUP; Carbon Trust

Comparing future energy scenarios - buildings

Figure 4.2.7 shows the different technologies that could be 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 there are higher demands. Heat storage also reduces greenhouse gas (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 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.

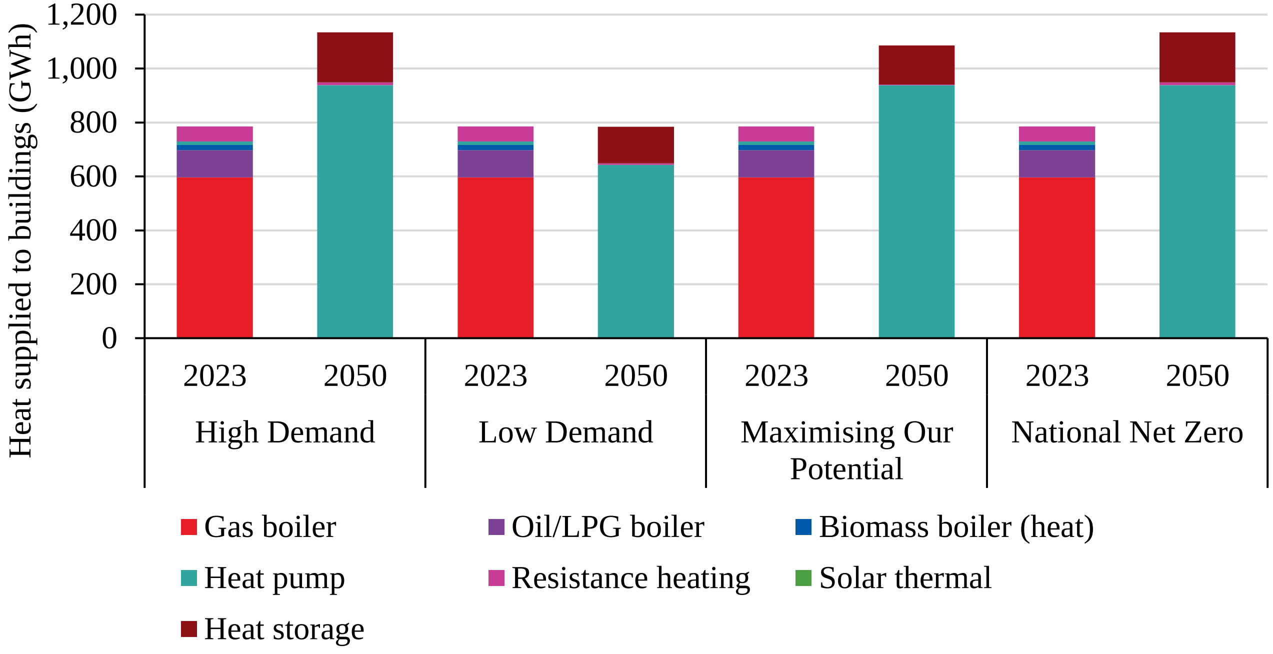


Figure 4.2.7: Proportion of heat supplied to buildings by technology in 2050 for each scenario

Comparing future energy scenarios - buildings

Figure 4.2.8 shows the total number of energy efficiency measures that could 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, loft, and sometimes floor 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.

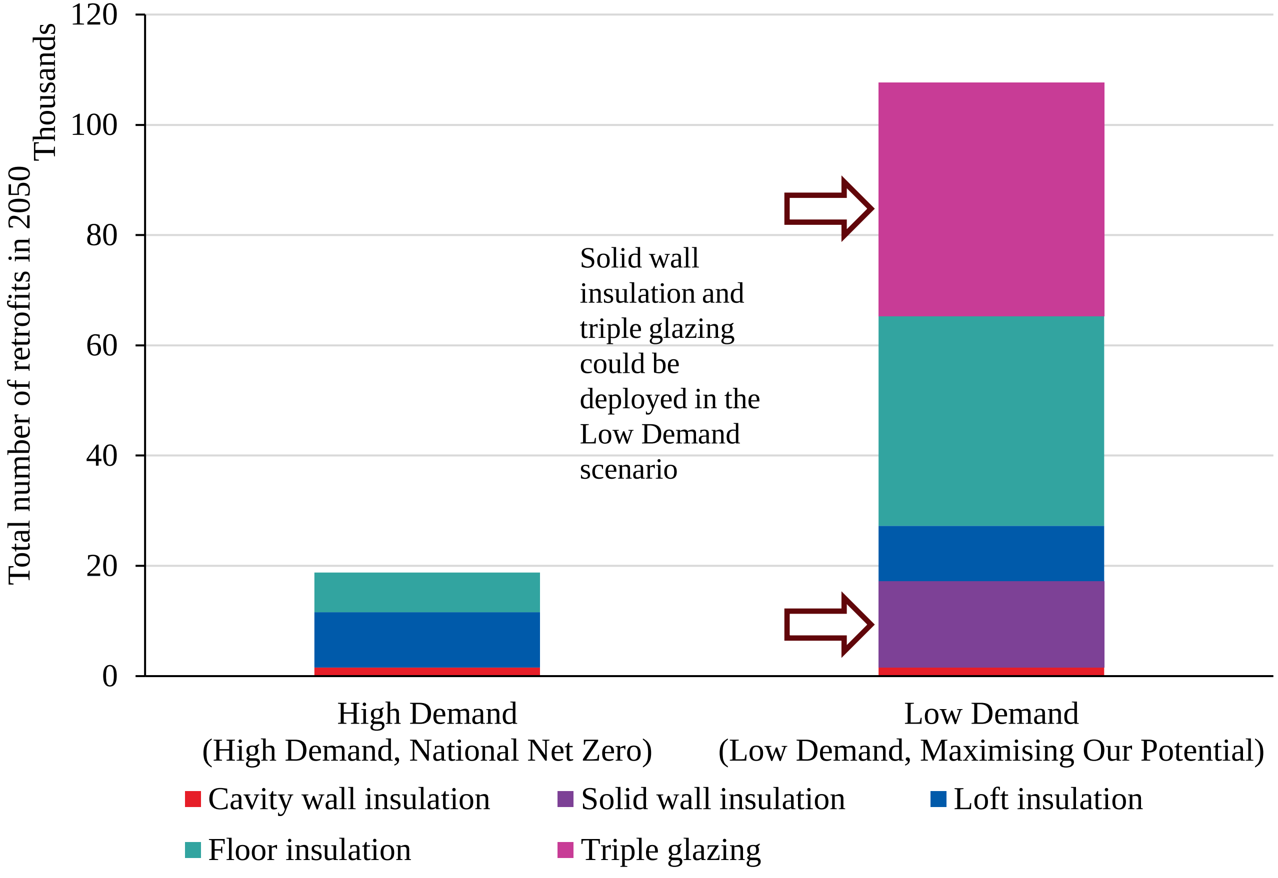


Figure 4.2.8: Proportion of homes with insulation measures

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. 18,000 retrofits could be completed between 2023 and 2050.

Low Demand: All buildings below EPC A upgraded with insulation measures associated with EPC A ratings. 45,000 retrofits could be completed between 2023 and 2050.

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.

Insulation retrofit measure	**Unit**	**High Demand** *(applies to: High Demand, National Net Zero*	**Low Demand** *(applies to: Low Demand, Maximising Our Potential*
Existing homes	Number	46,000	
Cavity wall insulation	number of retrofits (% total)	1,500 (3%)	1,500 (3%)
Floor insulation		7,200 (16%)	38,000 (83%)
Loft insulation		10,000 (22%)	10,000 (22%)
Solid wall insulation		0	16,000 (35%)
Triple glazing		0	42,000 (91%)
Existing commercial units	Number	4,000	
Cavity wall insulation	number of retrofits (% total)	65 (2%)	65 (2%)
Floor insulation		93 (2%)	1,900 (48%)
Loft insulation		260 (7%)	320 (8%)
Solid wall insulation		0	1,100 (28%)
Triple glazing		730 (18%)	2,900 (73%)

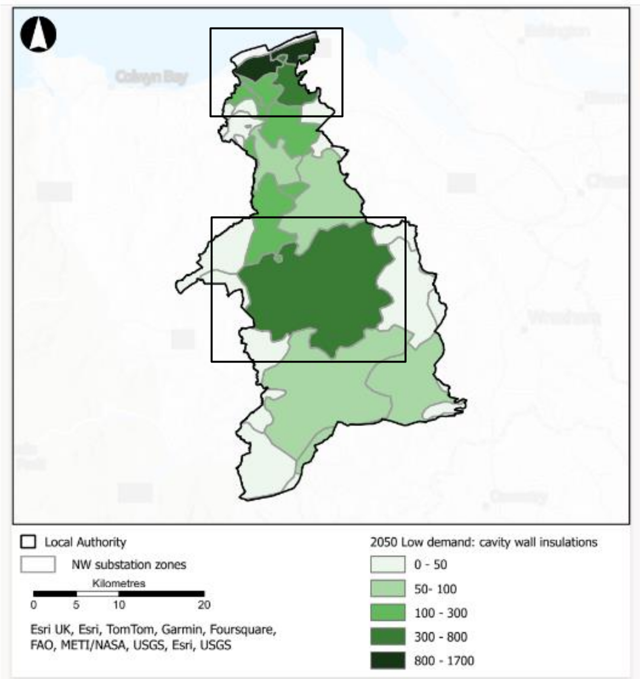
Table 4.2.3: Proportion of total homes that receive different insulation retrofit measures in each 2050 future energy scenario

4. The future energy system
Analysis

Comparing future energy scenarios - buildings

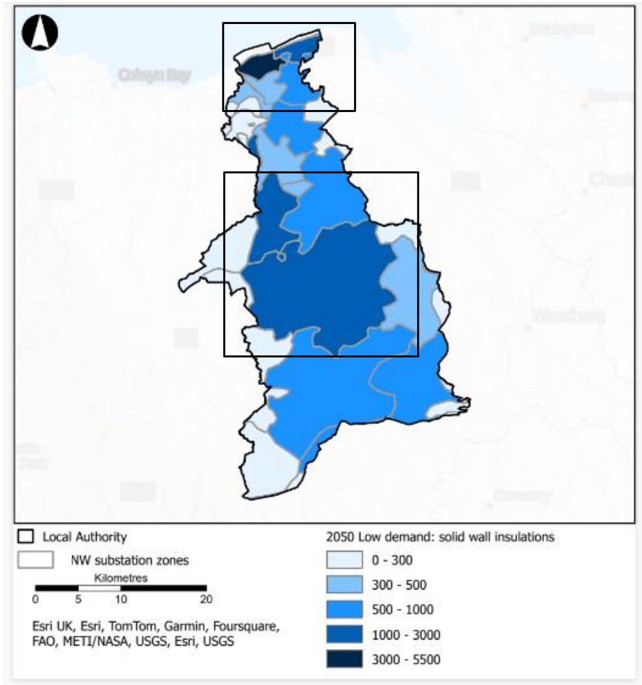
Overall, the maps show that a higher number of insulation measures could be installed in the substation zones that cover Rhyl, Prestatyn, Denbigh and Ruthin (Dyserth Road T_1, Church Lane T_1, Llanfwrog T_1, Denbigh T_1). This is likely due to:

- Relatively high housing density and commercial activity in these areas – this means greater opportunity for installation.
- The existing energy performance of buildings in each area – In some areas to the north of the County, the proportion of homes rated EPC A-C can be between 0-20% which means there is greater room for improvement compared to other areas.



- The map shows up to 1,700 cavity wall insulations could be installed in the northern parts of the County. This could be because buildings in this area are more likely to have cavity walls.

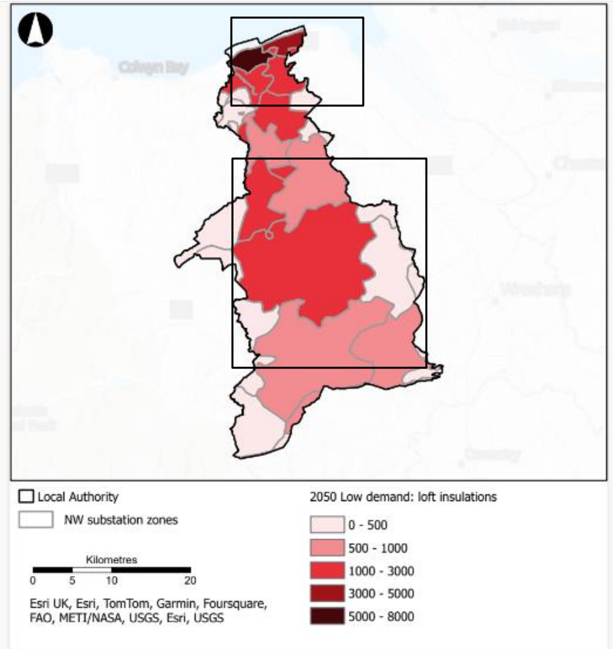
Figure 4.2.9: Map showing the number of additional cavity wall insulation measures fitted by 2050 by substation zone in the Low Demand scenario



- The number of solid wall insulations could be much higher in Corwen (Corwen T_1), and Llangollen (Llangollen T_1) compared to cavity wall insulations, suggesting that buildings in these areas are more likely to be of solid wall construction.

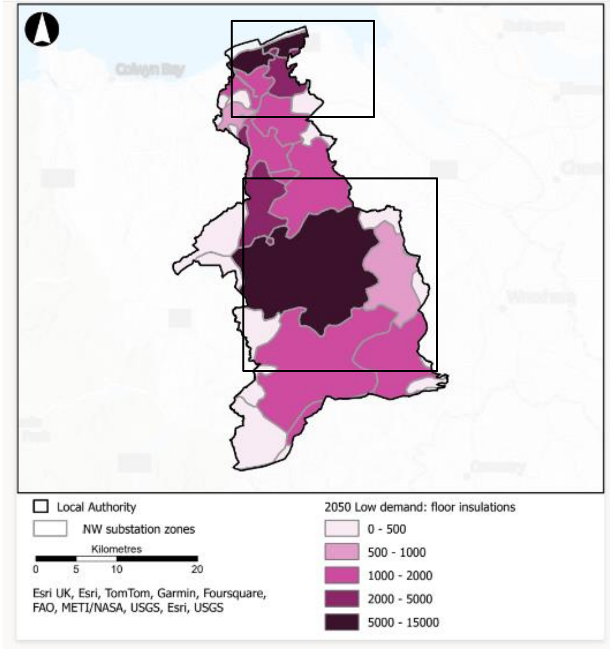
Figure 4.2.10: Map showing the number of solid wall insulation measures fitted by 2050 by substation zone in the Low Demand scenario

Comparing future energy scenarios - buildings



- Loft insulation is technically viable for a wide range of housing archetypes.
- Up to 8,000 buildings could be fitted with loft insulations in the northern parts of Denbighshire, with lower numbers in less populated areas such as the Clwydian Range and Dee Valley National Landscape (up to 500 homes).

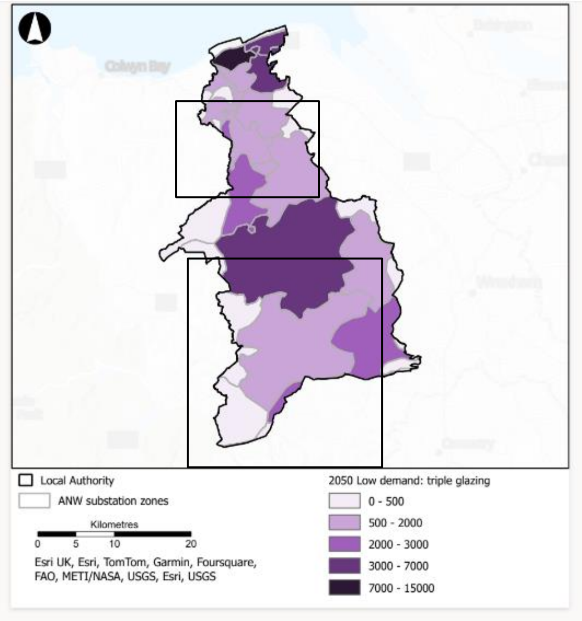
Figure 4.2.11: Map showing the number of additional loft insulation measures fitted by 2050 by substation zone in the Low Demand scenario



- Floor insulation is technically viable for a wide range of housing archetypes. In the Low Demand scenario, up to 40,000 buildings could be fitted with this measure, which in absolute terms is much higher than other types. This suggests that in Denbighshire (particularly the Denbigh/Ruthin, Prestatyn and Rhyl area), buildings are well-suited for this measure.

Figure 4.1.12: Map showing the number of additional floor insulation measures fitted by 2050 by substation zone in the Low Demand scenario

Comparing future energy scenarios - buildings



- Up to 7,000 triple glazing installations could be completed by 2050 in and around Ruthin, Rhyl and Prestatyn.

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

Comparing future energy scenarios - transport

Figure 4.2.14 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.

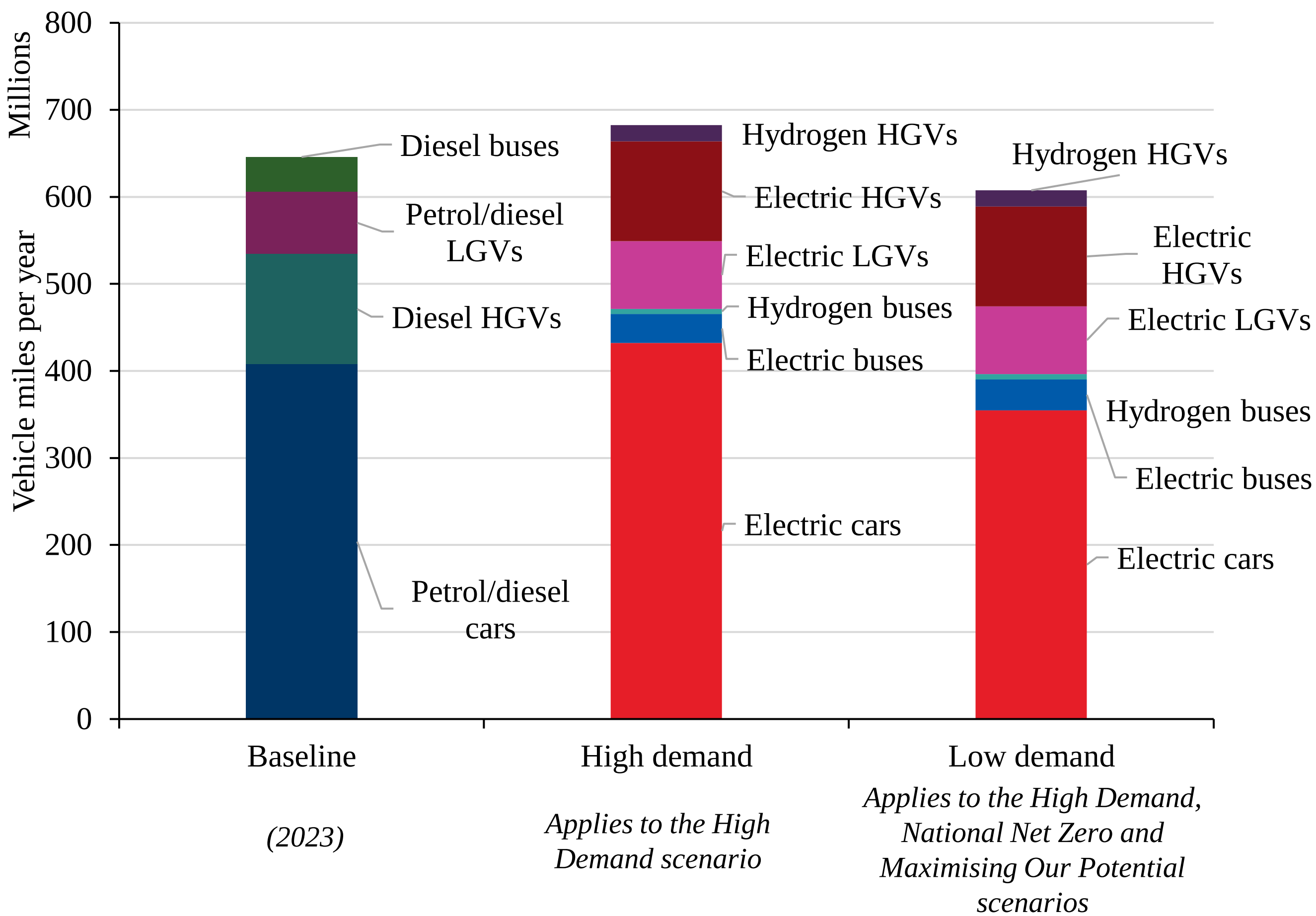


Figure 4.2.14: Total annual vehicle miles per year by scenario and vehicle type

Sponsors: Delivery partners:

Comparing future energy scenarios - onshore renewables (electricity generators)

In all scenarios, ground-mounted solar PV and onshore wind could provide between 67% to 87% of Denbighshire's total electricity generation capacity[a]. In the Maximising Our Potential scenario, both technologies could be developed to their maximum theoretical capacities which could equate to approximately 4% of the land area in Denbighshire (2% for each technology respectively).

In all scenarios, 100% of the theoretical maximum for rooftop solar PV is deployed, where it is technically viable. This could make up 11% of total electricity generation capacity and cover approximately 39,000 buildings in 2050 (assuming a capacity of 4kWp per rooftop solar PV array).

In the Maximising Our Potential scenario where grid import doesn't occur, it could be replaced by hydrogen combined-cycle gas turbine plant (CCGT) used to generate electricity, as the next most cost- and carbon-effective generation technology.

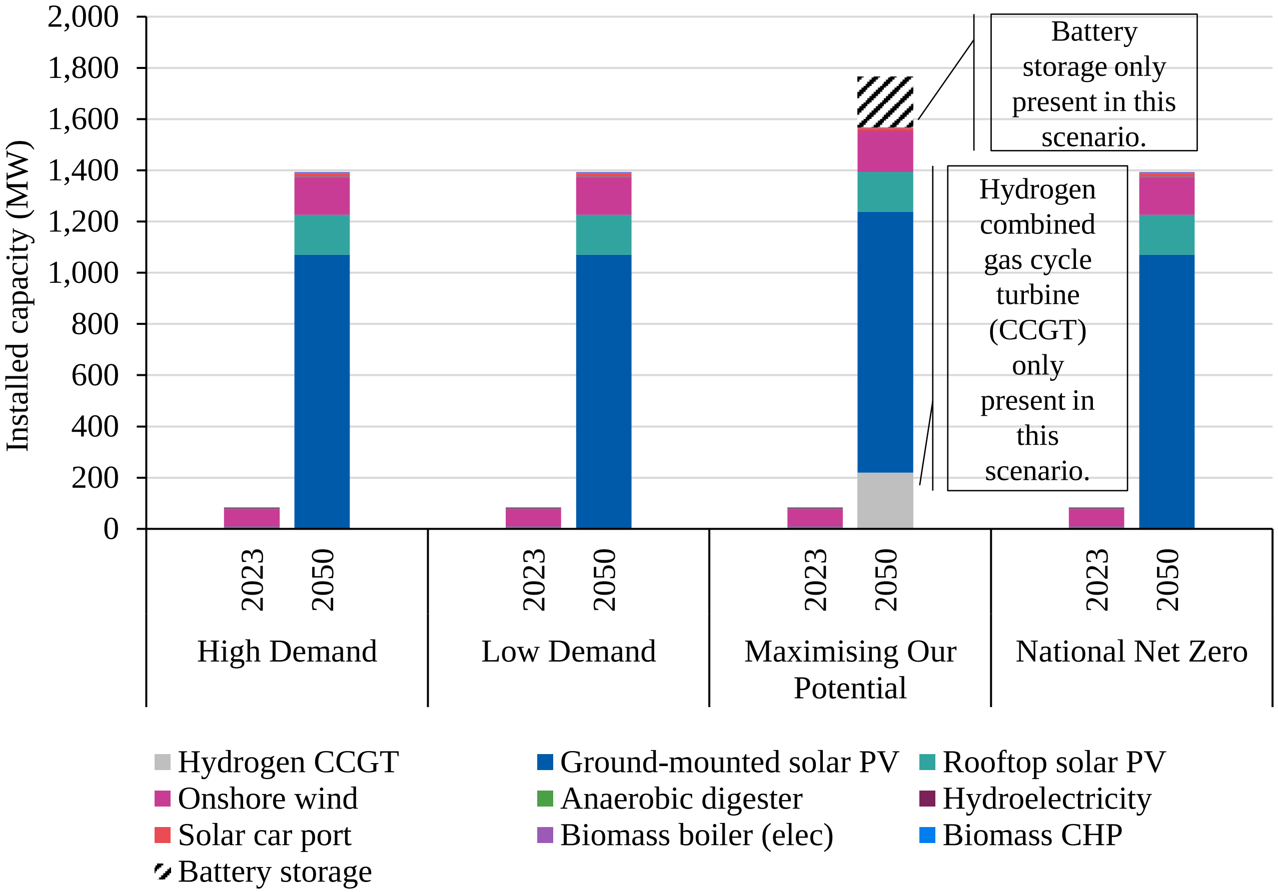


Figure 4.2.15: Future capacity of onshore renewables in each scenario

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Sponsors: Delivery partners: ARUP, CARBON TRUST

Comparing future energy scenarios - onshore renewables (electricity generators)

Battery storage could be used to store renewable electricity that is generated at a time when demand is low, ready to be discharged when demand is high. Batteries and other storage technologies can also provide flexibility services to the grid at times where additional generation is needed to meet demand in a particular area.

Table 4.2.4 summarises the existing capacities of the main electricity generation technologies used across the local energy system, and the theoretical future capacities of these technologies and others that appear in each scenario, to show the additional capacity[a] that scenario analysis suggests could be needed to meet future energy demand. If the additional theoretical capacity is less than zero, this indicates that there could be capacity that is decommissioned.

In practice, we know that achieving the levels of deployment indicated in the scenarios is ambitious and is beyond the rates of deployment we see today. This is further explored in the renewable energy proposition in Chapter 5: Action planning.

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Renewable technology	Baseline capacity (MW) (2023)	Total theoretical capacity across 2050 scenarios (MW)	Additional capacity indicated across 2050 scenarios (MW)	Percentage of total maximum theoretical capacity across 2050 scenarios (%)	Estimated land area requirement by 2050 (km^2)
Ground-mounted solar PV	1	1,070	+1,069	100%	20 (2%)
Rooftop solar PV	7	156	+149	100%	n/a
Onshore wind	69	148	+79	95%	19 (2%)
Anaerobic digester	1.3	1.3	0	n/a	n/a
Hydroelectricity	2	2	0	n/a	n/a
Solar car port	0	12	+12	n/a	n/a
Biomass boiler (elec)	3	3	0	n/a	n/a
Biomass CHP	0.1	0.1	0	n/a	n/a
Battery storage	0	197	+197[a]	n/a	n/a
Natural gas	3	0	-3	n/a	n/a
Hydrogen CCGT[b]	0	219	+219[a]	n/a	n/a

Table 4.2.4: Existing and future theoretical capacities of renewable electricity generators

[a]Only present in the Maximising Our Potential scenario
[b]Combined gas cycle turbine

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 (overleaf) summarises the impact of key sensitivities and uncertainties on the future energy system scenarios.

4. The future energy system
Analysis

Uncertainty	GHG[a] 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 carbon 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.

[a]GHG = Greenhouse gas

Table 4.2.5: Impact of key sensitivities on the future energy system

4. The future energy system
Analysis

Uncertainty	GHG[a] emissions	CAPEX	OPEX	Other notes
Lower uptake of cycling and other active travel modes	↑	?	?	Less people cycle or walk to make shorter journeys, and we see higher dependence on car usage, and increased demand for electric vehicle charging. CAPEX impact depends on roll-out of electric vehicle charging and/or hydrogen fuel cells.
Reduction in cost of energy storage solutions	↓	↓	↓	Lower energy infrastructure costs. Reduced costs to consumers and increased roll-out of storage technologies both at grid- and building-scale.

[a]GHG = Greenhouse gas

Table 4.2.5: Impact of key sensitivities on the future energy system

4. The future 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 complete modelling using a 1-hour time resolution, we can estimate what the expected impact would be. We have also observed how the system changes when we remove the electricity import. Figure 4.2.16 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[a]
- 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 4.2.16: Trends from optimisation model runs

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Sponsors:

Delivery partners:

Technical Report

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

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 greenhouse gas (GHG) emissions would change over time against national emissions reduction targets and indicate the capital investment requirements between the baseline year and 2050.

Figure 4.3.1 shows how assumptions were applied to near-term and long-term deployment trajectories. Near-term indicates the period for which local and national policy can be applied which is generally 2023-2030 but can vary depending on technology.

Table 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 A1.

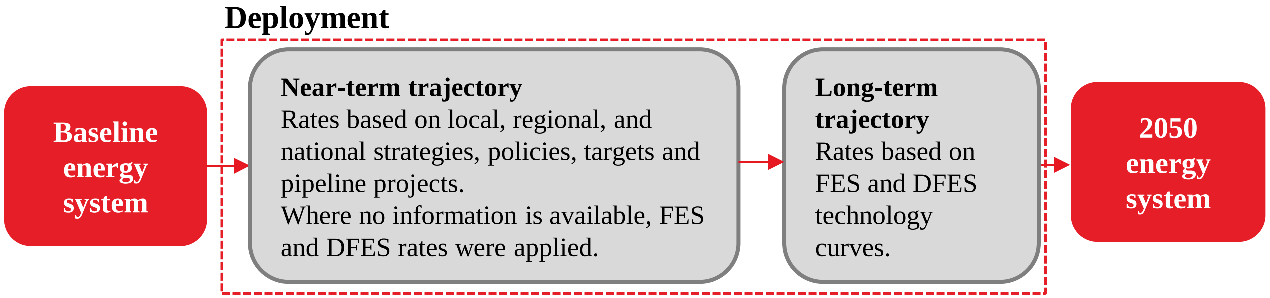


Figure 4.3.1: Deployment model overview of assumptions used to determine rates

Data source	Description
National Grid's Future Energy Scenarios (FES)[T31]	FES are a range of forecasted net zero technology trajectories to 2050 for the electricity system in Great Britain. They consider national policies and ambitions for an extensive list of supply and demand technologies at the distribution level.
Distribution Future Energy Scenarios (DFES)[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

Impact on total energy demand (GWh per year)

The following pages provide insight into the results of the deployment modelling, illustrating how energy demand could change over time in each scenario.

2030 Total energy demand could decrease between 2030 – 2042 in all scenarios driven by a switch to more efficient electric vehicles (EVs) and improving the energy performance of homes and commercial properties.

2042 In 2042 and later, energy demand could increase because the growth in housing and commercial property outweighs the energy reductions achieved through energy efficiency measures and the switch to EVs slows down. In 2042, we could also see the introduction of hydrogen vehicles, which contribute to an increase in demand.

2050 Total energy demand could decrease to much 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.

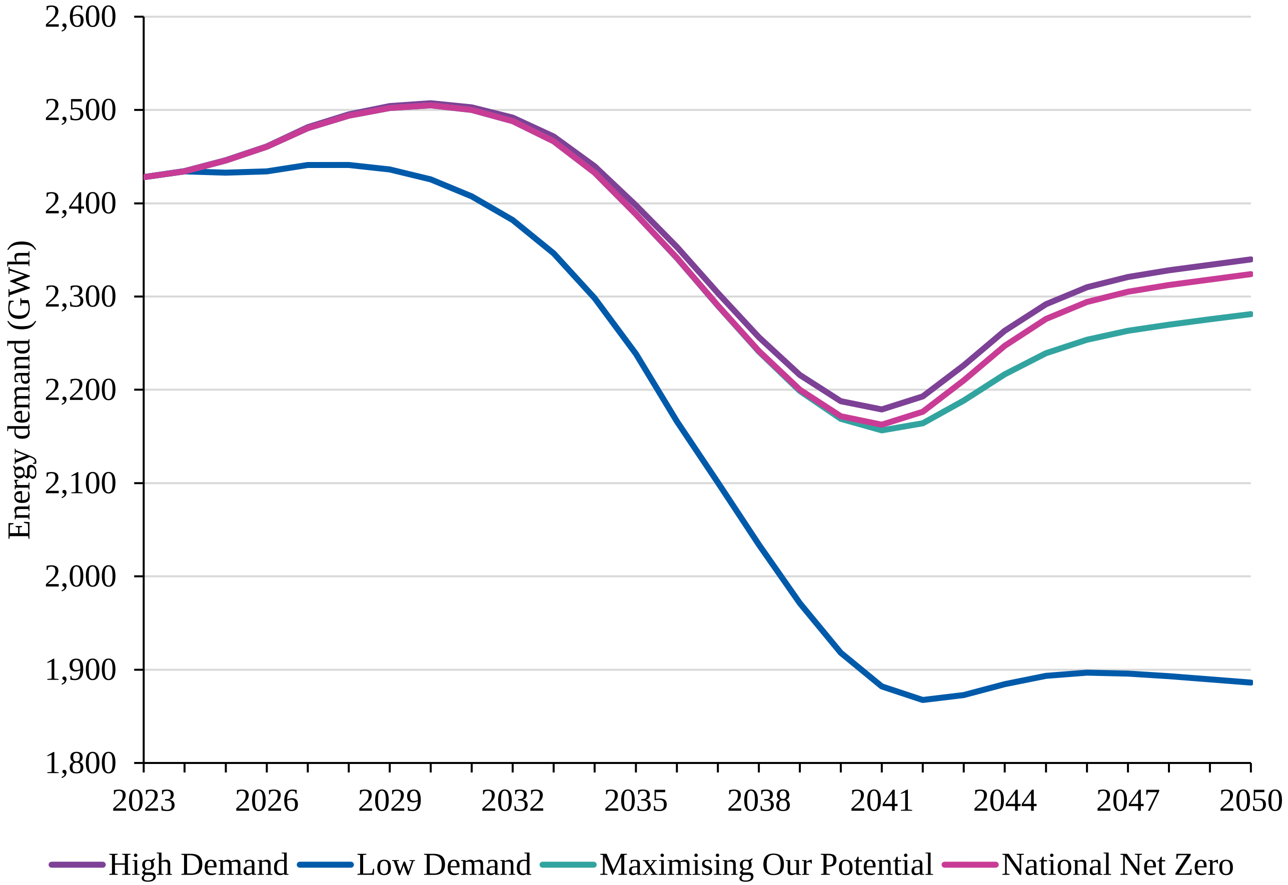


Figure 4.3.2: Change in total energy demand by scenario (GWh per year)

4. The future energy system
Deployment modelling

Impact on energy demand from buildings (GWh per year)

In all scenarios, buildings energy demand could increase overall between 2023-2050 because we assume an increase in the number of homes and commercial buildings between 2023 and 2050. However, on a per home or per unit commercial area basis, the average heat demand across all the scenarios decreases from approximately 13,000 to 11,000 kWh per home and commercial buildings 100 to 77 kWh per m^2.

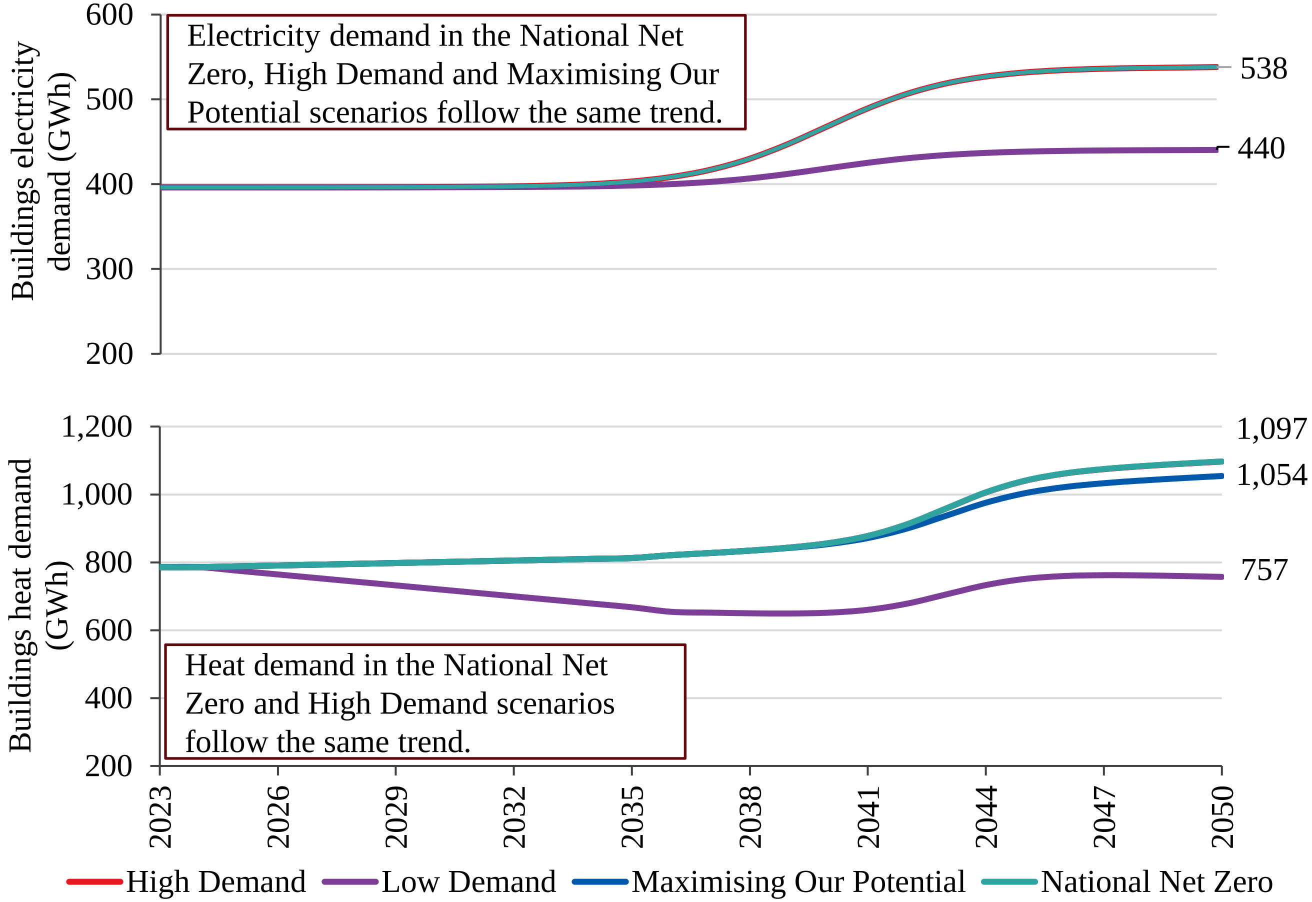


Figure 4.3.3: Projected electricity (top) and heat demand (bottom) for buildings in each scenario

Impact on energy demand from transport (GWh per year)

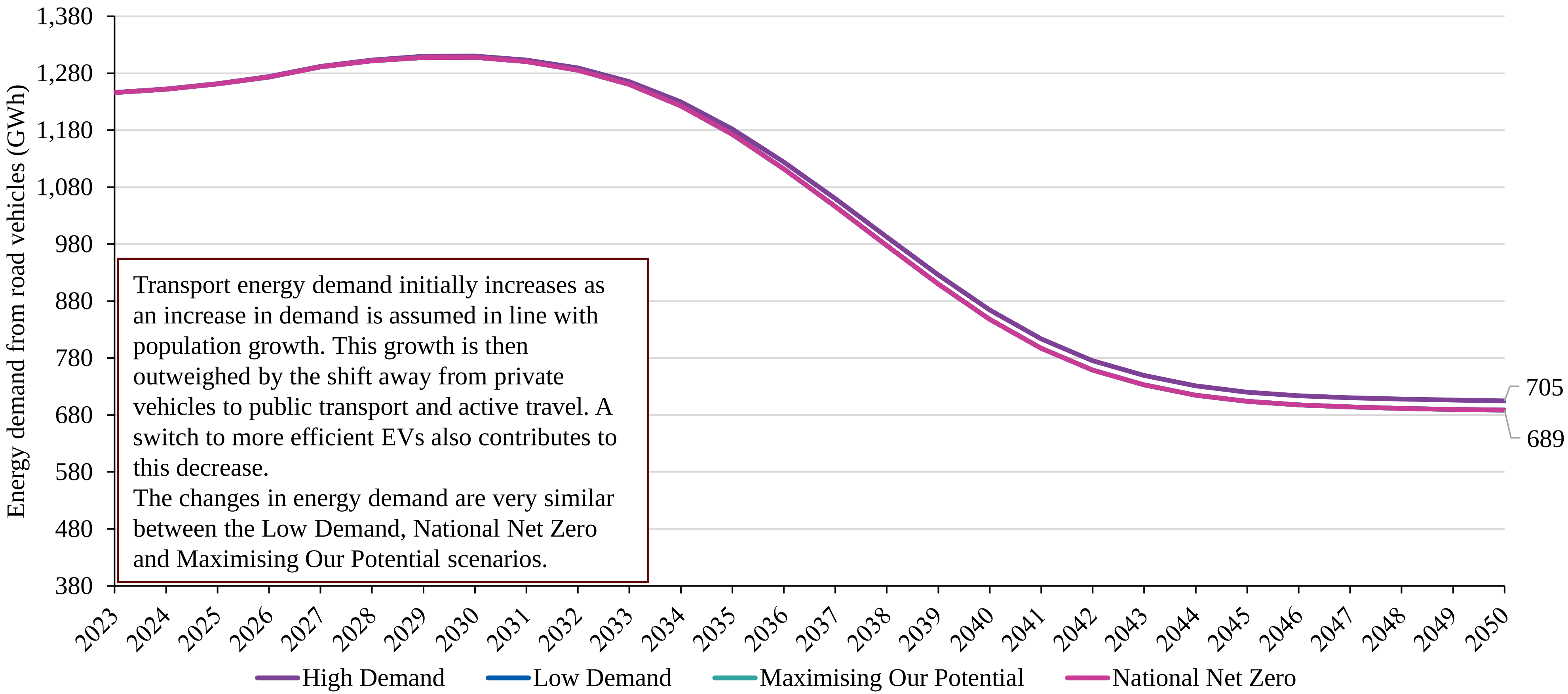


Figure 4.3.4: Evolution of heat technologies in the National Net Zero scenario

Sponsors: Llywodraeth Cymru Welsh Government; Uchelgais Gogledd Cymru Ambition North Wales
Delivery partners: ARUP; Carbon Trust

Summary of deployment for low-regret energy system components

Deployment modelling can help us better understand what the impacts of each scenario are over time. It provides a starting point to frame the challenge and for more detailed analysis. We have included theoretical pathways which have a high degree of uncertainty as there are many variable factors and unknowns. The deployment modelling can't consider every factor, some of the things that will impact deployment include:

- Technological advance and innovation
- Supply chains and how they develop;
- Large scale activity to decarbonise infrastructure at other levels: regional, UK and beyond;
- Whether practical application is actually feasible and deliverable.

2023:	By 2030:	By 2050:	
600 buildings with heat pumps installed[a]	**Up to 8,500 buildings** with heat pumps installed[a]	**Up to 55,000 buildings** with heat pumps installed[a]	**Min. 560 heat pump installations** per year[a]
27% (13,000) homes rated EPC A-C	**Up to 17,500 insulation measures retrofitted**	**Up to 42,400 insulation measures retrofitted**	**Min. 1,014 insulation measures retrofitted** per year
72 EV charge points[b]	**Up to 5,700** EV charge points[c]	**Up to 40,400** EV charge points[c]	**Min. 719 chargepoints** per year[c]
7MW (1,800 buildings) with rooftop solar PV[d,e]	**46MW (11,500 buildings)** with rooftop solar PV[d,e]	**156MW (39,000 buildings)** with rooftop solar PV[d,e]	**Min. 5MW (1,370 installations)** per year[d,e]
1 MW of ground solar PV capacity[e]	**Up to 293 MW** of ground solar PV capacity[e]	**Up to 1,070MW** of ground solar PV capacity[e]	**Min. 42 MW of ground solar PV** per year[e]
69 MW of onshore wind capacity[e]	**Up to 72 MW** of onshore wind capacity[e]	**Up to 156MW** of onshore wind capacity[e]	**Min. 1 MW of onshore wind** per year[e]

Figure 4.3.4: Summary of key deployment metrics from optimisation modelling

[a]According to the National chargepoint Registry[T15] as of May 2023. Refers to individual charge points

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

[c]Assuming 4kWp per roof and per installation

[d]Renewable generation capacity (maximum power output) is shown for technologies where current installed capacity is >5MW

Impact on greenhouse gas (GHG) emissions

Figure 4.3.6 (overleaf) compares GHG emissions reductions between the Do Nothing scenario and the optimised scenarios (see Chapter 4. The future energy system (methodology) for a description of scenarios). The deployment modelling provides evidence on the realism of delivering the changes suggested by the optimisation modelling. It helps us to determine the actions needed in the next five years to set Denbighshire on a pathway to Net Zero.

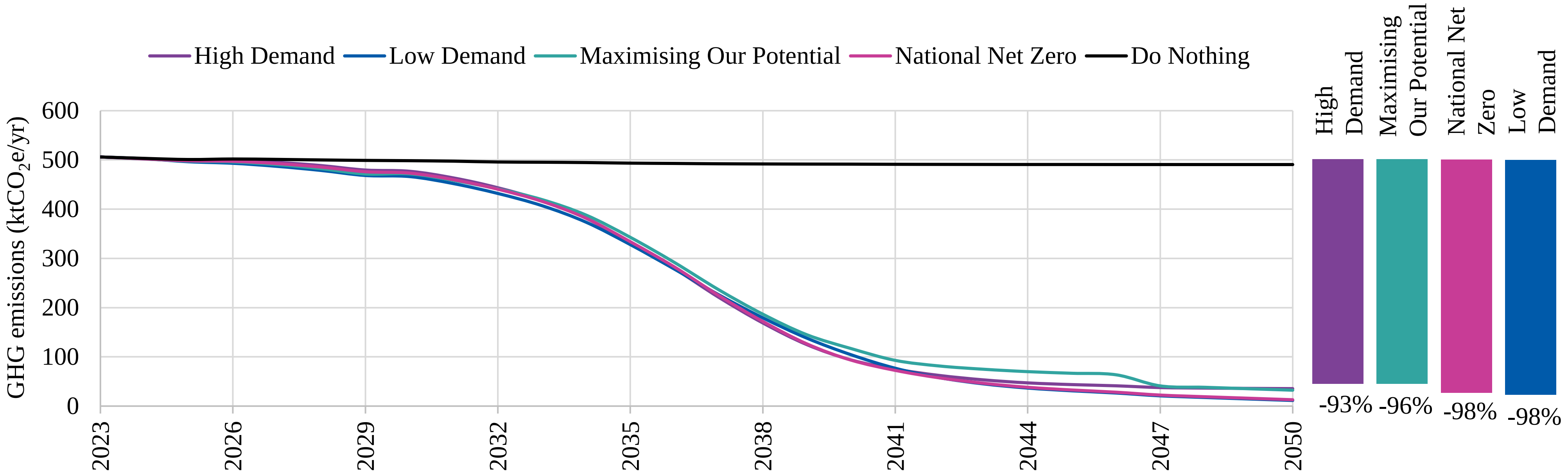
The deployment modelling also shows how these pathways contribute to the Welsh Government emissions reduction targets (shown in Table 4.3.6 overleaf). In 2030, deployment pathways across all scenarios miss the target level of reduction required to align with the reduction target set by Welsh Government. However, by 2040 they have come into closer alignment. This is likely driven by different assumptions being made about the deployment rates of different technologies between 2023 – 2030.

In 2023, Denbighshire's GHG emissions were 36% lower than 1990 levels, with reductions just below the % reduction required to align with Wales' net zero target. Pathways suggest a residual amount of GHG emissions remains in 2050 even with the ambitious changes set out in each scenario. This emphasizes the importance of exploring alternative ways to address hard-to-reduce GHG emissions through mechanisms such as offsetting.

Sponsors:

Delivery partners:

Impact on greenhouse gas (GHG) emissions



Scenario	2030	2040	2050
Welsh Government targets	-63%	-89%	-100%
National Net Zero	-40%	-88%	-99%
High Demand	-39%	-88%	-96%
Maximising Our Potential	-40%	-88%	-98%
Low Demand	-40%	-88%	-99%
Do Nothing	-36%	-37%	-37%

Figure 4.3.6: (Top) GHG emissions ($ktCO_2e$) over time for each scenario compared to the Do Nothing scenario
(bottom) Percentage GHG emissions reduction for each scenario compared to the Welsh Government emissions reduction targets

Impact on employment

Reducing the amount of energy we use and how we generate energy can bring significant benefits so it is important that these benefits and impacts are understood to support decisions that impact the future of the energy system. 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 as well as associated supply chain and multiplier effects[T37].

Method

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

Our assessment considers jobs that might be displaced in other parts of the economy owing to an investment in energy efficiency or renewable energy. For example, investment in renewable energy might displace jobs in other parts of the power sector such as those associated with power generation from gas-fired plant. Where possible, indicators from surveys or studies completed for projects in Wales have been used so that the employment impacts reflect the economic conditions in Wales as closely as possible.

We compared the employment impacts for each scenario to the employment impacts in the Do Nothing scenario, to help us understand what alternative jobs may have been created if the money were invested in similar ways to what it is today.

4. The future energy system
Deployment modelling

Impact on employment

Results

Table 4.3.2 shows the employment impacts in Full-Time Equivalent (FTE). This is so that impacts can be adjusted for the lifetime of the project or plant and duration of the job. For example, a job that lasts 1 year for a project where plant lifetime is 10 years would count at 1*1*0.1 = 0.1FTEs over the duration of the project.

Employment impacts are greatest in the Maximising Our Potential scenario, which driven partly by the need for greater renewable capacity[a] 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	Maximising Our Potential
Energy change (GWh, relative to 2023)	0	-142 (-4%)	-88 (-4%)	-542 (-22%)	-142 (-6%)
Employment impacts between 2023-2050 relative to the Do Nothing scenario (net FTE)	0	3,400	3,400	4,600	6,400

Table 4.3.2 Summary of the employment impacts and change in energy demand by 2050. A negative number indicates a reduction, and a positive number represents an increase or addition.

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

4. The future energy system
Deployment modelling

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 of 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 4.2.3 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[T50] does not include air quality impacts of landfill gas, organic matter, sewage gas, or hydrogen. We assumed that these fuels have the same air quality impact as natural gas.

Fuel	Air quality cost (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 4.2.3 Air quality activity cost factors (pence per kWh)

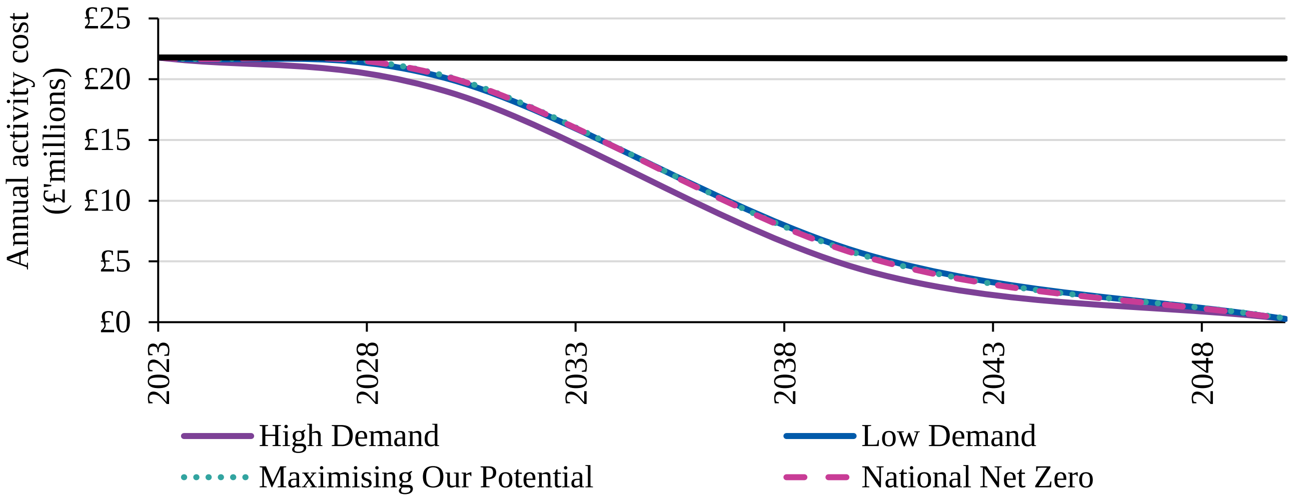
Impact on air quality

Results

Activity costs presented in Table 4.3.8 show estimates for the impact of air pollution in each future energy scenario, compared to the Do Nothing scenario.

The costs associated with poorer air quality (for example, this could be health impacts such as mortality and morbidity effects, environmental impacts such as ecosystem damage, and economic effects such as productivity because of poor health) are less in all future energy scenarios that we modelled.

The greatest economic savings from improving air quality are produced in the High Demand scenario. In this scenario, the rate of emissions reduction is quicker than in other scenarios, resulting in greater cumulative air quality benefits over time.



Metric	Do Nothing	National Net Zero	High Demand	Low Demand	Maximising Our Potential
Change in greenhouse gas (GHG) emissions ($ktCO_2e$, relative to 2023)	-15 (-3%)	-495 (-98%)	-472 (-93%)	-496 (-98%)	-487 (-96%)
Cumulative air quality savings between 2023-2050 relative to the Do Nothing scenario (£'million) (2022 prices)	0 (Reference case)	-£291	-£317	£-292	£-290

Figure 4.3.7 (top): Annual costs associated with changes in air quality in each scenario; Table 4.3.8 (bottom): 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

Investment requirements

High levels of investment will be required to achieve the scale of change required to achieve a net zero energy system. Table 4.3.3 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.

The total capital investment requirements between now and 2030 are estimated to be from **£300 million to £2 billion**, which is mostly invested in reducing the energy demand in buildings with energy efficiency retrofit, followed by renewable capacity[a] and low carbon building heating systems.

Some of these changes 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.

[a] Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Investment requirements

Energy proposition	Indicative CAPEX (by 2030) (£'millions)	Indicative CAPEX (by 2050) (£'millions)	Basis for CAPEX estimate	Types of stakeholders that could be responsible for raising capital	Dependencies on other investments
1. Energy efficiency of buildings	100 - 1,300	240 - 3,300	Cost of insulation retrofit (solid wall, cavity wall, floor, lift and triple glazing)	Local authority, housing associations, building developers, public	
2. Onshore renewables (ground-mounted solar PV and onshore wind)	120 - 130	530 - 560	Equipment costs	Local authority, housing associations, building developers, public, renewable energy providers	Electricity network
3. Rooftop solar PV	43	160	Equipment costs	Local authority (owned buildings), housing associations, building developers, public, renewable energy providers	Electricity network, energy efficiency
4. Transport (electric vehicle chargepoints and hydrogen refuellers)	20 - 35	135 - 140	Equipment costs	Local authority, building developers, public,	Electricity network

Table 4.3.3: Indicative investment requirements

4. The future energy system
Deployment modelling

Investment requirements

Energy proposition	Indicative CAPEX (by 2030) (£'millions)	Indicative CAPEX (by 2050) (£'millions)	Basis for CAPEX estimate	Party responsible for CAPEX	Dependencies on other investments
5. Low carbon heating systems (heat pumps, resistance heaters, solar thermal, biomass boilers)	20 - 35	120 - 240	Equipment costs	Local authority, housing associations, building developers, public	Electricity network
6. Electricity network intervention	Key uncertainty		Electricity network intervention costs will depend on the extent of network upgrades which will be needed across the LV, HV and EHV networks, requiring a more detailed analysis.		
7. Hydrogen	2 – 4	50 – 190	Gas distribution network interventions, hydrogen combined gas cycle turbine (CCGT), electrolysers	Gas network	Electricity network
8. Energy storage (battery storage, heat storage)[a]	<0.5 (heat and electricity)	10 – 15 (heat) Up to 32,000 (electricity)	Thermal storage costs	Project developers, building owners, energy providers, public	Electricity network
Project costs (incl. contingency, prelims, professional and development costs etc)	Key uncertainty		50% of CAPEX above	n/a	n/a

[a]Heat storage is only present in the Low Demand and Maximising Our Potential scenarios. Battery storage is only present in the Maximising Our Potential scenario

Table 4.3.3 (continued): Indicative investment requirements

Technical Report

Chapter 5: Action planning (stages 6-7)


Figure 5.1.1: Denbighshire

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 Denbighshire.

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 (0-5 years). 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

After reviewing and discussing these results and revisiting what we learnt from scenario analysis and deployment modelling with stakeholders, **five energy propositions** were agreed. These form the strategic foundation for Denbighshire's LAEP and consolidate the evidence to describe what, how and where to prioritise the deployment of these energy system components.

Creating the plan

Enabling actions

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

Chapter 4: The future energy system

Chapter 5: Action planning

Energy propositions

- We looked at **where** critical system components could be prioritised for deployment and identified priority focus zones, accounting for technical and social factors.
- We took what we learnt from scenario analysis, deployment modelling and zoning analysis to create 5/6 energy propositions that form the framework for Denbighshire's LAEP, and the focus for the next 5-6 years.

Creating the plan

- We asked local stakeholders to think about their influence over the energy system, and what they could do to support delivery of each energy proposition.
- We then combined this feedback into an action routemap to describe the collective effort required to deliver the ambitions and near-term energy propositions set out in Denbighshire's LAEP.

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

Identifying priority focus zones

Figure 5.1.3 (overleaf) shows our approach to prioritise low-regrets energy system components to take forwards when identifying priority focus zones for their deployment. We consulted primary and secondary stakeholders across the county and asked:

1. Is the energy system component deployed in all scenarios, and if this is the case, is it a low-regret option to pursue?
2. Is this component a strategic priority identified by stakeholders during previous engagement?
3. Does this energy system component align with the vision and energy objectives set for Denbighshire's LAEP?
4. Is this energy system component identified as a priority in North Wales' energy strategy?

We combined this feedback with insights from scenario modelling to develop Denbighshire's energy propositions, which are a framework for the LAEP. Denbighshire's energy propositions focus on areas of the energy system that are currently significant contributors to area-wide greenhouse gas (GHG) emissions and have been identified as a priority 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[a] is needed and by when, as well as indicative investment requirements to achieve it.

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

5. Action planning
Energy propositions

Identifying priority focus zones

Certainty of outcome

High

Time to deliver

	Short-term	Long-term
High	• **Retrofit** ***(newer homes)*** • **Retrofit beyond social housing (ECO4)** • **Active travel** shift in areas with a higher population density • **EV chargers** in urban areas and town centres • **Ground-mounted solar PV** • **Onshore wind** • **Heat pumps and solar PV in off gas grid homes and new builds**	• **Heat pumps in on 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** • **Ground-mounted solar PV** • **Onshore wind** • **Electrical infrastructure upgrades**
Low	• **Energy from waste (EfW)** – significant EfW plant in Flintshire so waste is currently exported.	• **Increasing public transport/buses in rural areas** • **Anaerobic digestion** • **Electrolysers** • **Hydroelectricity** • **Hydrogen refuellers** • **Hydrogen imports**

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: Minimise energy demand, and support shift to low carbon, flexible heating systems in homes

The priority is to reduce the amount of energy used to minimise emissions and cost to consumers. Most homes will need some form of retrofit in Denbighshire, and this is likely to become even more critical where energy prices have increased. Scenarios show heat pumps as the near-term, least regrets technology to decarbonise heating systems in homes and areas where grid capacity (its maximum power output) would make this more favourable. Innovative business models should be explored to maximise local benefits, buy-in and confidence in low carbon heating systems.

Proposition 2: Maximise local potential for onshore renewables without compromising natural assets

Denbighshire currently has several onshore wind schemes with some further schemes proposed. These schemes meet local and broader energy needs. Theoretically they could be enhanced in the future. A large agricultural sector also presents opportunities to capitalise on unused waste resources for the generation of electricity. Consider storage technologies to minimise dependency and exposure to grid price volatility and connection challenges.

Proposition 3: Decarbonise transport

Develop EV charging infrastructure and support decarbonisation of heavy transport. Support a fair transition to ultra-low emissions (ULEV) vehicles and make it easier for people to choose public transport and active travel over other modes. EV chargepoint access should be considered across the borough, including more rural areas. Where car journeys can't be avoided, support a fair transition to ultra-low emissions vehicles (ULEV) which will include transitioning public service buses and taxis.

Figure 5.1.4: Summary of energy propositions (energy propositions 1-3)

Energy propositions in more detail

Proposition 4: Reinforce the energy networks

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. This means that reinforcement to meet up to a 95% increase in electricity generation capacity (its maximum power output) could be needed, based on scenario analysis.

Even if hydrogen is not used for heating, the gas grid will need to be repurposed to provide hydrogen for uses that are not easily electrified such as industry, and to manage costs in a fair way as home heating transitions away from gas.

Proposition 5: Promote smart local energy systems

Smart systems bring together energy generation, storage, demand and infrastructure and connects them in a smart way. It presents an opportunity for energy resources to be used more efficiently, and opportunity to alleviate pressures on grid reinforcement and avoid delays for connection where it isn't needed.

Figure 5.1.5: Summary of energy propositions (energy propositions 4-5)

Energy propositions

Identifying priority focus zones

Denbighshire's Plan on a Page (shown in Figure 5.1.6) identifies modelling zones that rank highly against selected criteria for different low carbon technologies identified in Denbighshire's energy propositions: heat pumps, EV chargers, rooftop solar PV, ground-mounted solar PV, onshore wind, and insulation retrofits. The accompanying tables indicate what the modelling suggests could be developed in these priority focus zones to meet the future energy demand in the High Demand scenario.

To rank deployment of each low-regret energy system component in included modelling zones, we considered two or more of the considerations summarised in Table 5.1.1 (overleaf), each weighted by the percentage indicated. A modelling zone was only considered for ranking 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**[a] - 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 chargepoints built in the High Demand scenario.
- **Built additional capacity of each local generation technology** (rooftop solar PV, ground-mounted solar PV, or onshore wind) – prioritise zones where the most additional new capacity is built between the baseline and 2050 High Demand scenario.

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Identifying priority focus zones

In Denbighshire's Plan on a Page (Figure 5.1.6), green areas show priority focus zone for at least one energy system component. The tables indicate the total scale of change that the modelling suggests is needed by 2030 and indicates either the total capacity[a] (MW) to be installed or the number of homes requiring retrofit and the associated investment figures. Blue areas show "progress" zones where the conditions are ranked less favourably against the assessment criteria summarised in Table 5.1.1 compared to the green areas. Only tried and tested delivery models should be deployed in these modelling zones. A consistent level of deployment will still be required in these zones to transform the local energy system at the pace indicated by the deployment analysis.

Data	Heat pumps	EV chargepoints	Local generation	Insulation retrofits
Off-gas homes[T07]	25%	-	-	-
Socioeconomics[T28]	25%	30%	-	20%
Property ownership[T07]	25%	-	-	20%
Substation generation headroom[TN06]	-	-	50%	-
Listed buildings[T04]	-	-	-	5%
Domestic energy efficiency[T07]	-	-	-	35%
Built additional substation capacity	25%	40%	-	20%
Built EV charging capacity	-	30%	-	-
Built additional capacity of each local generation technology	-	-	50%	-

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

[a]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

5. Action planning
Energy propositions

Identifying priority focus zones

Reading the Plan on a Page

The Plan on a page is presented by "modelling zone", which was chosen as the smallest level of granularity used to present results in the LAEP. They are derived from primary substation service areas which are areas bounding the buildings or other electricity demands which are served by a primary substation or group of primary substations that act together. **They do not represent locations for specific projects.** This level of granularity has been chosen for several reasons:

- We needed to model for the most cost- and carbon- optimal generation profile using parameters that reflected the state of the current electricity grid.
- Presenting the results in this way helps Distribution Network Operators – who manage the operation, maintenance and interventions for primary substations - understand how future energy demand could change and how this might impact how investment in primary substation is prioritised.

In the map overleaf, green areas show priority focus zones for at least one energy system component. The tables indicate the total scale of change that the modelling suggests is needed by 2030 and indicates either the total capacity (MW) to be installed or the number of homes requiring retrofit and the associated investment figures.

Blue areas show "progress" zones where the conditions are ranked lower against the selected criteria compared to the green areas. Only tried and tested delivery models should be deployed in these modelling zones. A consistent level of deployment will still be required in these zones to transform the local energy system at the pace indicated by the deployment analysis.

Using the Plan on a Page

The Plan on a Page is a high level, theoretical assessment for the areas where different low carbon technologies could be deployed, considering the impacts of grid capacity, cost and greenhouse gas emissions. The plan is not a presumption in favour of development nor is it a material planning consideration.

5. Action planning

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

Sponsors: *Delivery partners:*

Figure 5.1.6 identifies priority focus zones that rank highly against the previously specified criteria for specific energy components, making them ideal locations for pilot or scale-up projects (green areas). The summary tables (shown below) detail the (i) installed capacity[b] opportunity, (ii) required investment for each component and (iii) total investment necessary for both energy component installation (prioritised and unprioritised) 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 modelled (see Chapter 4 for more detail). Note: intervention should still be carried out in 'progress' zones to transition the local area to Net Zero.

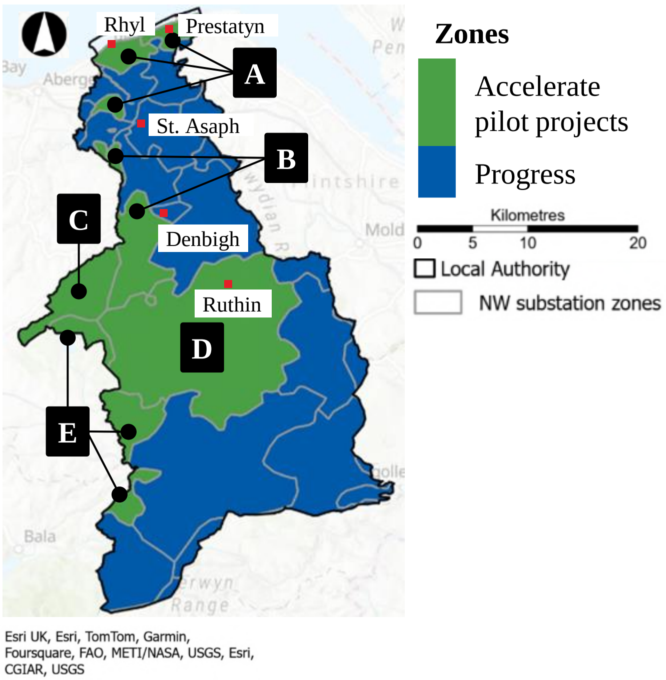


Figure 5.1.6: Denbighshire's spatial representation of opportunities, including 2030 ambition and investment (million £). Zone boundaries are defined by primary substation service areas

[a]Assuming average 6kW per heat pump
[b]Capacity is the maximum amount of energy that a generator can produce, also known as its maximum power output

Zone		(i)	(ii)	(iii)
A		1,000 – 5,000 homes	£28M-£500M	Total for zone (max.): £550M
		14MW	£15M	
		100 EV chargers (0.4MW)	£0.3M	
B		270 chargers (1MW)	£0.8M-£0.9M	Total for zone (max.): £73M
C		0.1MW	£0.04-£0.08M	Total for zone (max.): £16M
		23MW	£9.7M	
D		96MW	£42M	Total for zone (max.): £210M
		0.4MW	£0.4M	
E		0.1-0.2MW (10-30 heat pumps)	£0.06-0.1M	Total for zone (max.): £38M
		0.4MW	£0.5M	

Suggested energy components to pilot in each zone

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

1. Minimise heat demand, and support shift to low carbon, flexible heating systems in homes

Focus zones for retrofit

National policy indicates a "fabric, worst and low carbon first approach to improve the energy efficiency of the least thermally efficient low-income households in Wales"[T38]. The priority in Denbighshire 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 is through insulation retrofit (discussed here) and replacing gas boilers with heat pumps in most cases (discussed overleaf).

Insulation retrofits

We used several factors (refer to Table 5.1.1 in the methodology section of this chapter) to rank each modelling zone's favourability for near-term insulation retrofits. Figure 5.1.7 (overleaf) illustrates the results; the highest-scoring zones are included in Figure as priority focus areas.

For reference, the zones which are focus zones for heat pump installation (discussed later) are also highlighted in Figure 5.1.7 (overleaf). 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.

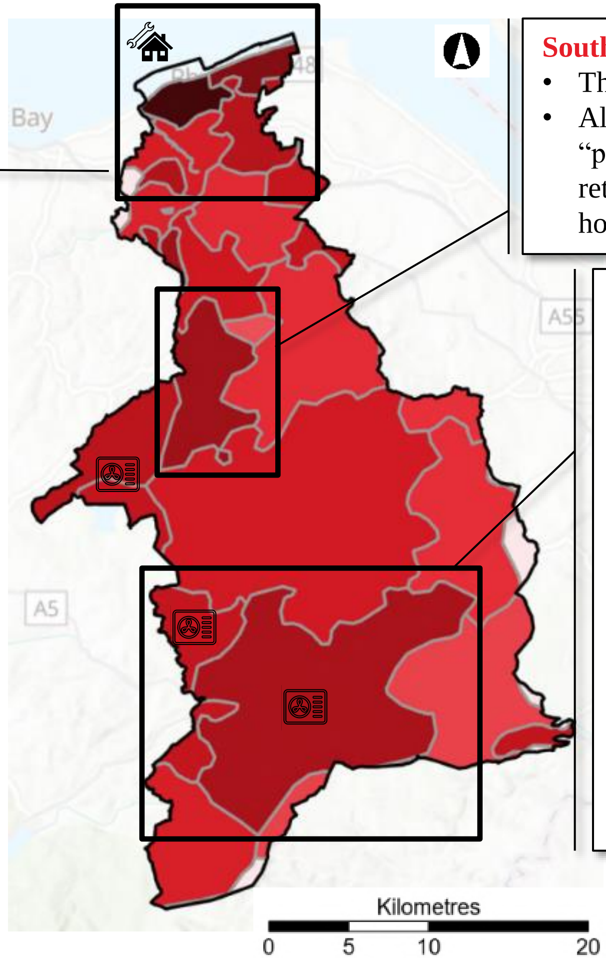
1. Minimise heat demand, and support shift to low carbon, flexible heating systems in homes

Sponsors: Delivery partners:

Focus zones for retrofit

Focus zone A (Rhyl, Prestatyn, Glan Clwyd)

- There are approximately 25,000 homes in these substation zones.
- The average energy performance of homes is lower in this area 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 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.



Southwest of Denbigh

- There are approximately 2,400 homes in this substation zone.
- Although not identified as a priority focus zone, this is still a "progress" zone with considerably favourable conditions for retrofit (high levels of multiple deprivation and proportion of homes with below average EPC ratings.

Corwen and Dee Valley (Corwen to Llangollen)

- There are approximately 2,000 homes in these substation zones.
- Although not identified as a priority focus zone for insulation retrofit, the Dee Valley from Corwen to Llangollen still has relatively favourable conditions for retrofit. It is an area with below average EPC ratings, a relatively high index of multiple deprivation and high amount of social housing. This zone has been identified as a priority focus zone for installing heat pumps largely driven by the high proportion of off-gas homes and spare capacity at the primary substations that distribute electricity to this area. There is an opportunity to achieve material environmental and social benefits by investing in improvements to energy performance and installing heat pumps in this area.

Figure 5.1.7: Focus zone rankings for domestic insulation retrofits across Denbighshire by modelling zone

Now: **27% (13,000 homes)** rated EPC A-C

By 2030: **Up to 17,500 insulation retrofits**

By 2050: **Up to 42,400 insulation retrofits**

Min. 1,014 insulation retrofits per year

1. Minimise heat demand, and support shift to low carbon, flexible heating systems in homes

Focus zones for heat electrification

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 (refer to Table 5.1.1 in the methodology section) to compare each modelling zone's favourability for near-term heat pump retrofits. Figure 5.1.8 illustrates the results; the highest-scoring zones are included in Figure 5.1.6 as priority focus zones.

For comparison, Figure 5.1.8 also shows the fraction of homes in Denbighshire currently not served by the gas network. These homes could be low-regrets options for retrofits since they will be the most challenging to serve via a future hydrogen network.

For reference, the zones which are also focus zones for insulation retrofits, discussed previously, are also highlighted in Figure 5.1.8.

1. Minimise heat demand, and support shift to low carbon, flexible heating systems in homes

Focus zones for heat electrification

Zones C and E

- There are approximately 2,600 homes in these zones.
- Most homes are not connected to the gas grid.
- The substation(s) that service(s) this area is less likely to require upgrades to meet future energy demand making new connections easier 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.

Corwen and Dee Valley (Corwen to Llangollen)

- There are approximately 1,800 homes in this zone.
- Most homes are not connected to the gas grid.
- The substation(s) that service this area are less likely to require upgrades to meet increased energy demands in the future.
- The area has a relatively high index of Multiple Deprivation compared to other areas in Denbighshire.
- The number of social homes in this area is relatively high, which gives the Council and social landlords more influence over how energy performance is addressed, as well as opportunities to explore street-by-street approaches to retrofit and heat pump installation.

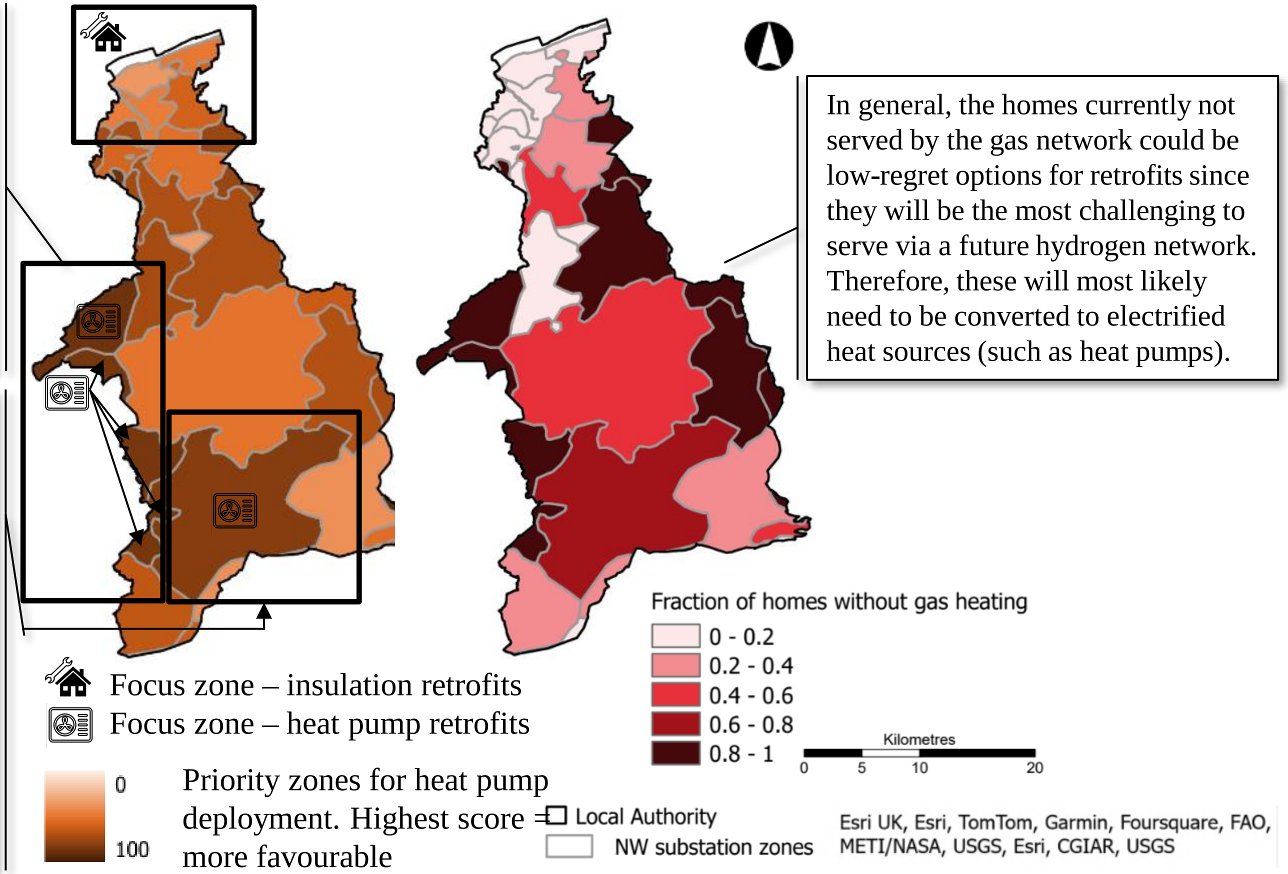


Figure 5.1.8 (left) Focus zone rankings for heat pump deployment and (right) fraction of homes without gas heating across Denbighshire

Now:	By 2030:	By 2050:	
600 buildings with heat pumps installed	**Up to 8,500 buildings** with heat pumps installed	**Up to 55,000 buildings** with heat pumps installed	**Min. 560** heat pump installations/year

Sponsors: Delivery partners:

Focus zones for rooftop solar PV

In all scenarios, rooftop solar PV is used to meet a proportion of building energy demand. In all scenarios, all viable rooftop space is used. The modelling zone with the most favourable conditions for rooftop solar PV is in the Rhyl East and Prestatyn coastal area, where there is a high density of housing and commercial buildings and therefore the greatest potential capacity for rooftop solar PV. This area has limited substation capacity so encouraging residents to generate their own electricity would relieve pressures on the grid at times of peak demand.

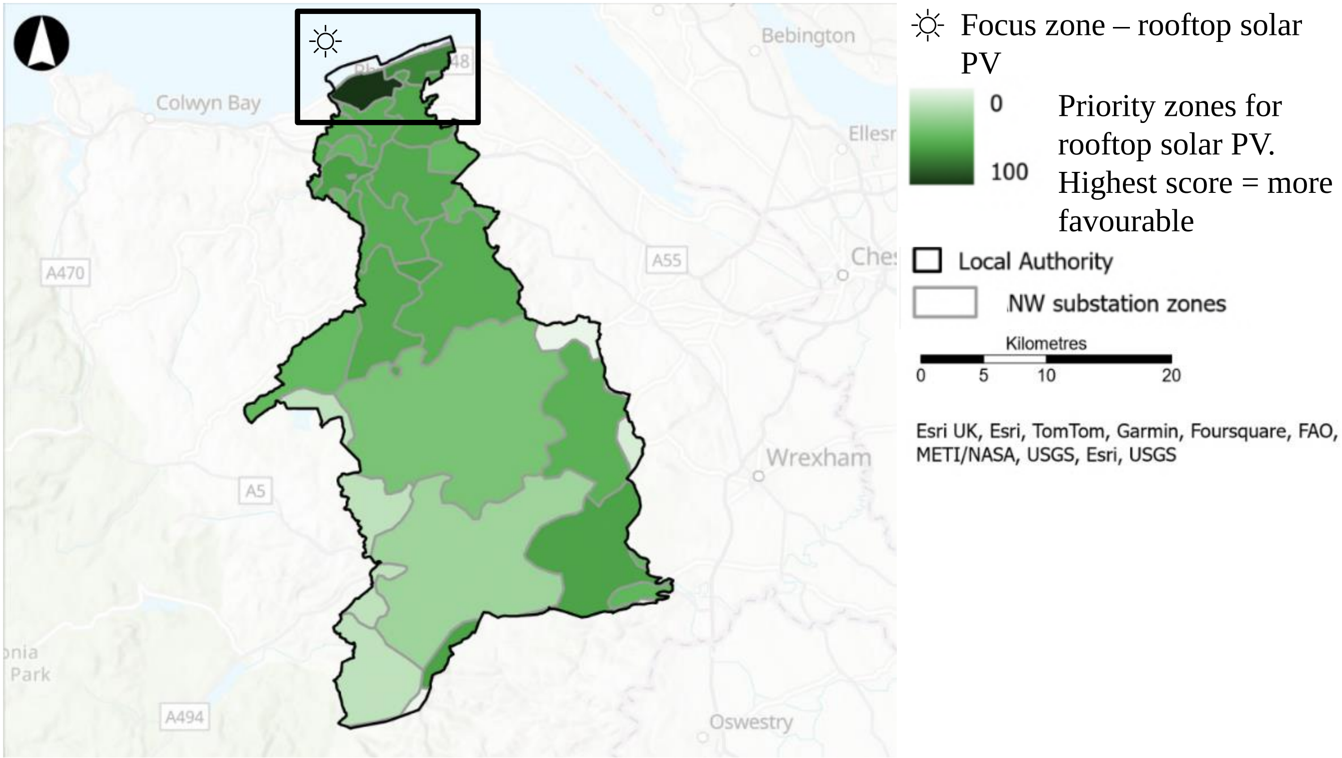


Figure 5.1.9: Focus zone rankings for rooftop solar PV

1. Minimise heat demand, and support shift to low carbon, flexible heating systems in homes

Investment requirements

The deployment model estimates the capital investment required for insulation retrofits and heat pumps. These are discussed separately below, along with potential funding opportunities.

Investment requirements for insulation retrofit

The upfront investment for retrofit varies depending on the package of measures appropriate for each archetype as well as to what level of performance buildings are retrofitted.

In the High Demand scenario, the cost of retrofit can be between £1,300 - £10,000 per household and £1,300 – £83,000 per commercial property.

In the Low Demand scenario, the cost of retrofit between £10,000 - £130,000 per property and £1,400 - £83,000 per commercial property.

Investment requirements for heat pumps

On average, the upfront cost for a heat pump is estimated at £4,500.[T42] For most homeowners, the cost of equipment is a significant barrier to installation, which has contributed to a slow uptake across the UK.[T43]

Investment requirements for rooftop solar PV

On average, the upfront cost for one rooftop solar PV panel (4kW) is £4,400.[T52]

Energy system component	Indicative investment (£'millions) required, range between scenarios	
	2023 - 2030	2030 - 2050
Retrofit (domestic)	<£1 – £1,200	£95 - £1,700
Retrofit (non-domestic)	£30 - £140	£45 - £200
Heat pumps	£20 - 40	£100 - £210
Heat networks	0 (none identified)	0 (none identified)
Rooftop solar PV (incl. car ports)	£45	£130

Table 5.1.2: Indicative investment costs by energy system component

5. Action planning

1. Minimise heat demand, and support shift to low carbon, flexible heating systems in homes

Investment requirements

Funding opportunities

For some buildings types there are obvious funding routes, and for others there is limited funding. This page sets out potential routes.

Funding opportunities and support schemes

- The Great British Insulation Scheme (GBIS)[TL01] 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)[TL02] 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[TL03]. The program aims to create a route to net zero for each home.

Focus zones for local electricity generation

All scenarios indicate that to achieve net zero will require a shift to electrified heating and transport, which could increase the need to harness renewable electricity sources. We used Denbighshire's Renewable Energy Assessment (2018) to understand the amount of suitable land for solar PV and onshore wind, accounting for the protection of good quality agricultural land (grades 1,2 and 3) and environmental and historic designations (See Chapter 4). For onshore wind, hub heights of 80m and outputs of 2MW were considered.

Figure 5.1.12 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 1,069MW and 156MW could be developed in the highlighted areas. The most ambitious National Grid's Future Energy Scenarios (FES) 2022[TL04] assume there could be another 77.2GW of solar and 30.8GW of onshore wind across the UK. Assuming that this is split by land area, the solar and onshore wind could cover 0.6% and 1.6% of the land area in Denbighshire, respectively. The highlighted areas in Figure 5.1.12 represent 4% of Denbighshire's total land area.

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 5.1.12 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.

Denbighshire is already, on average, a net exporter of renewable generation with significant potential for increasing the amount it exports based on this assessment. It will be for Denbighshire to decide what a realistic contribution to Wales' targets will be, so that it maximises local benefits and doesn't compromise other development priorities.

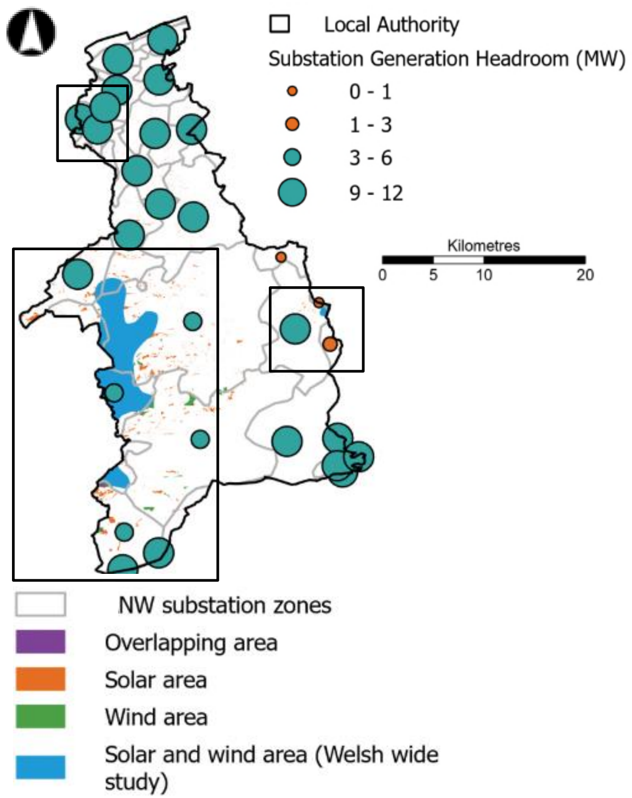


Figure 5.1.12: Areas suitable for wind and ground-mounted solar PV development in Denbighshire and substation generation headroom (MW)

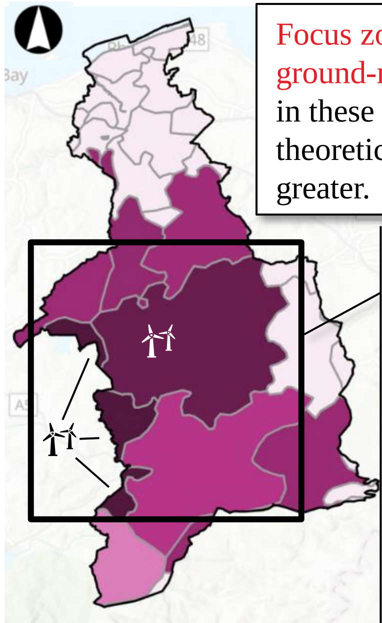
Sponsors:

Delivery partners:

Focus zones for local electricity generation

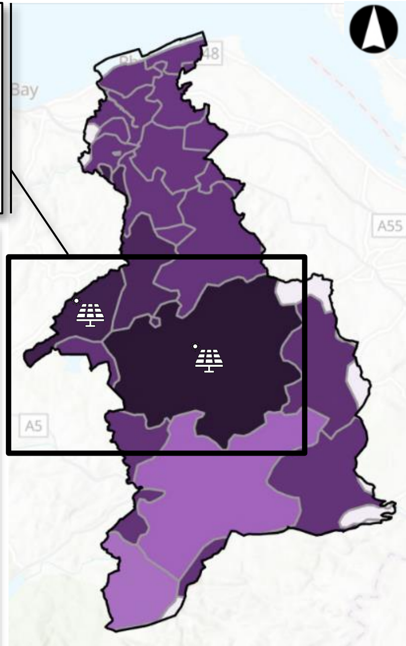
We used several factors (refer to Table 5.1.1) to compare each modelling zone's favourability for near-term installation of ground-mounted solar PV and onshore wind. Figures 5.1.13 illustrates the results and highlights the focus zones with the highest rankings for favourability. Since suitable land for wind and solar resource is generally focused to the west of Denbighshire, (the highlighted areas in Figure 5.1.12 on the previous page), most of the focus zones are in this area. However, the other four zones should be investigated, 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 C and D have been prioritised for ground-mounted solar PV. There is suitable land in these locations which means that the theoretical capacity for solar generation is greater.

Focus zones D and E have been prioritised for onshore wind. These zones have the greatest amount of land suitable for onshore wind. There is more spare capacity in zone E (on the border with Wrexham) compared to other areas in Denbighshire, which means less grid intervention may be required to accept new renewable generation connections here.



0 – 100 Focus zones for onshore wind. highest score = more favourable

0 – 100 Focus zones for ground-mounted solar PV. highest score = more favourable

Focus zone – onshore wind

Focus zone – ground-mounted solar PV

Local Authority

Substation boundary

Kilometres 0 5 10 20

Esri UK, Esri, TomTom, Garmin, Foursquare, FAO, METI/NASA, USGS, Esri, Ordnance Survey, NASA, NGA, USGS

Figure 5.1.13: (left) Focus zone rankings for onshore wind by modelling zone and (right) focus zone rankings for ground-mounted solar PV by substation zone

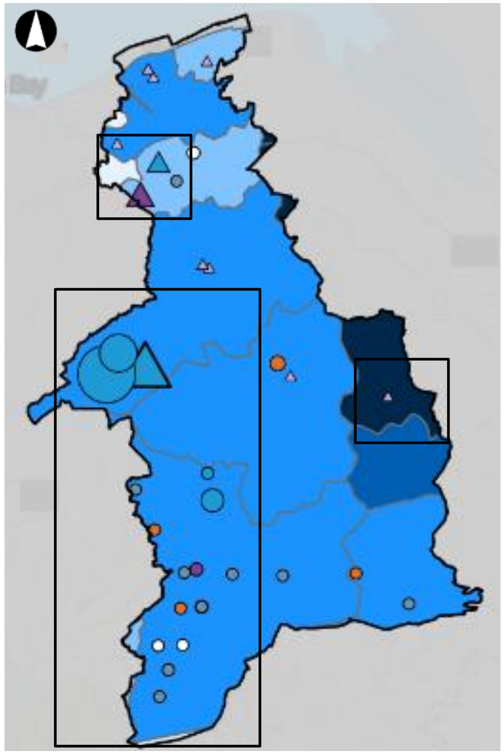
2. Maximise potential for onshore renewables without compromising natural assets

Focus zones for local electricity generation

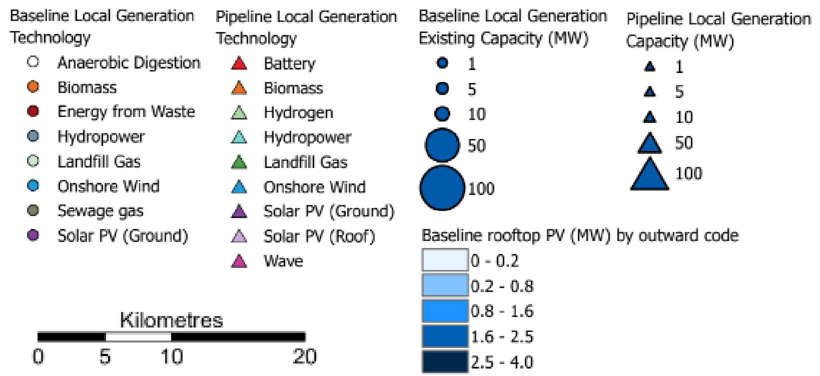
Figure 5.1.14 shows all electricity generation projects in the pipeline. There are plans to develop onshore wind farms around the Clocaenog Forest area, where there is already an installed capacity of 96MW, as well as a solar PV project with a capacity of 20MW to the west of St. Asaph. There are some smaller rooftop solar PV projects in Rhyl and Prestatyn that have also been registered. The 2050 results suggest that all these projects could be built in any scenario, since the projected capacities in each scenario exceed the combined theoretical capacity of projects in the pipeline.

Investment requirements

The deployment model estimates the capital investment required for ground-mounted solar and onshore wind. These are shown in Figure 5.1.14.



Energy system component	Investment (£'millions) required, range between high and low demand scenarios	
	2023 - 2030	2030 - 2050
Ground-mounted solar PV	120 - 126	320 - 340
Onshore wind	3	80 - 90



Esri UK, Esri, TomTom, Garmin, Foursquare, FAO, METI/NASA, USGS, Esri, CGIAR, USGS

Figure 5.1.14: (from left to right) Electricity generation projects in the pipeline and baseline rooftop solar PV by outward code, investment requirements for priority focus zones for onshore wind and ground-mounted solar PV

2. Maximise potential for onshore renewables without compromising natural assets

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

Delivery partners: ARUP; Carbon Trust

Local electricity generation - rate of deployment

Figure 5.1.15 shows the range of possible deployment of ground-mounted solar and onshore wind across the scenarios in Denbighshire, 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 Denbighshire, the rate of installation is the fastest in the National Net Zero, High Demand and Low Demand scenarios.

Now:
- **1 MW** ground solar PV capacity
- **69 MW** onshore wind capacity

By 2030:
- **Up to 293 MW** ground solar PV capacity
- **Up to 72 MW** onshore wind capacity

By 2050:
- **Up to 1,070MW** ground solar PV capacity
- **Up to 156MW** onshore wind capacity

Figure 5.1.15: Maximum deployment rates for ground-mounted solar PV and onshore wind in 2023, 2030 and 2050

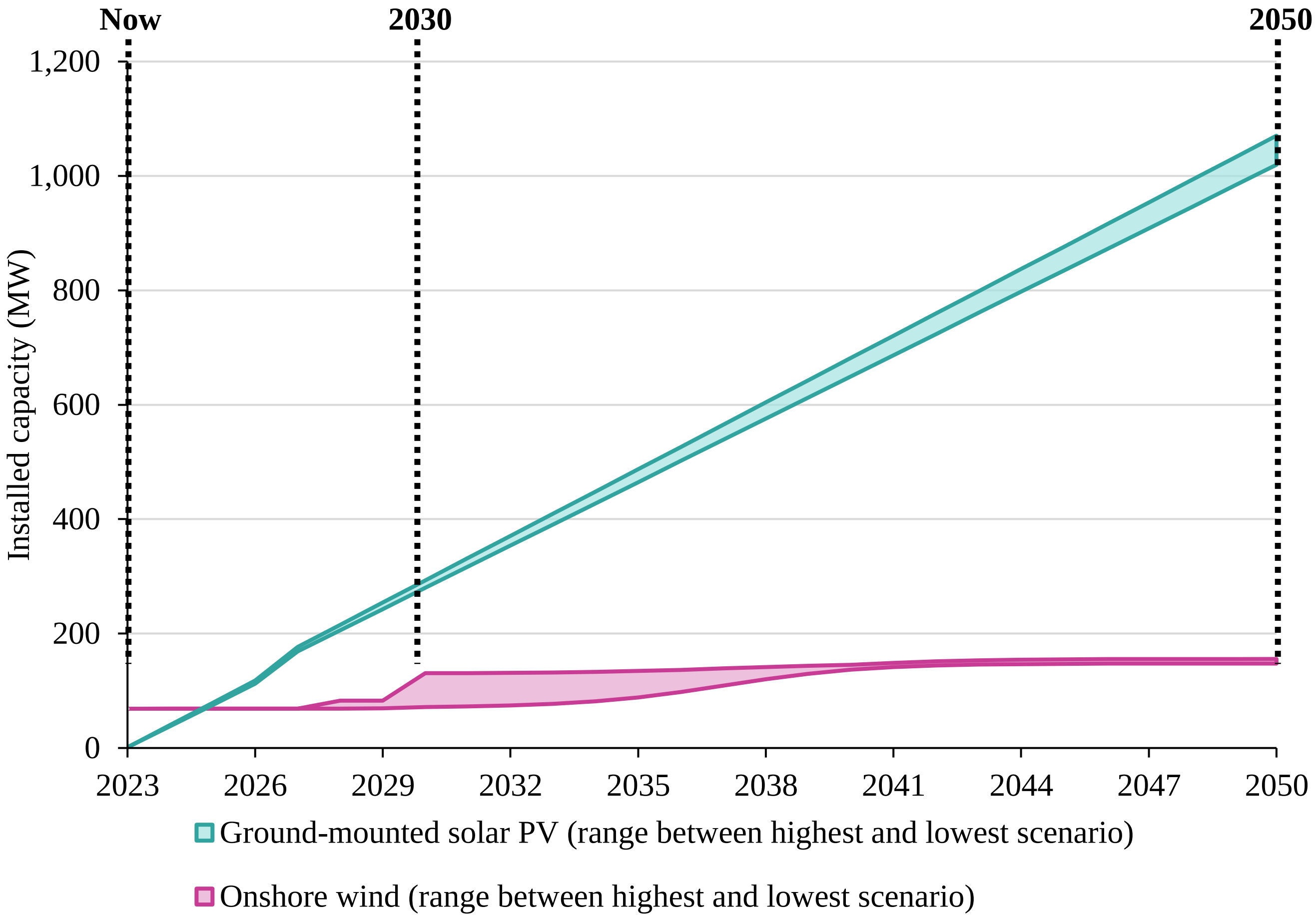


Figure 5.1.16: Summary of scale of renewables deployment across scenarios

Focus zones for public transport and EV chargepoints

The transport proposition for Denbighshire prioritises a reduction in car use as much as is possible through improved provision of active travel routes and public transport. Denbighshire County 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[TL05] 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. Denbighshire's Sustainable Transport Plan (2023-2028)[TL06] sets out key actions that it will take to achieve this in the next 5 years.

Sponsors: Delivery partners:

Focus zones for public transport and EV chargepoints

EV charging infrastructure

Predicted EV chargepoint deployment from Wales' EV Charging Strategy[TL07] (fast charging dominant scenario) is that by 2030, there are a total of 30,125 EV chargers in Denbighshire, of which:

- 65 are rapid
- 1,720 are fast
- 23,070 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 5.1.10).

To date, Denbighshire County Council has leveraged grant funding from the UK government's Office of zero Emission Vehicles (OZEV), levelling up funding and Welsh Government's ultra-low emissions vehicle transformation (ULEVT) funding to install public chargepoints in public car parks across Denbigh, Rhyl, Llangollen, Ruthin and Prestatyn. It has also committed to expanding this further, subject to funding, in its Sustainable Transport Plan (2023-2028)[TL06].

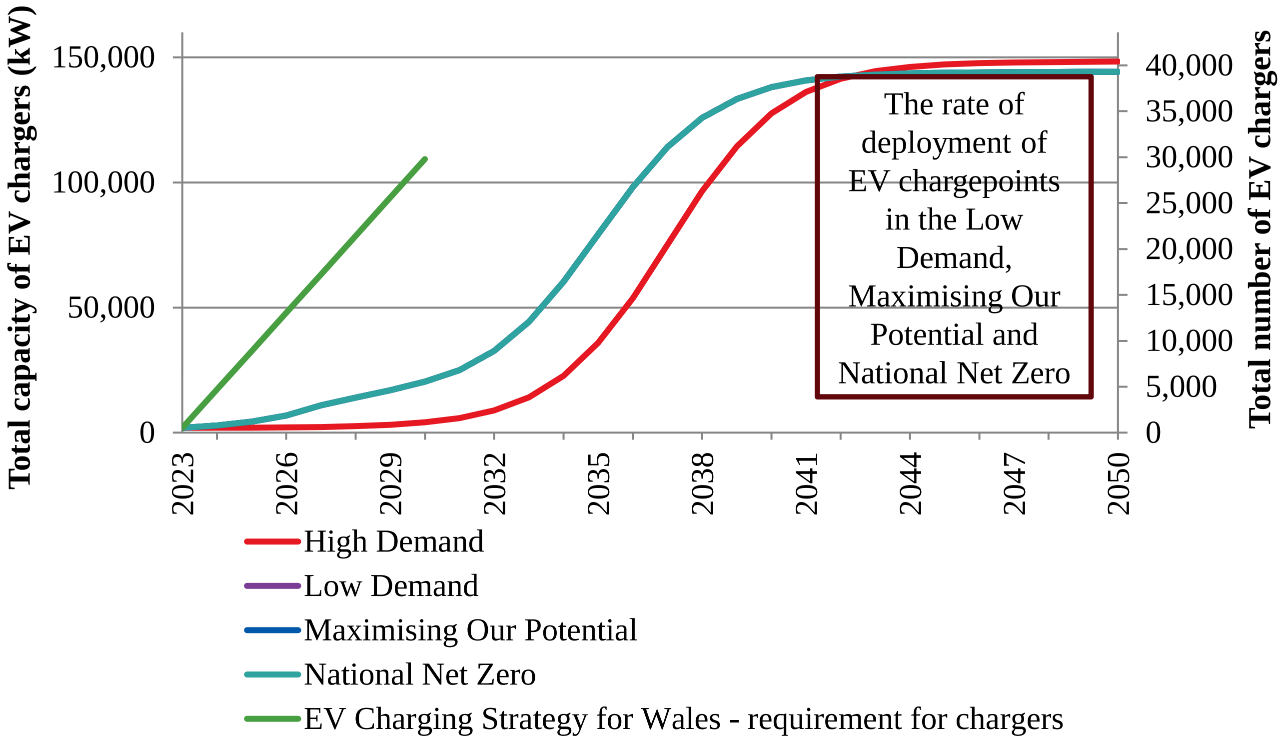


Figure 5.1.10: Capacity and EV chargepoint deployment over time

3. 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 (refer to Table 5.1.1 in the methodology section) to compare each modelling zone's favourability for near-term installation of EV chargers. Figure 5.1.11 (overleaf) illustrates the results; the highest-scoring zones are considered priority focus zones.

The maps shown in Figure 5.1.11 (overleaf) 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.

Figure 5.1.11 shows one priority 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.

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	£15 - £16	£100

Figure 5.1.3: Investment costs by energy system component

Now: **72** EV charge points

By 2030: **Up to 5,700** EV charge points

By 2050: **Up to 40,400** EV charge points

Min. 719 EV charge points/year

Sponsors: Delivery partners:

5. Action planning
3. Decarbonise transport

Focus zones for public transport and EV chargepoints

The coastal towns of Rhyl and Prestatyn and around Ysbyty Glan Clwyd are 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. As substation capacity is still limited in this area, the priority should be to make it easier for the public to access public transport and/or active travel for shorter journeys in and around the area to reduce car dependency as much as possible, which could in turn ease congestion, improve air quality and minimise additional costs for substation intervention.

Focus zone B (Southwest Denbigh) has a relatively high index of multiple deprivation and available capacity at the substation that services this area which could make conditions more favourable for installing EV chargepoints in the near-term.

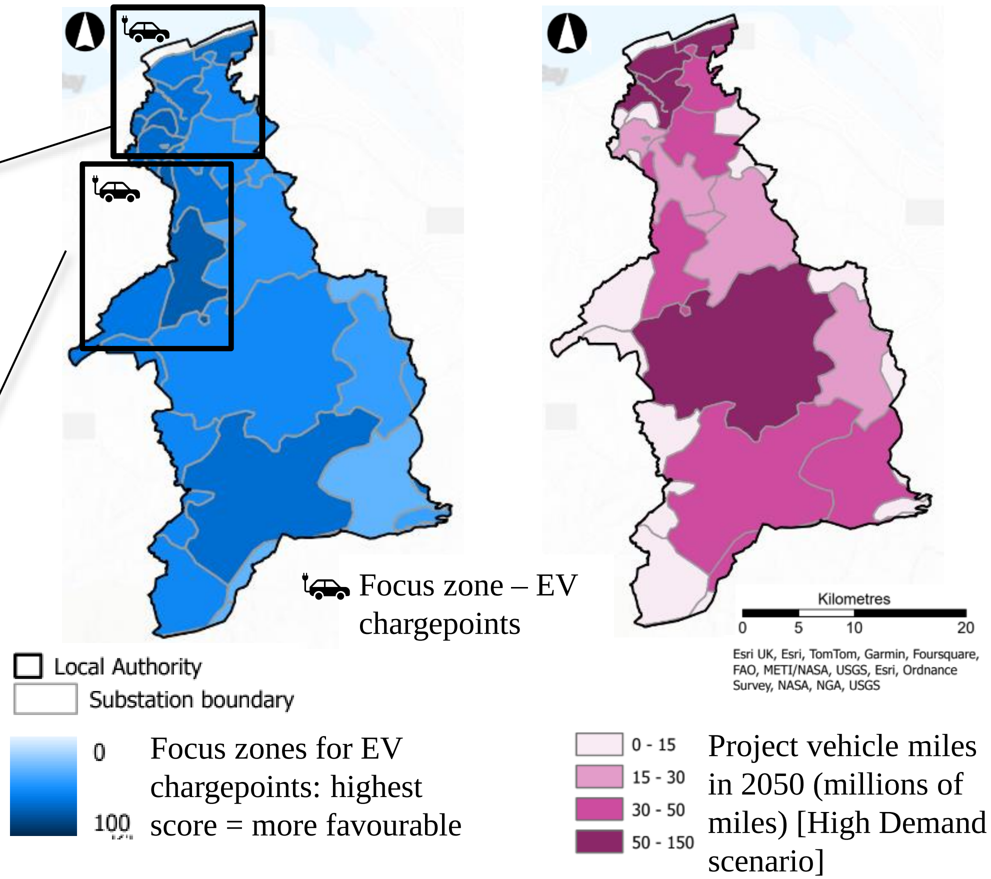


Figure 5.1.11: (Left) Priority focus zones for EV chargepoints by modelling zone and (right) projected vehicle miles (millions of miles) in 2050 by modelling zone across Denbighshire

Now:	By 2030:	By 2050:	
72 EV charge points	Up to 5,700 EV charge points	Up to 40,400 EV charge points	Min. 719 EV charge points/year

Sponsors: Delivery partners:

Network transition planning

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 RIIO-ED3 will commence in 2028; the exact time period hasn't been announced yet.
- For gas networks: RIIO-GD2 runs from 2021 to 2026. It was considered whether to extend RIIO-GD2 to align the two networks. However, it's been announced that RIIO-GD3 will start in 2026 for a "medium term ex-ante" period. Consideration is being given to the length of RIIO-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 have undertaken annual planning through the process called DFES (Distribution Future Energy Scenarios)[TN35], shown in Figure 5.1.17. 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.

Electricity distribution network

Denbighshire County Council area is served by the section of network fed via the 240MVA 400/132kV SGT at St Asaph and the four 240MVA 400/132kV SGTs at Legacy. These two network groups supply around 330,000 consumers in the North Wales area, which includes the Denbighshire County Council constituents.

Planned interventions to be delivered by 2028 will release up to 180MW of additional capacity and up to 120MW of flexibility services opportunities across both grid groups.

Various primary transformer and switchgear replacements and modernisations being delivered between 2024 and 2028 will provide shorter term deliverables throughout the RIIO-ED2 period and the full capacity release will become available following installation of an additional 132kV transformer by 2028.

Existing and further planned contracted flexibility services will mitigate low voltage issues in both groups whilst this planned replacement and modernisation work is being delivered, which will manage thermal constraints on the network during the RIIO-ED2 period.

SPEN is actively seeking further flexibility opportunities in this area and our partner, Piclo, is facilitating our procurement process on their Dynamic Purchasing Platform[TL08].

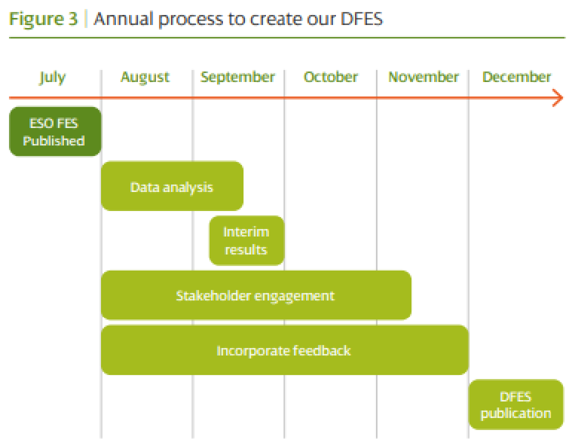


Figure 5.1.17: SPEN's annual DFES process (credit: SPEN)

Sponsors:

Delivery partners:

Network transition planning

Gas distribution network

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

£1.4million 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 RIIO-GD2 due to end in 2026 this was already awarded. WWU is currently preparing our RIIO-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.

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
4. Reinforce and transition the energy 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 5.1.18 shows areas where substation upgrades are needed if the rest of LAEP is carried out.

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

Electricity networks

To undertake the level of change shown in the map above 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 **21.** This equates to a total of 305MW capacity. Additional upgrades to the network may be required following comprehensive contingency analysis.

The cost of this is estimated at £50million, which equates to approximately £1,080 per home.

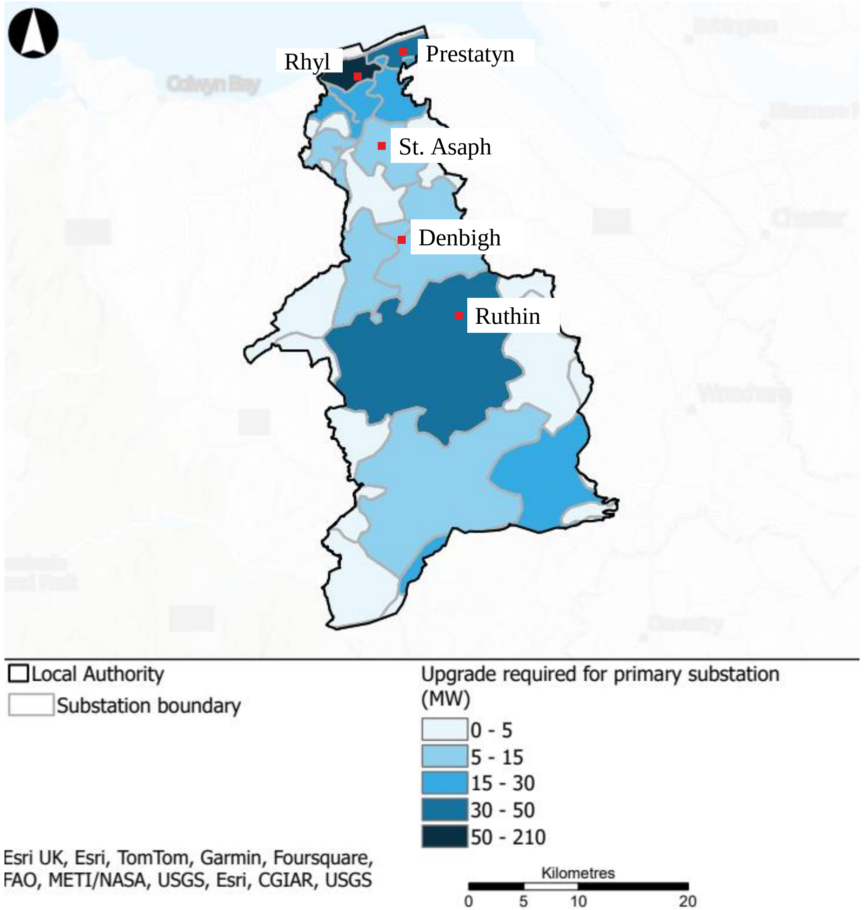


Figure 5.1.18: Map showing electricity substation upgrades that will be required by 2050 in the High Demand scenario

5. Action planning
4. Reinforce and transition the energy networks

Network transition planning

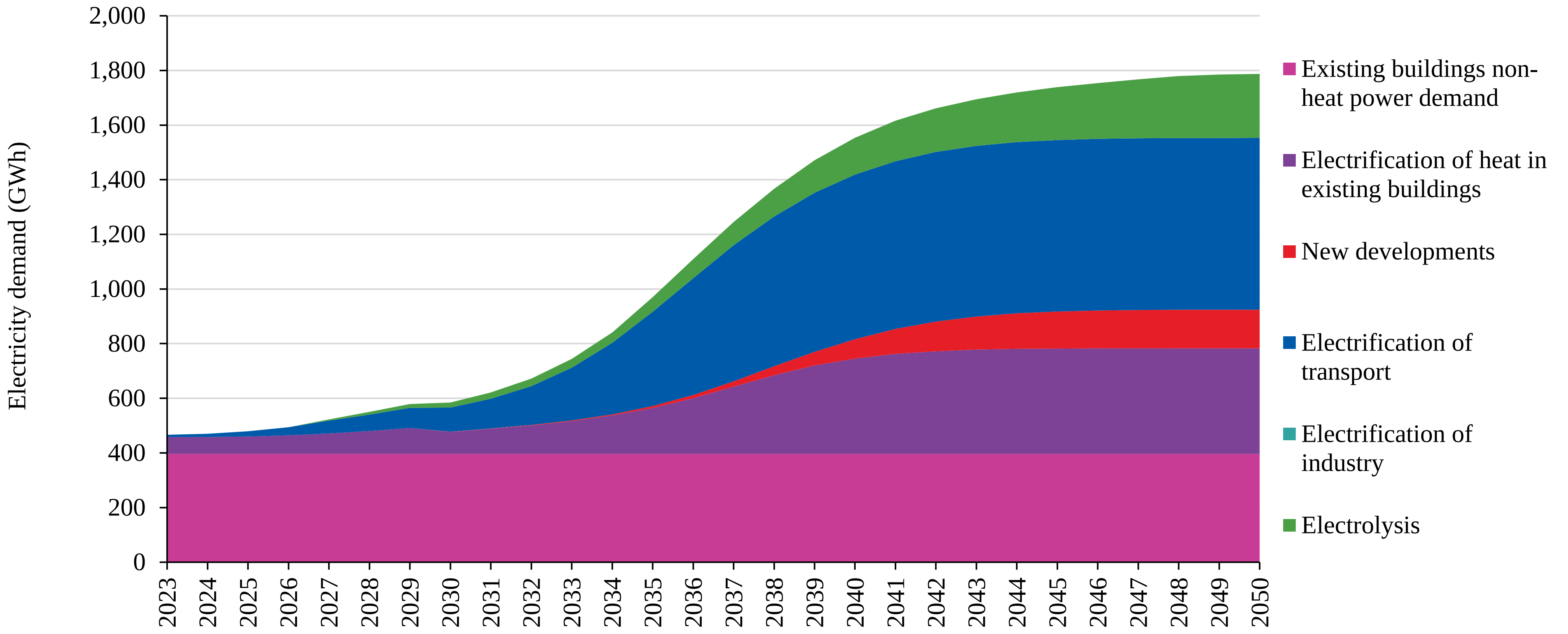


Figure 5.1.19: Projected change in electricity demand by end use between 2023 and 2050 in the High Demand scenario

4. Reinforce and transition the energy networks

Network transition planning

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 Denbighshire this is 70% complete.

Our modelling has shown a demand of up to 77 GWh per year for hydrogen in the future from 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 (6MW of capacity by 2030 and 71MW by 2050) which contributes to the UK's target of 10GW by 2030.[T51] Hydrogen is currently localised in the model, which means it is used at the point of production or imported into the system to the point of production from a national asset that could be inside or outside the county boundary.

The investment needed for hydrogen in Denbighshire could be between £2-£4million between now and 2030.

5. Action planning
4. Reinforce and transition the energy networks

Network transition planning

Storage

Short-term and seasonal storage also needs consideration. While our modelling, does not show a lot of electrical storage, many 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 Combined Cycle Gas Turbine (CCGT) and Carbon Capture and Storage (CCS), 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 1,610GWh per year of electricity imported in the High Demand scenario, this could equate to £10million per year.

5. Action planning

5. Promote smart local energy systems

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 is 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

Sponsors:

Delivery partners:

Appendices
Section A

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 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.

Sponsors: Delivery partners:

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	An energy proposition is an energy component with a scale and a timescale. For instance, 15MW capacity of wind turbine to be built in 5 years, 10,000 buildings to retrofit with heat pumps 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'[T57] 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 Denbighshire.

Appendix A2
Glossary of terms

Term	Definition or meaning
Net Zero	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 North Wales, a group of primary substations acting together to serve one area).

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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.

Sponsors: Delivery partners:

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 $kgCO_2e$.
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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Appendices

Section B

Appendices
Section B

Sponsors:

Delivery partners:

Appendix B1
Emissions sources in scope

LAEP emissions source	Inclusion	Comment
Domestic		
Electricity	✓	
Gas		
‘Other fuels’	✓	Oil, biomass, coal, LPG
Road transport		
‘A’ roads	✓	
Minor roads	✓	
Other (off-road, machinery)	✓	

Sponsors: Delivery partners:

Appendix B1
Emissions sources in scope

LAEP emissions source	Inclusion	Comment
Commercial and public sector		
Electricity	✓	
Gas		
'Other fuels'	✓	
Industry	✓	
Electricity	✓	
Gas	✓	
'Other fuels'	✓	
Large installations		Partial inclusion
Agriculture	✓	Emissions from agricultural processes not included but emissions from energy use is included.
Other fuels demand		
Domestic	✓	
Commercial	✓	
Industrial	✓	
Transport		

Appendix B1
Emissions sources in scope

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

Sponsors: Delivery partners:

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.

Appendix B1
Emissions sources in scope

LAEP emissions source		Comment
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	$kgCO_2e/kWh$	DESNZ, 2023 (Average of 4 biomass fuels: wood logs, wood chips, wood pellets, grass/straw)
Sewage gas	0.0002		DESNZ, 2023 (Biogas - Biogas)
Organic matter	0.0002		DESNZ, 2023 (Biogas - Biogas)
Natural gas	0.1843		DESNZ, 2023 (Gaseous fuels - natural gas, Gross CV)
Oil/LPG	0.2413		DESNZ, 2023 (Average of LPG and Fuel Oil, Gross CV)
Diesel	0.2391		DESNZ, 2023 (Liquid fuels - Diesel (average biofuel blend), Gross CV)
Petrol	0.2217		DESNZ, 2023 (Liquid fuels - Petrol (average biofuel blend), Gross CV)
Landfill gas	0.0002		DESNZ, 2023 (Biogas - Landfill gas)
Waste incineration	0.0380		Tolvik, 2021 (https://www.tolvik.com/published-reports/view/uk-energy-from-waste-statistics-2021/)
Coal	0.3226		DESNZ, 2023 (Coal - Industrial, Gross CV)

Grid electricity carbon factor source	National Grid's Future Energy Scenarios 2023 (average scenario)

Sponsors: Delivery partners:

Appendix B3
Buildings - assumptions

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

Appendix B3
Buildings – domestic archetypes

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

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

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

Sponsors: Delivery partners: ARUP

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

Sponsors: Delivery partners: ARUP

Appendix B3
Buildings – non-domestic archetypes

Archetype	Description	Age	Wall	Roof	Floor	Window	Heat demand (kWh/m²)	Electricity demand (kWh/m²)	Cooling demand (kWh/m²)
22	Warehouse	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					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

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 facade)	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/m^2)	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/m^2)	Cost £
12	73.8																			66.5	£1,517 +£82/m^2
13	95.8																			94.8	£1,250 +£0/m^2
14	120.9																			118.5	£11,250 +£0/m^2
15	72.4																			70.9	£26,000 +£0/m^2
16	127.7																			110.0	£27,295 +£32/m^2
17	107.3																			88.5	£49,620 +£45/m^2
18	141.0																			132.7	£5,120 +£10/m^2
19	113.3																			108.4	£11,250 +£22/m^2
20	177.8																			173.7	£5,120 +£0/m^2
21	162.6																			157.8	£83,076 +£69/m^2

22-27 not modelled, Industry modelled separately

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

Sponsors: Delivery partners:

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: $\text{Mileage}_{AB} = \text{distance}_{AB} * \text{number of trips}_{AB}$
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

Sponsors: Delivery partners:

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
Cardiff	Yes
Merthyr Tydfil	Yes
Monmouthshire	No
Torfaen	No
Rhondda Cynon Taf	No
Vale of Glamorgan	No
[AREA]	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	ºC	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	0.1304	£/kWhe	HMT Green Book central commercial/public sector price
ASHP source ΔT	10	ºC	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Electricity supply connection cost	200	£/kWe	Based on average of DNO connection offers in urban areas
ASHP supply ΔT	5	ºC	Typical ambient temperature during heating hours – inputs give equivalent COP to calliope	Building supply temperature	65	ºC	Typical building supply temperature – inputs give equivalent COP to calliope

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

Sponsors: Delivery partners:

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./kWht h	Used in the NCA study – error in calliope input	Elec boiler O&M costs	0.0075	£ p.a./kWht h	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	°C	Typical ambient temperature during heating hours – same as counterfactual	Elec boiler efficiency	100	%	Taken from calliope inputs
ASHP carnot cycle ef ficiency	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	°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	°C	Typical technology assumption– same as counterfactual	Heat network supply tempe rature	65	°C	Consistency in supply temperature

Sponsors: Delivery partners:

Appendix B6
Heat networks – assumptions

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

Assumptions log – 2/3

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

Sponsors: Delivery partners:

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	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	850	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

Sponsors: Delivery partners:

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	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	180	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

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	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	180	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

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	ºC	LSBU waste heat research
Heat capture ΔT	5	ºC	Typical industry assumption
Capture plant capex rate	180	GBP/kWth	Estimate based on data from other Arup projects
Capture plant Opex rate	0.005	GBP/kWhth	Estimate based on data from other Arup projects

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	ºC	Assumes high grade heat; no heat pump boosting required
Capture plant capex rate	350	GBP/kWth	Estimate based on data from other Arup projects
Wholesale electricity cost	0.06	GBP/kWhe	Taken from calliope inputs
Z factor	10		https://assets.publishing.service.gov.uk/media/605b862ed3bf7f2f0b5830ec/draft-sap-10-2-appendix-c.pdf
Capture plant Opex rate	0.010	GBP/kWhth	Estimate based on data from other Arup projects plus lost electricity production costs

Sponsors:

Delivery partners:

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	ºC	Assumes high grade heat; no heat pump boosting required
Capture plant capex rate	350	GBP/kWth	Estimate based on data from other Arup projects
Wholesale electricity cost	0.06	GBP/kWhe	Taken from calliope inputs
Z factor	10		https://assets.publishing.service.gov.uk/media/605b862ed3bf7f2f0b5830ec/draft-sap-10-2-appendix-c.pdf
Capture plant Opex rate	0.010	GBP/kWhth	Estimate based on data from other Arup projects plus lost electricity production costs

Appendix B6
Heat networks – assumptions

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

Assumptions log: Industry – 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	ºC	Assumes high grade heat; no heat pump boosting required
Capture plant capex rate – large sites	650	GBP/kWth	Estimate based on data from other Arup projects – for sites >3 MWth
Capture plant capex rate – small sites	350	GBP/kWth	Estimate based on data from other Arup projects - for sites <3 MWth
Wholesale electricity cost	0.06	GBP/kWhe	Taken from calliope inputs
Z factor for power producers	10		Assumes same Z factor as EfW plants
Capture plant Opex rate – non-power producers	0.004	GBP/kWhth	Estimate based on data from other Arup projects
Capture plant Opex rate – power producers	0.010	GBP/kWhth	Uplifts rate to account for lost electricity sale revenue

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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	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) of capex	BEIS (2021) Hydrogen Production Costs 2021. Available at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	50:50 SEM and Alkaline electrolyser from 2050.

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Technology	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	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/electrolysers.Hydrogen_Production_Costs_2021.pdf (Accessed 2023).	Medium scenario for both Alkaline and PEM
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 CHP	Energy efficiency	0.42	fraction	2G Energy Ltd (2024) Leading Combined Heat and Power Technology. Available at: https://www.2-g.com/en/hydrogen-chp/ (Accessed 2023).	Assume same as hydrogen CHP. Heating efficiency.
Biogas CHP	Lifetime	15	years	2G Energy Ltd (2024) Leading Combined Heat and Power Technology. Available at: https://www.2-g.com/en/hydrogen-chp/ (Accessed 2023).	Assume same as hydrogen CHP.
Biomass boiler to heat	Energy CAPEX	750	£ / kW	Biomass boilers: SPONS mechanical and electrical services	
Biomass boiler to heat	Energy efficiency	0.7	fraction	BEIS (2019) Measurement of the in-situ performance of solid biomass boilers. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831083/Full_technical_report.pdf (Accessed 2023).	Mean gross %
Biomass boiler to heat	Lifetime	20	years	BEIS (2019) Measurement of the in-situ performance of solid biomass boilers. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/831083/Full_technical_report.pdf	
Biomass boiler to heat	Operational cost of production	0.004	£ / kWh generated	IRENA (2012) Biomass for Power Generation. Available at: 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	Setting	Value	Units	Reference	Notes
Biomass boiler to electricity	Energy CAPEX	3141.74	£ / kW	BEIS (2020) BEIS Electricity Generation Costs. Available at: https://www.gov.uk/government/publications/beis-electricity-generation-costs-2020 (Accessed 2023).	CAPEX includes Pre-development cost (medium scenario) in £/kW, Construction cost (medium scenario) in £/kW and Infrastructure cost. Infrastructure cost (£'000) is converted to £/kW by dividing by reference plant size (MW*1000).
Biomass boiler to electricity	Energy efficiency	0.29	fraction	BEIS (2020) Electricity Generation Costs.	
Biomass boiler to electricity	Lifetime	25	years	BEIS (2020) Electricity Generation Costs.	
Biomass boiler to electricity	Operational cost of production	0.009	£ / kWh generated	BEIS (2020) Electricity Generation Costs.	OPEX includes Fixed O&M, Variable O&M, Fuel Costs, Decommissioning and waste, Steam Revenue, Additional Costs (all provided in £/MWh).
Biomass boiler to electricity	Opex	96	£ / kW / year	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Operational cost of production	0.013	£ / kWh	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Energy CAPEX	5551.4	£ / kW	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Lifetime	24	years	BEIS (2020) Electricity Generation Costs.	
Biomass CHP	Annual operational cost	307	£ / kW / year	BEIS (2020) Electricity Generation Costs.	
Biomass CHP to heat	Energy efficiency	0.43	fraction	Digest of UK Energy Statistics (DUKES) (2023) combined heat and power. Available at: https://www.gov.uk/government/statistics/digest-of-uk-energy-statistics-dukes-2023 (Accessed 2023).	Heat efficiency calculated using heat output and total CHP fuel use in 2022.

Sponsors: Delivery partners:

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Technology parameters for future energy system scenario modelling

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	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.

Sponsors: Delivery partners:

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Technology parameters for future energy system scenario modelling

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

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Methane reformation	Operational cost of production	0.01	kgCO2e / kWh	Timmerberg, Kaltschmitt, and Finkbeiner (2020)Hydrogen and hydrogen-derived fuels through methane decomposition of natural gas – GHG emissions and costs. Available at: https://doi.org/10.1016/j.ecmx.2020.100043 (Accessed 2023).	Assuming that our methane reformation technology is SMR with CCS. After converting units, the value to 3 significant figures is 0.013kgCO2e/kWh.
Resistance heating	Annual operational cost	0	£/kW/year	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	Annual maintenance costs for resistance heaters zero. Does not change between years.
Resistance heating	Energy CAPEX	150	£ / kW	Imperial College London for CCC (2018) Analysis of alternative UK heat decarbonisation pathways. Available at: https://www.theccc.org.uk/publication/analysis-of-alternative-uk-heat-decarbonisation-pathways. (Accessed 2023).	CAPEX includes unit and installation costs. Values used for Residential. Does not change through the years.
Resistance heating	Energy efficiency	1	fraction	National Renewable Energy Laboratory (1997) 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)	Energy CAPEX	625.54	£/kW	NGED charging statements - CDCM model for South Wales (2021)	Assuming grid level electricity distribution lines correspond to 132kW network level assets, which have a cost of 13.9 £/kW/year. Multiplying by the asset lifetime of 45 years gives an energy CAPEX of 625.54.

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

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Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Battery	Energy efficiency	0.92	fraction	Cole, Wesley and Akash Karmakar.(2023) Cost Projections for Utility-Scale Battery Storage: 2023 Update. Golden, CO: National Renewable Energy Laboratory. Available at: NREL/TP-6A40-85332 https://www.nrel.gov/docs/fy23osti/85332.pdf (Accessed 2023).	Changed energy efficiency to 0.92 this means a round trip efficiency of 0.85
Battery	Lifetime	15	years	Cole, Wesley and Akash Karmakar. 2023. Cost Projections for Utility-Scale Battery Storage: 2023 Update. Golden, CO: National Renewable Energy Laboratory. 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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Appendix B7
Technology parameters for future energy system scenario modelling

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

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Technology parameters for future energy system scenario modelling

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

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Technology parameters for future energy system scenario modelling

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

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Technology parameters for future energy system scenario modelling

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

Appendix B8
Air quality – method, assumptions, and data sources

Calculation Method (all fuels other than electricity)

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

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

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

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

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

where

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

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

Appendix B8
Air quality – method, assumptions, and data sources

Primary Fuel Use

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

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

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
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

Year	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Electricity	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 B9.1. Air quality activity costs from primary fuel use, 2022 p/kWh – Electricity [1]

Appendix B8
Air quality – method, assumptions, and data sources

Primary Fuel Use

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)

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

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.

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