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Flintshire

Local Area Energy Plan (LAEP)

Technical Report

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Abbreviations

Acronym	Definition or meaning
ANW	Ambition North Wales.
BEIS	Business, Energy and Industrial Strategy.
CAPEX	Capital Expenditure.
CCGT	Combined Cycle Gas Turbine.
CCR	Cardiff Capital Region.
COP	Coefficient of Performance.
DESNZ	Department for Energy Security and Net Zero.
DFES	Distribution Future Energy Scenarios.
DfT	Department for Transport.
DNO	Distribution Network Operator.
EfW	Energy from Waste.
EPC	Energy performance certificate.
ESC	Energy Systems Catapult.
EV	Electric Vehicle.

Acronym	Definition or meaning
GHG	Greenhouse Gas.
HGV	Heavy Goods Vehicles.
LAEP	Local area energy planning or Local area energy plan.
LGV	Light Goods Vehicles.
LSOA	Lower super output area, a small area classification in the UK designed to have a comparable population.
LULUCF	Land Use, Land Use Change and Forestry.
MSOA	Middle super output area, a medium-sized area classification in the UK designed to have a comparable population.
NAEI	National Atmospheric Emissions Inventory.
NGED	National Grid Electricity Distribution.
NZ	Net Zero.
NWTM	North Wales Transport Model.
OPEX	Operational Expenditure.
RFI	Request for Information.

Abbreviations

Acronym	Definition or meaning
RIIO	Revenue = Incentives + Innovation + Outputs, a regulatory framework used by the UK energy regulator, Ofgem.
SDP	Strategic Development Plan.
SMR	Steam Methane Reformation.
SPEN	SP Energy Networks.
SSE	Scottish and Southern Energy plc.
TfW	Transport for Wales.
WWU	Wales and West Utilities.

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Contents

This report was prepared by Arup, Carbon Trust and Afallen on behalf of Flintshire County Council and co-ordinated across the region by Ambition North Wales. Energy Systems Catapult is the Technical Advisor for the LAEP Programme in Wales.

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

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Technical report

Chapter 1: Introduction (stage 1)

1. Introduction

Introduction to Technical Report

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

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

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

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

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

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

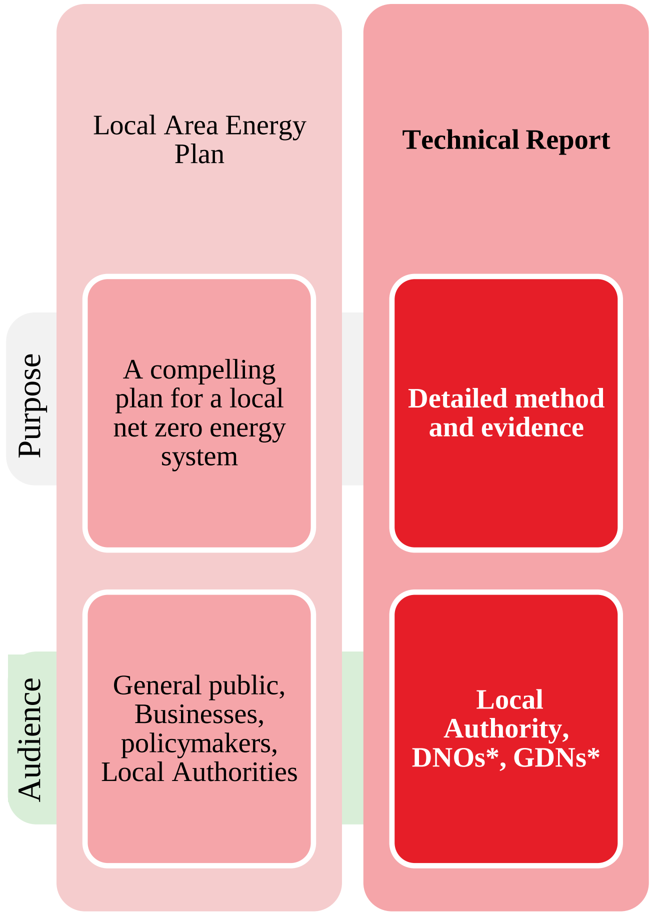


Figure 1.1.1: Summary of LAEP reports' purpose and audience. *DNO – electricity distribution network operator, GDN – gas distribution network operator

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

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

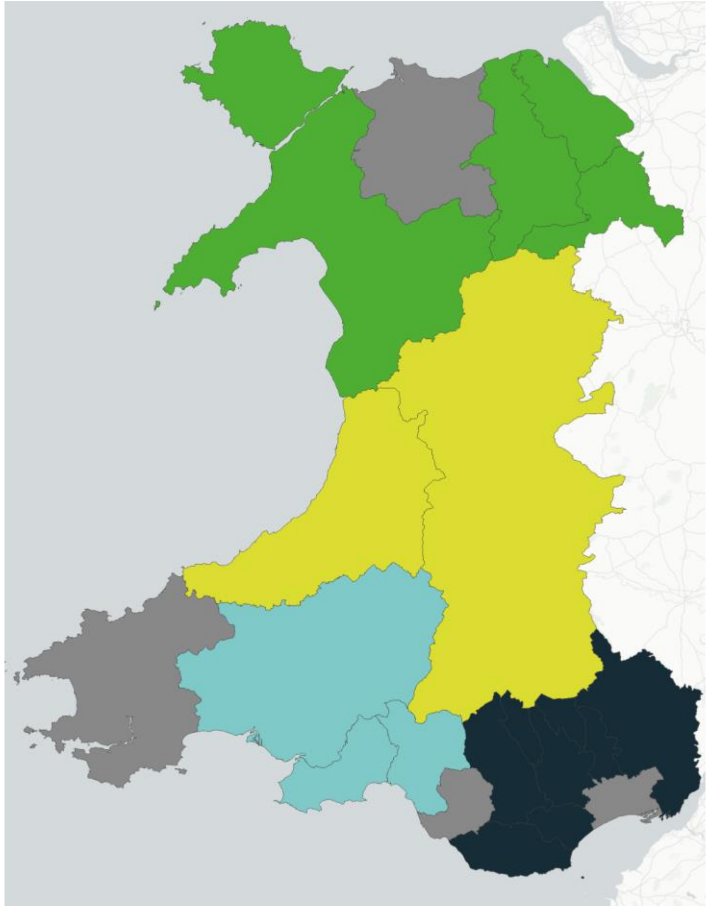
1. Introduction

The energy transition across Wales

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

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

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



North Wales
by Arup, Carbon Trust and Afallen

Mid Wales
by Energy Systems Catapult

South West Wales
by City Science

Cardiff Capital Region
by Arup, Carbon Trust and Afallen

Existing LAEPs

Figure 1.1.2: Progress made in the development of LAEPs across Wales

The local energy system

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

There are three core parts to the local energy system:

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

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

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

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

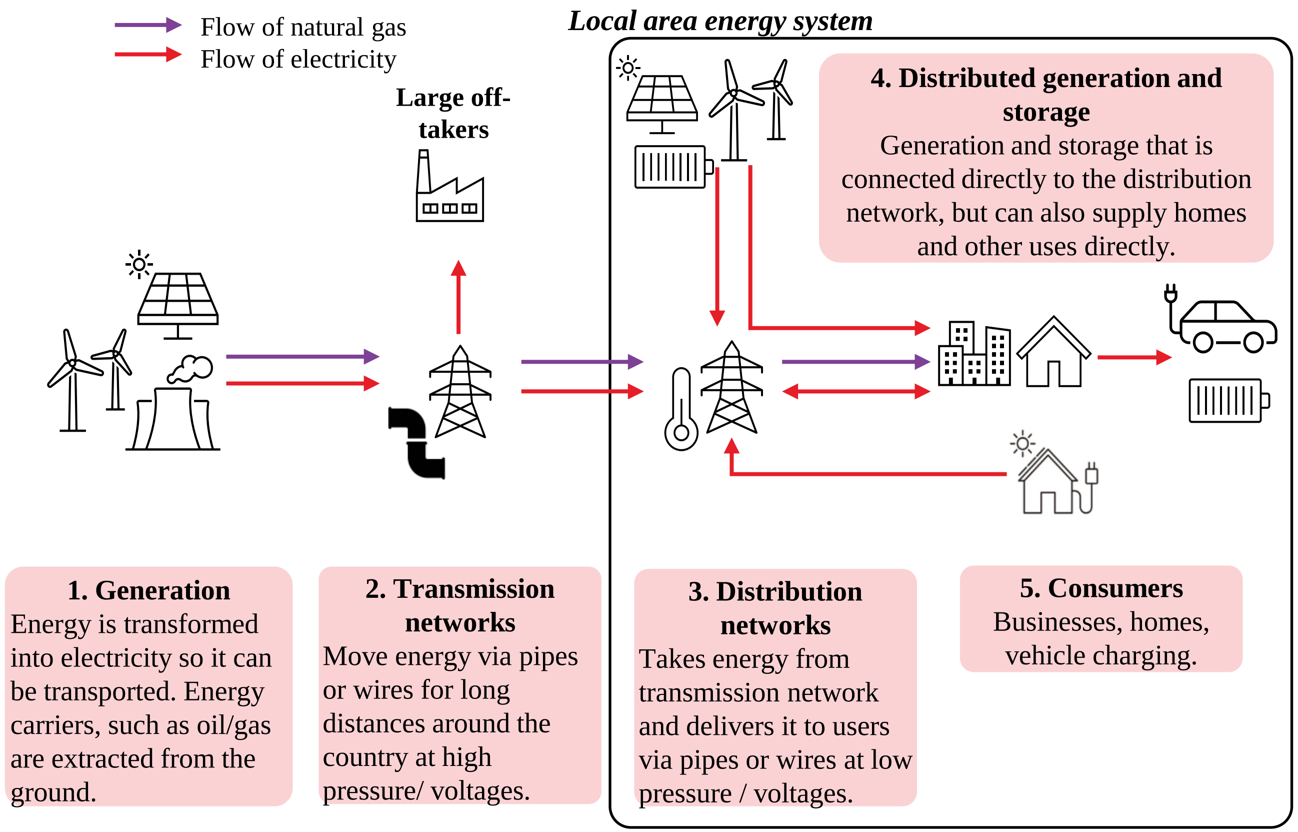


Figure 1.1.3: Illustration of transmission and distribution of gas and electricity from supply to consumer, and what parts of this system are included in the system boundary for LAEP

The local energy system

Boundary

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

Scope

The scope of the LAEP was then determined based on ESC's LAEP Guidance[T03]. The Guidance states that certain energy assets should be considered national rather than local, where the asset serves the wider energy needs of the UK. Considering this, electricity connection at lower voltages (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 > 100 MW were considered "national" and excluded from the modelling unless otherwise specified. This includes, for example, Connah's Quay Power Station.

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

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

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

Emissions

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

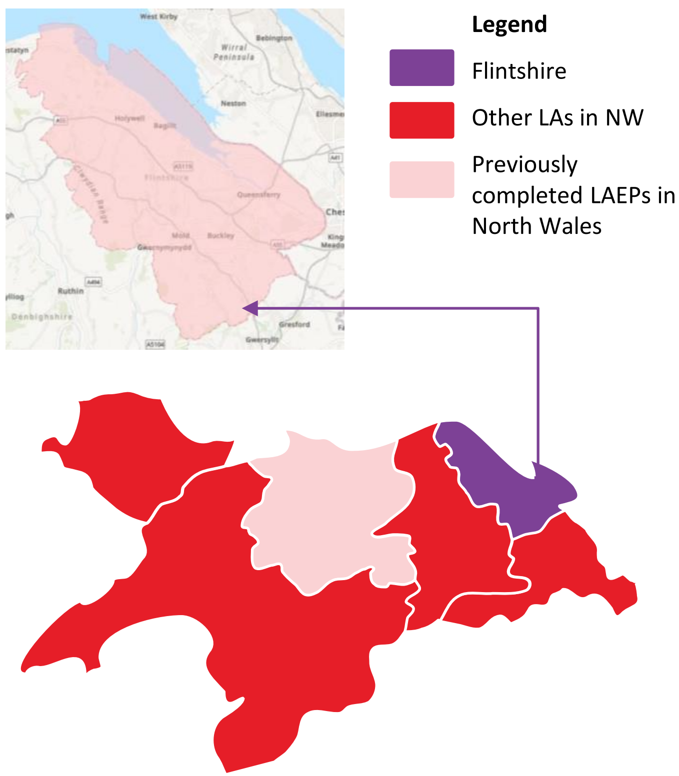


Figure 1.1.4 Location of the North Wales economic region (red) and the LAEP system boundary for Flintshire (purple)

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Chapter 2: Stakeholder engagement (stage 2)

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 2.0.0 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 teams so that their wider knowledge of the local energy system and potential stakeholders could be used to jointly iterate and continuously improve the final stakeholder map. The mapping tool was then used to allocate identified stakeholders to either a primary or secondary stakeholder role based on a scoring schema that reflected their respective knowledge and influence of the local energy system.

3. Stakeholder engagement planning

We reviewed the scored stakeholder lists with each Local Authority and ANW and using the results from the 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.

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.

2. Stakeholder engagement

Stakeholder identification process

Stakeholder group	Organisations	Role in LAEP development	Method of engagement
Primary stakeholders	Local Authority officers, council member(s), energy network operators i.e. Distribution Network Operators, (DNOs) and Gas Distribution Networks (GDNs).	Responsible for the creation of the LAEP, as well as having executive decision-making powers. Contribute existing and future policies and programmes relevant to the LAEP.	Steering groups, workshops, bi-weekly meetings, emails, 121 interviews
Secondary local stakeholders	Other local government organisations, major energy users, organisations with influence over and / or local knowledge of specific energy system components (e.g. developers, housing associations), community energy organisations, local organisations active in net zero and decarbonisation, transport sector organisations	Responsible for shaping the direction and actions collectively agreed in the LAEP. Contribute advice and guidance to the LAEP programme given influence over and / or local knowledge of specific element(s) of the local energy system, e.g. share details of existing programmes and projects.	Interactive workshops
Secondary regional stakeholders	Transmission network operators, transport providers, housing associations, growth deal organisations, landowners, national parks, further education, public bodies or national organisations (e.g. TfW) with a regional influence, trade organisations.	Responsible for shaping the actions and considering opportunities to deliver at scale across local authority boundaries by providing advice and guidance given regional influence and / or knowledge of specific elements of the regional energy system.	Interactive workshops
Technical advisors for LAEP	Energy Systems Catapult (ESC).	Ensuring a consistent approach is taken to the development of LAEPs in Wales.	Monthly meetings and invited to attend all workshops

Table 2.1.1: Overview of engagement activity for identified stakeholder groups

2. Stakeholder engagement

Overview of stakeholder engagement plan

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

1. Contract meetings

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

We held regional steering groups for Cardiff Capital region/North Wales, attended by the regional and local authority leads, as well as bi-weekly meetings with the local authority 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 2.0.1 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 through the use of chat, and facilitation introducing chat comments on participants behalf, and the opportunity to contribute for an extended period after the workshop by email.

2. Stakeholder engagement

Regional
Local

Overview of stakeholder engagement plan

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

3. The current energy system

Methodology overview

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

1. Data collection

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

We collected baseline data for 2023 to include the most up to date data for housing stock and renewable generation installations. The exception to 2023 datasets was for transport (2019 for North Wales) 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

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

3. Data analysis

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

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 head and the proportion of properties that are not connected to the gas.
4. **Supply:** maps showing energy generators.

Methodology – electricity and gas network infrastructure

Electricity

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

In some cases, these primary substation did not have corresponding capacity and/or headroom. For modelling purposes, they were assigned an unlimited capacity.

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.

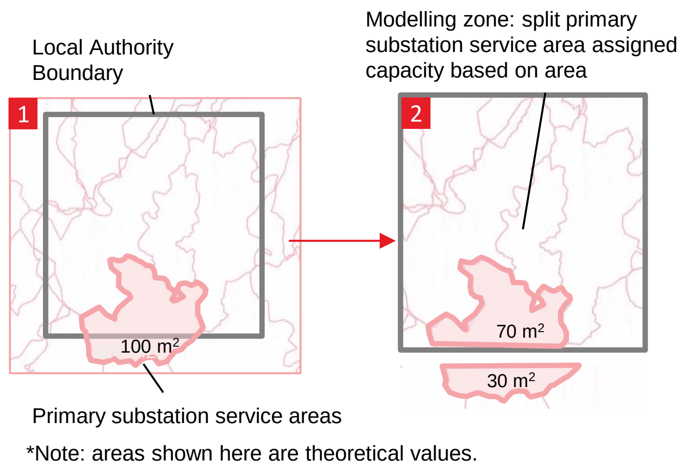

Figure 3.1.1: Process of mapping primary substation service areas to the local authority boundary

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

Table 3.1.1: Electricity and gas network infrastructure – data sources

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Methodology – electricity and gas network infrastructure

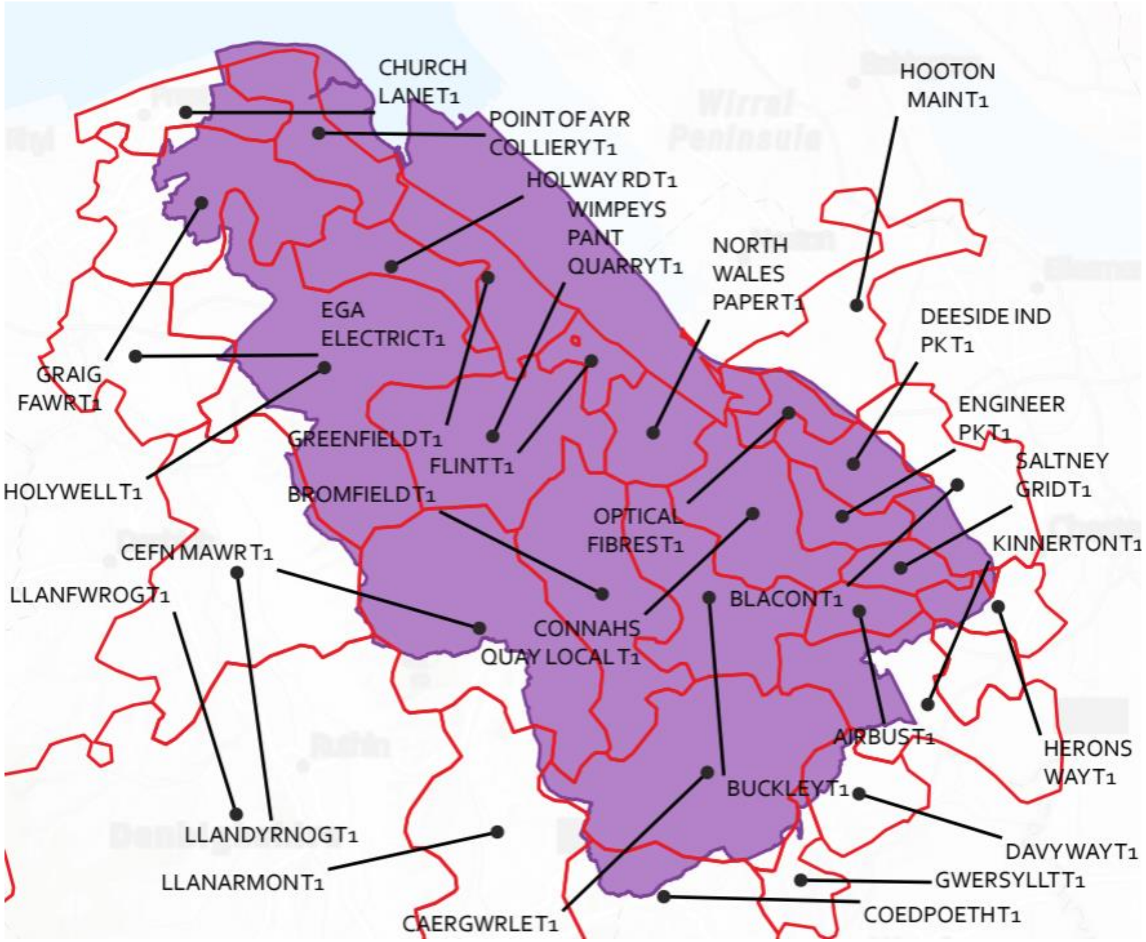

Figure 3.1.2: Map of substation zones in Flintshire

Figure 3.1.2 shows the geographic boundary of Flintshire county borough (purple) which is also the boundary used for Flintshire's LAEP. The primary substation service areas that supply energy 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."

Key

ANW substation zones

Local Authority

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Methodology – buildings energy demand

Carbon Trust has a well-established address-level database that uses a "bottom-up" approach for both domestic and non-domestic properties. 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[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.
Gas and electricity consumption data	Council-supplied data	Primary	Council-owned stock only.
Domestic heat and electricity demand profiles	Profiling tool commissioned by NGED and developed by Hildebrand[T09]	Secondary	Uses data from approximately 10,000 smart meters from across the UK categorised by archetype to estimate average electricity and heat demand profiles.
Non-domestic heat, electricity and cooling profiles	CIBSE non-domestic electricity and gas benchmarks[T10] and Arup's normalised profiles	Secondary	Building profiles used have been tested against other buildings of the same type.

Table 3.1.2: Baseline data sources (buildings)

3. The current energy system

Methodology – buildings energy demand

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

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

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

Data validation

We generated building profiles at the archetype level and aggregated to Local Authority area to compare the annual consumption with DESNZ's sub-national energy consumption statistics[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 high Consumption taken from DESNZ's statistics[T05] is 13% lower per domestic address than the bottom-up generated profiles for electricity. One possible reason for the difference is occupancy – the bottom-up method assumes all properties are occupied, which is important for sizing a 2050 electricity network.

For non-domestic consumption, one limitation of the archetype approach is that it does not capture the range of ways floor area can be used in each archetype. See Appendix B3 for a detailed list of energy benchmarks.

Flintshire	% diff
Domestic electricity demand difference	-13%
Domestic heat demand difference*	-16%
Non-domestic electricity demand difference	80%
Non-domestic heat demand difference	89%
Un-occupancy (Census 2021)[T11]	5%
% non-domestic properties with no archetype	56%

Table 3.1.3: Demand differences between sub-national energy consumption statistics and building profiles. *Sub-national statistics reports gas consumption which was used as a proxy for heat demand

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

Table 3.1.4: Summary of building archetypes used

3. The current energy system

Methodology – transport energy demand

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

We used data from Transport for Wales (TfW) transport models[T12] to estimate annual road mileage data between different parts of a local area. TfW's data provided the number of trips between two different 'travel zones' (defined by TfW) on an average day according to vehicle type. In this data, a trip is defined by the 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 travel zones to substation zones. We summed over vehicle types to produce the map shown on the right in Figure 3.0.2.

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 3.1.3: baseline data sources (transport). The sum of this over a local authority resulted in the transport demand value for the baseline.

Exclusions

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

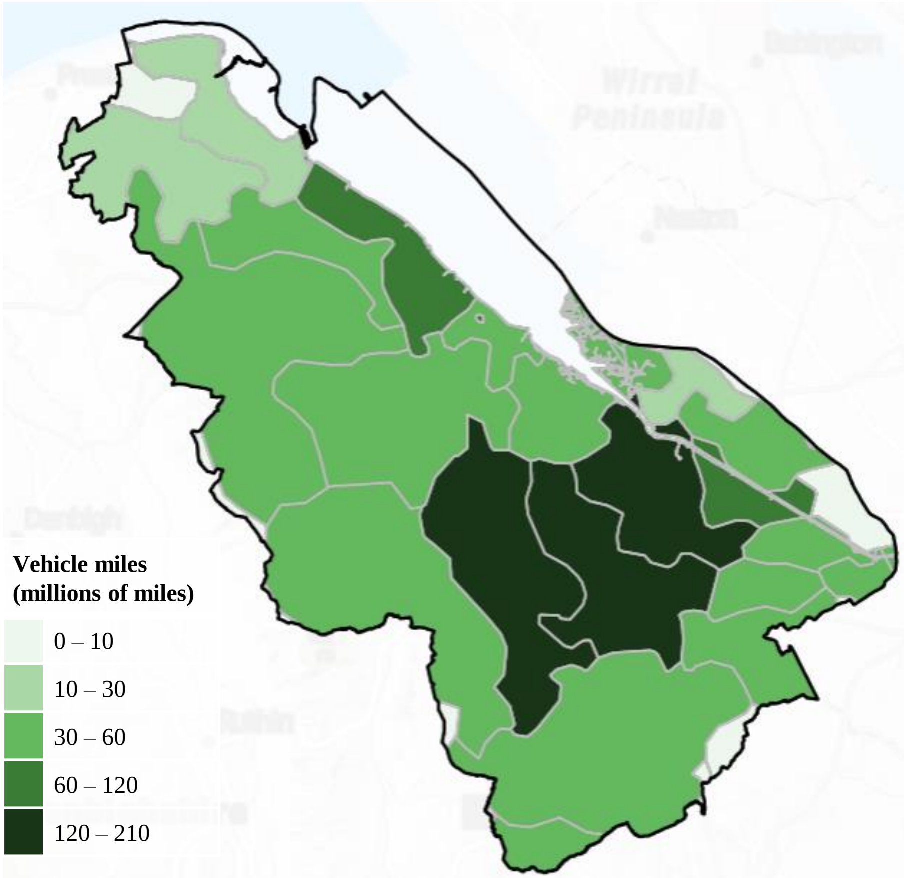


Figure 3.1.3: Estimated annual mileage (million miles / year) for all vehicles in Flintshire by substation zone (2019)

3. The current energy system

Methodology – transport energy demand

Data validation

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

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

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

Please see the energy consumption comparison on the next page.

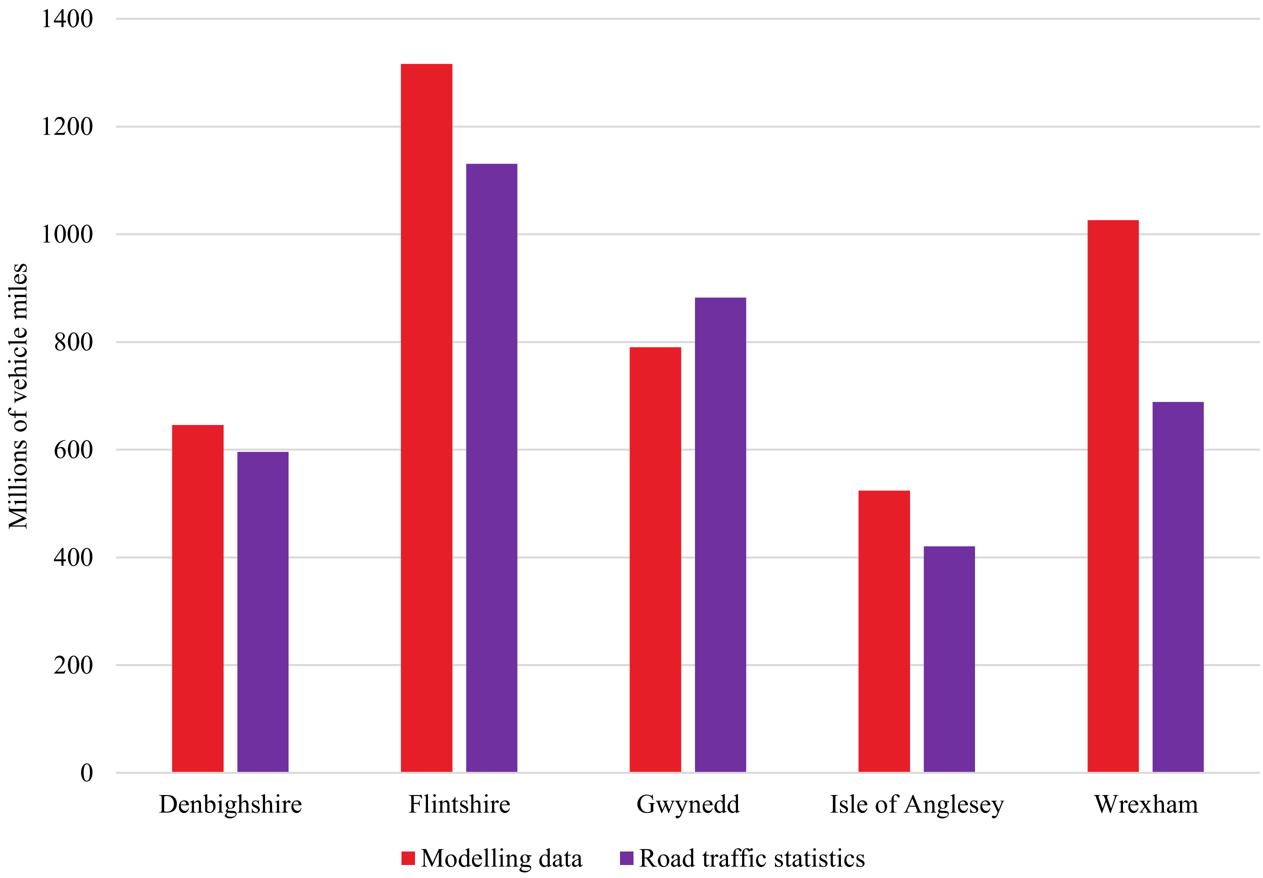


Figure 3.1.4: Comparison of modelling data to DfT road traffic statistics[T13]

Sponsors: Delivery partners:

Methodology – transport energy demand

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

Mapping of local electric vehicle charge points

In the baseline maps, we mapped local charge points according to the postcodes supplied in the National Chargepoint Registry[T15] and, where provided, local authority records. For Flintshire'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 Flintshire County Council wasn't included in Figure 3.0.4 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.

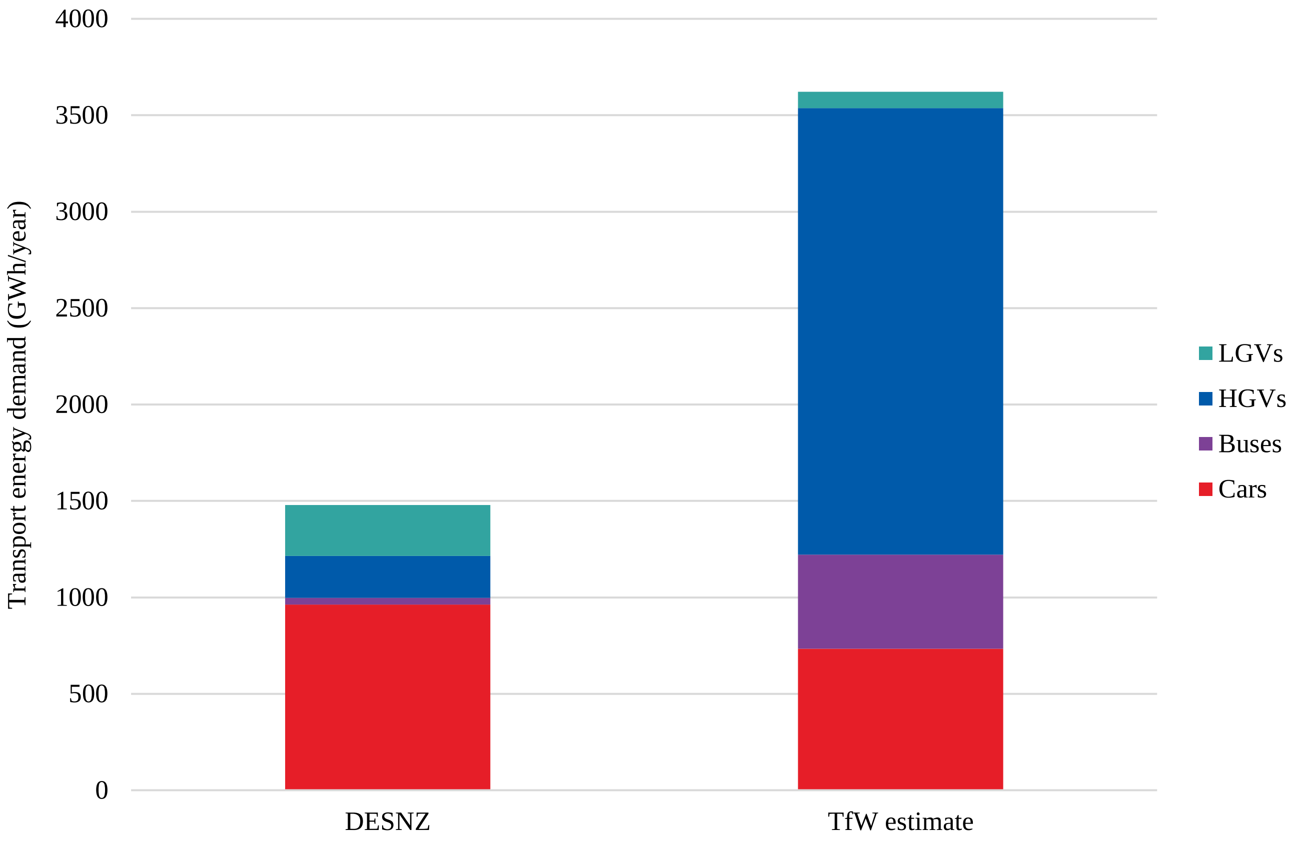


Figure 3.1.5: Annual transport energy consumption; our analysis based on TfW data compared to DESNZ sub-national fuel consumption statistics

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

Table 3.1.5: Baseline data sources (transport)

Methodology – industry energy demand

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

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

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

We sent industry stakeholders an 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 Flintshire did not respond to this information request, we used the NAEI emissions to provide a proxy for the energy used by the site. When calculating energy demand, we only considered carbon emissions in the conversion from carbon emissions to energy demand.

Data validation

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

Exclusions

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

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

Table 3.1.6: Baseline data sources (industry)

3. The current energy system

Methodology – local energy generation

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

Data validation

We cross-checked data against the energy generation in Wales (EGW)[T23] 2021 report to capture any operational generators that were not captured in renewable energy planning database (REPD[T22] or SPEN's embedded capacity registers (ECR))[TN24]. This was the latest report available at the time of developing the baseline.

As the EGW dataset[T23] includes ground-mounted generators connected to the transmission network, we cross-checked any additional generators identified in EGW against the transmission embedded capacity register (TEC)[T25] to ensure only generators connected to the distribution network were captured.

Exclusions

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

Data input	Data source	Data type	Data quality
Installed renewable electricity capacity (MWe) for ground-mounted solar PV, commercial rooftop solar PV, onshore wind, hydropower, biomass, anaerobic digestion, landfill gas, sewage gas, energy from waste, natural gas, oil.	REPD (January 2023)[T22] ECR (April 2023)[TN24] EGW (2021)[T23] Council-supplied data (where available)	Primary	Distribution-connected generators only. REPD: Renewable generators greater than 150kW*, UK wide, updated quarterly. ECRs: Generators or storage greater than or equal to 1MW, DNO supply area, updated monthly. EGW: Generators connected to distribution or transmission network, Wales-wide, updated annually.
Thermal generator installed capacity (MWth)	EGW (2021)[T23]	Secondary	Generators listed by outward code (first half of postcode) as no full postcode available.
Domestic rooftop solar PV	EGW (2021)[T23] Council-supplied data (where available)	Secondary	Rooftop solar PV data was compiled using feed-in-tariff registers and other micro-generator databases. Generators listed by outward code as no full postcode available.

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

Table 3.1.7: Baseline data sources (local energy generation)

Methodology – Greenhouse gas (GHG) emissions

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

GHG emission factors and their relevant sources are presented in Table 3.0.7. Each emission factor is a 2023 estimation except for electricity, where a projection was used to reflect grid decarbonisation.

Exclusions

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

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

Table 3.1.8: Baseline emission factors (local energy generation)

Sponsors:

Delivery partners:

Technical report

Chapter 3: The current energy system (stage 3)

Analysis

3. The current energy system

Analysis - local context

Flintshire, located in the northeast corner of Wales, serves as a key gateway to North Wales from Northwest England. It stands out with a robust industrial sector, notably in advanced manufacturing, setting it apart from other areas in Wales and the UK. The region is recognised nationally for its employment opportunities and economic significance in Wales, with broader importance to the Northwest sub-region.

Diverse towns, villages, employment parks, and picturesque landscapes define Flintshire. Its unique blend of culture and language is evident across various regions. While two-thirds of its population resides near the border, the rest of the county remains rural, hosting diverse landscapes and habitats.

The county's rich heritage, including conservation areas and listed buildings, contributes to its appeal. The natural and built environment serves as a primary asset, pivotal for conservation efforts, attracting investments, promoting tourism, and ensuring sustainability for residents and businesses.

Most of Flintshire's population resides in the east and along the coast, forming key towns like Buckley, Flint, Holywell, Saltney, and Mold. The Deeside area, particularly the Deeside Industrial Park, acts as a growth hub and a major economic driver, housing key employers such as Airbus UK and Toyota. Flintshire plays a pivotal role in the regional economy, contributing high-value manufacturing employment and demonstrating a positive economic outlook despite global challenges.

Flintshire has excellent transport links to the rest of North Wales and Northwestern England being at the intersection of the A55 and A494. Improving rail links through the North Wales Metro programme is increasing sustainable travel options in the region, with new or improved stations at Greenfield, Shotton and Deeside and enhanced rail frequency along the line.

Flintshire has a strong base in renewable energy production, hosting the largest solar park in the UK. This and other solar farms support some of the vast industrial energy demand in the region. Future developments in renewables will focus on solar PV due to the local constraints on wind energy from flight paths and the Clwydian range and Dee Valley area of outstanding natural beauty (AONB).

Climate change poses various risks, including flooding along the Dee Estuary and River Dee, impacting landscapes, habitats, and community well-being

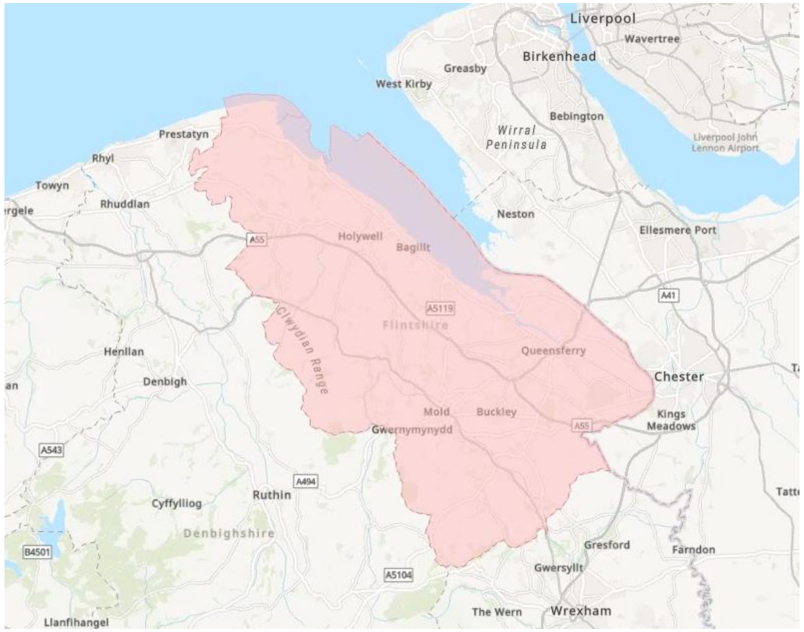


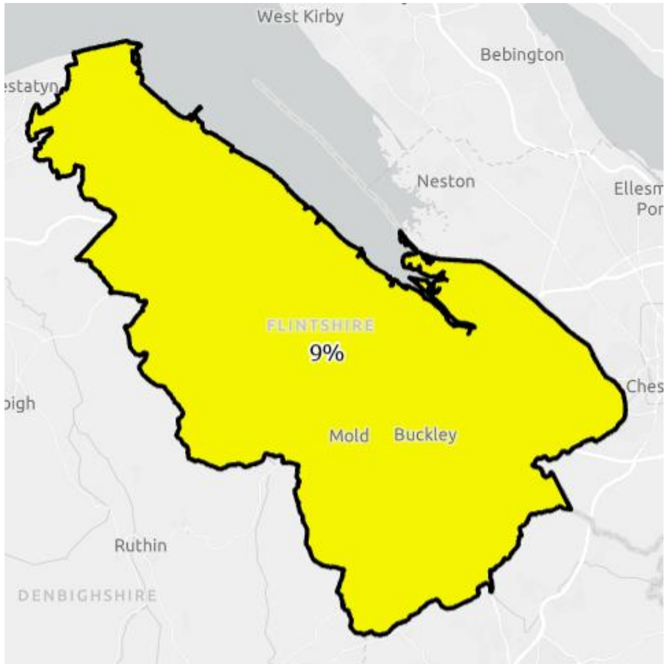
Figure 3.2.1: Map showing the boundary of Flintshire

3. The current energy system

Analysis – socio-economic context

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, 9% of households in Flintshire 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.

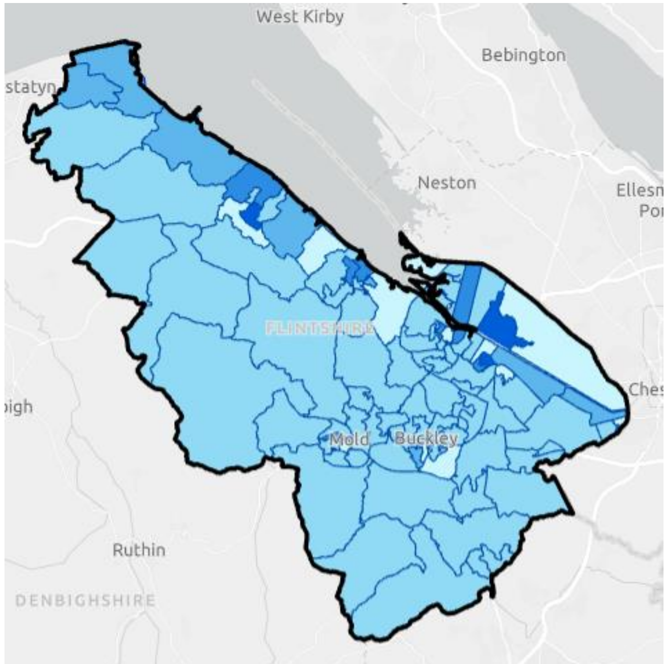


Fuel Poverty (% households in fuel poverty)

- 0 – 10
- 10 – 15
- 15 – 20
- 20 – 25
- >25

Figure 3.2.2: Fuel poverty in Flintshire in 2019. Data on fuel poverty is only available at the Local Authority level.

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 Flintshire in WIMD 2019 was Shotton and Garden City[T28].



Deprivation group

- 10% most deprived
- 20% most deprived
- 30% most deprived
- 40% most deprived
- 50% most deprived

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

Sponsors: Delivery partners:

Analysis – greenhouse gas (GHG) emissions by sector

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

The emissions shown in Figure 3.2.4 include:

Buildings: emissions from heating and electricity use from all buildings

Transport: emissions from road vehicles including cars, vans, lorries, and buses. Trains are not included.

Energy: emissions from electricity plants fired by fossil fuel

Industry: emissions from the large industry sites identified from the NAEI emissions dataset

Greenhouse gas (GHG) emissions in Flintshire in 2023 were 1,187ktCO_2e. GHG emissions per capita were 7.6tCO_2e per capita..

The largest contributors were:

- Road vehicles (60%)
  - 52% of total GHG emissions are from the use of diesel in road vehicles
- Energy used in buildings (34%)
  - 29% of total GHG emissions are from the use of natural gas in buildings.

Flintshire's CO_2e emissions are reducing over time.

NB: The emissions in Figures 3.2.4 and 3.2.5 exclude emissions from waste and land use, land use change and forestry (LULUCF).

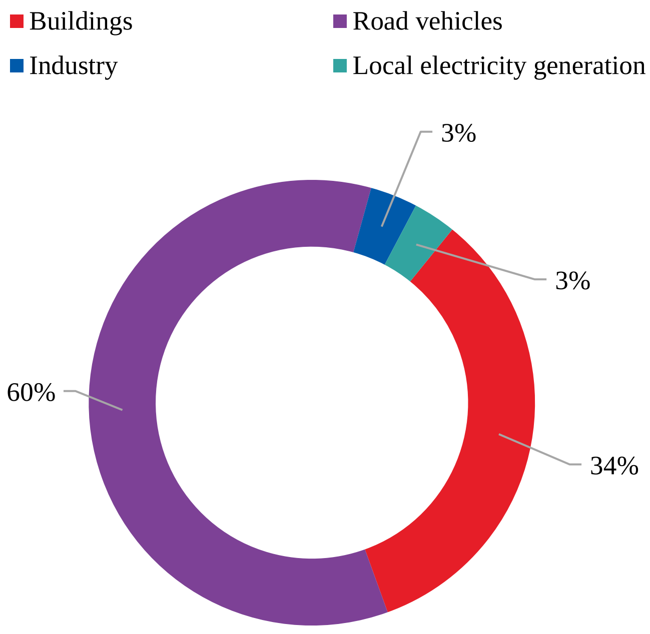


Figure 3.2.4: CO_2 emissions by sector in 2023, excluding LULUCF

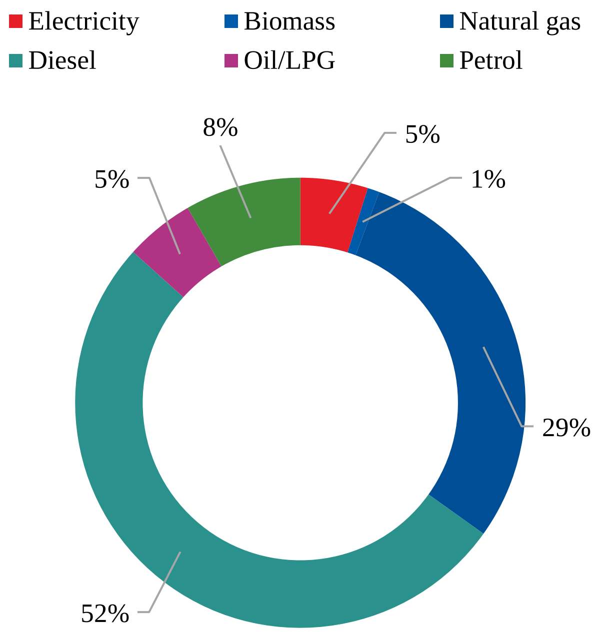
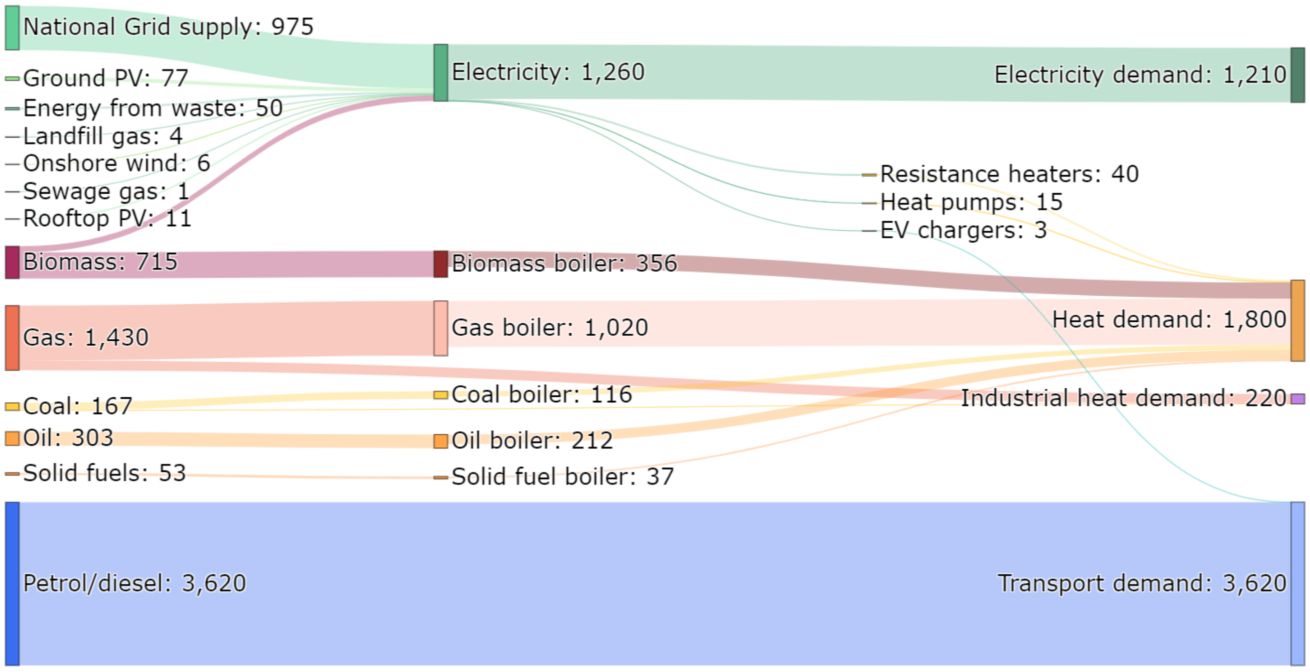


Figure 3.2.5: CO_2 emissions by fuel in 2023, excluding LULUCF

3. The current energy system

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 Flintshire 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 in GWh/year)

Sponsors: Delivery partners:

Analysis – annual energy flows

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

Most of the **electricity** within the system is supplied by the National Grid, accounting for 77% of total electricity consumed.
Ground PV, onshore wind and energy from waste generated, on average, 77GWh, 6GWh and 50GWh in 2019 respectively.
Almost all electricity was used to fulfil electricity demand from buildings and industry (i.e. not heat or transport).

Heating comprises the second largest component of energy demand, accounting for 29% of total energy across Flintshire. Due to the moderately high penetration of the gas network in Flintshire, most properties (82%) have heating delivered by gas. 1,430GWh is supplied to the system to meet demand. The remaining heat demand is met by other fuels such as oil, biomass, coal and solid fuels.

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

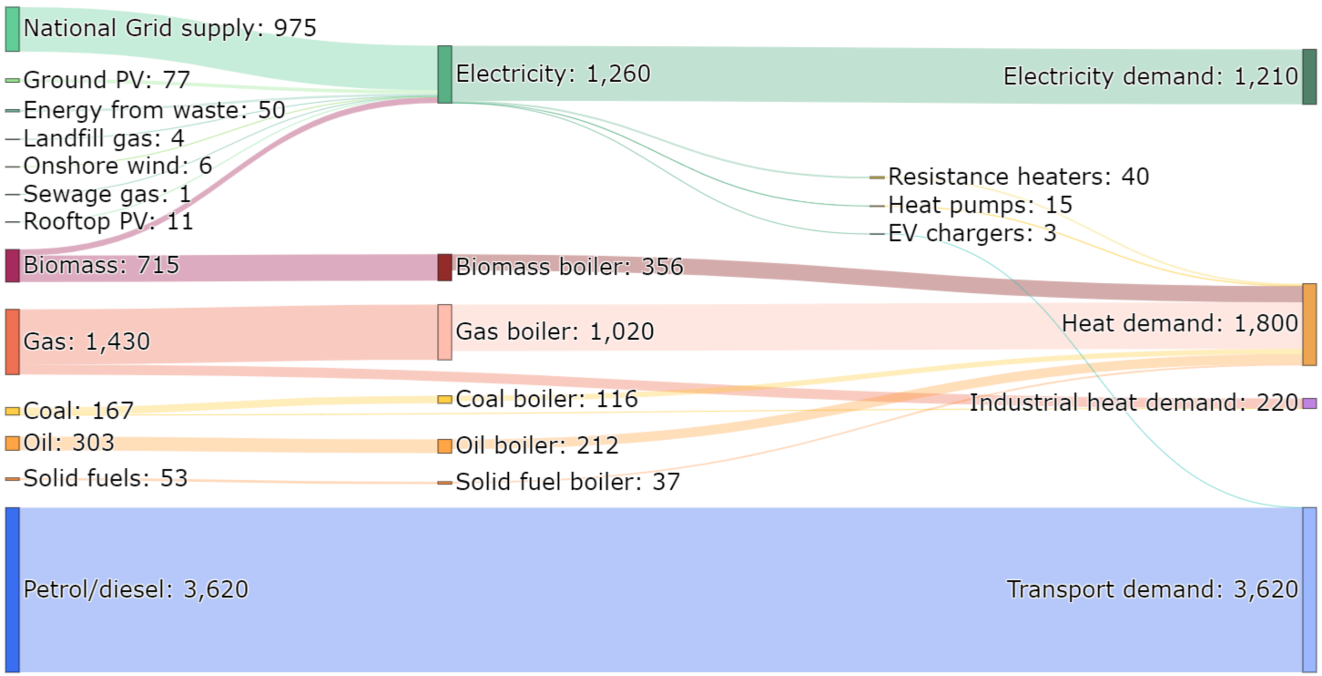


Figure 3.2.7: baseline Sankey diagram, representing energy flows in Flintshire in GWh/year (2023)

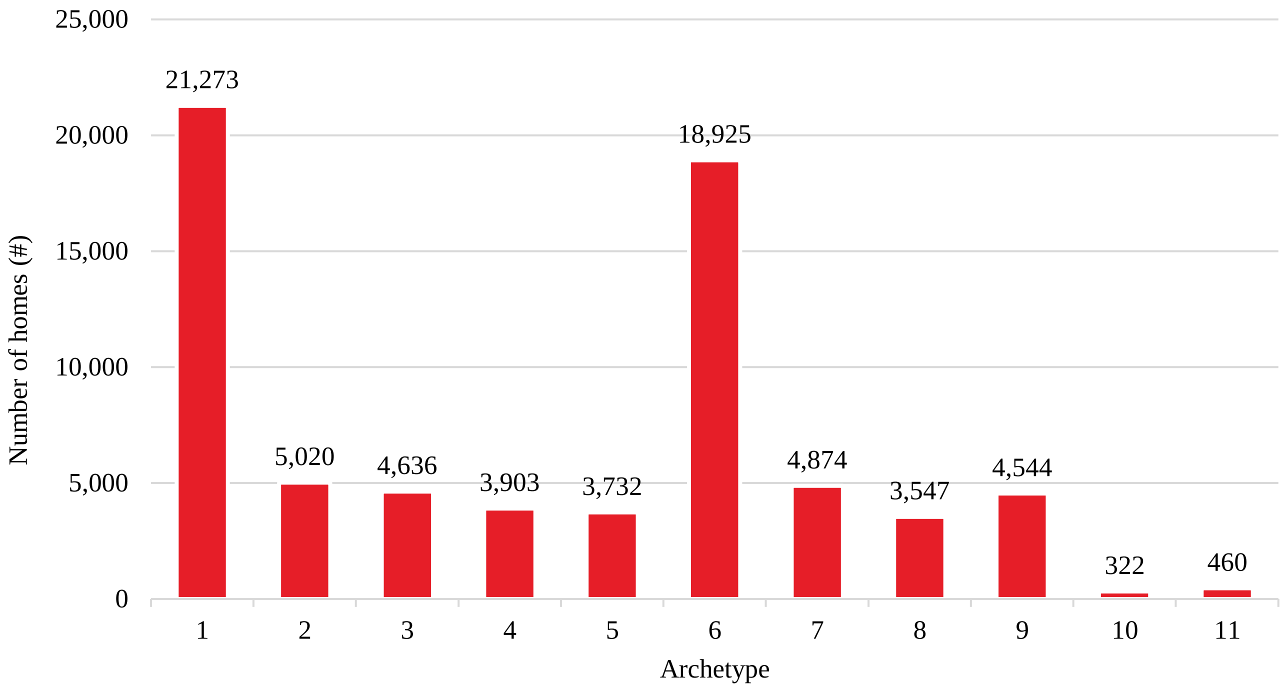
Analysis – buildings energy demand

Heat in buildings constituted 29% of total energy demand in 2023 and domestic heating was responsible for 49% of total heat demand from buildings.

In total, there were 71,236 domestic properties. 81% of homes were semi-detached or detached. Unoccupied homes in Flintshire accounted for 5% of the total stock, this is below the Welsh average of 7%[T11].

82% of homes were connected to the gas grid. This figure was equal to the regional average for Wales[T29], of 82%. Homes that are not connected to the gas network mostly use oil, and to a lesser extent LPG, electricity or a combination for heating.

The energy efficiency of Flintshire's housing stock varies considerably. On average, properties here exhibit below average levels of insulation, influencing their overall energy performance. These distinctions are shown in the EPC ratings, with 42% of properties achieving A-C ratings, above the Welsh average of 40%.



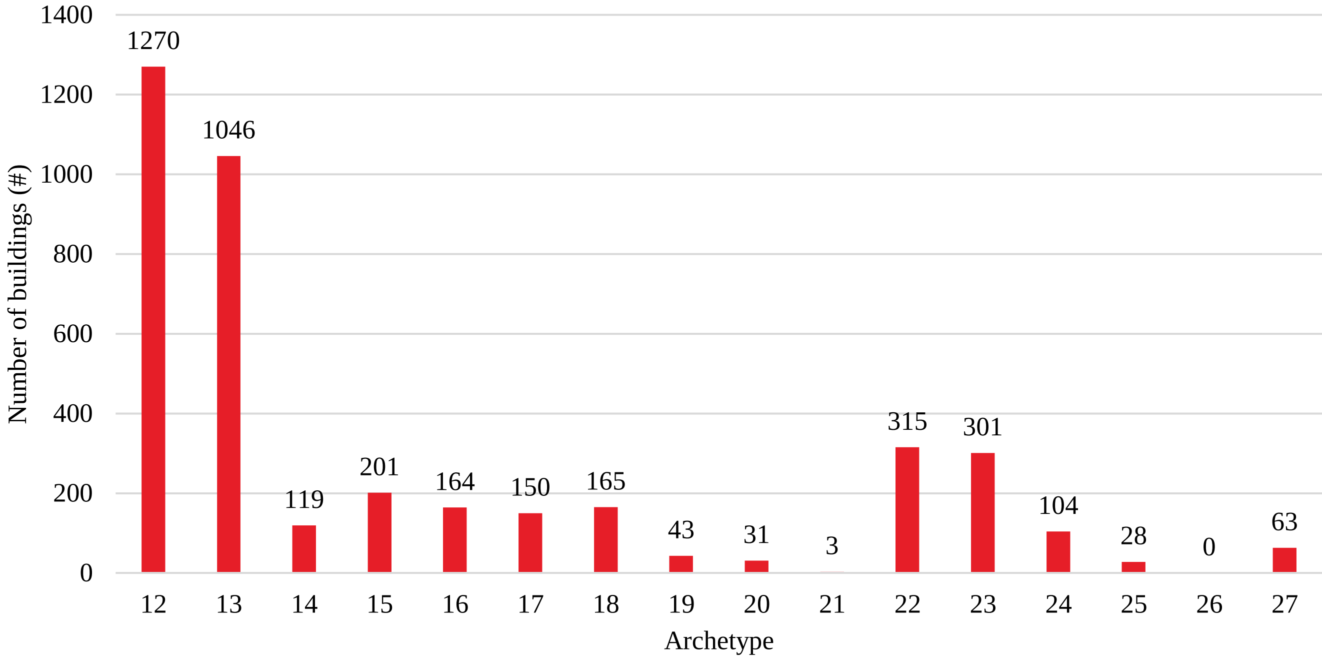
No.	Description	No.	Description
1	Detached - after 1930 - medium/high efficiency	7	Semi-detached - before 1930 - low efficiency
2	Detached - low efficiency	8	Semi-detached - before 1930 - high efficiency
3	Terrace - medium efficiency	9	Flat - high efficiency
4	Terrace - before 1930 - low efficiency	10	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

Analysis – buildings energy demand

51% of heat demand in buildings was for non-domestic properties in 2023.

There were a total of 4,003 non-domestic properties with offices being the predominant type, accounting for 32% of non-domestic buildings. 26% of non-domestic properties are used for retail.



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

Figure 3.2.9: Distribution of non-domestic properties by archetype

Analysis – monthly buildings energy demand profile

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

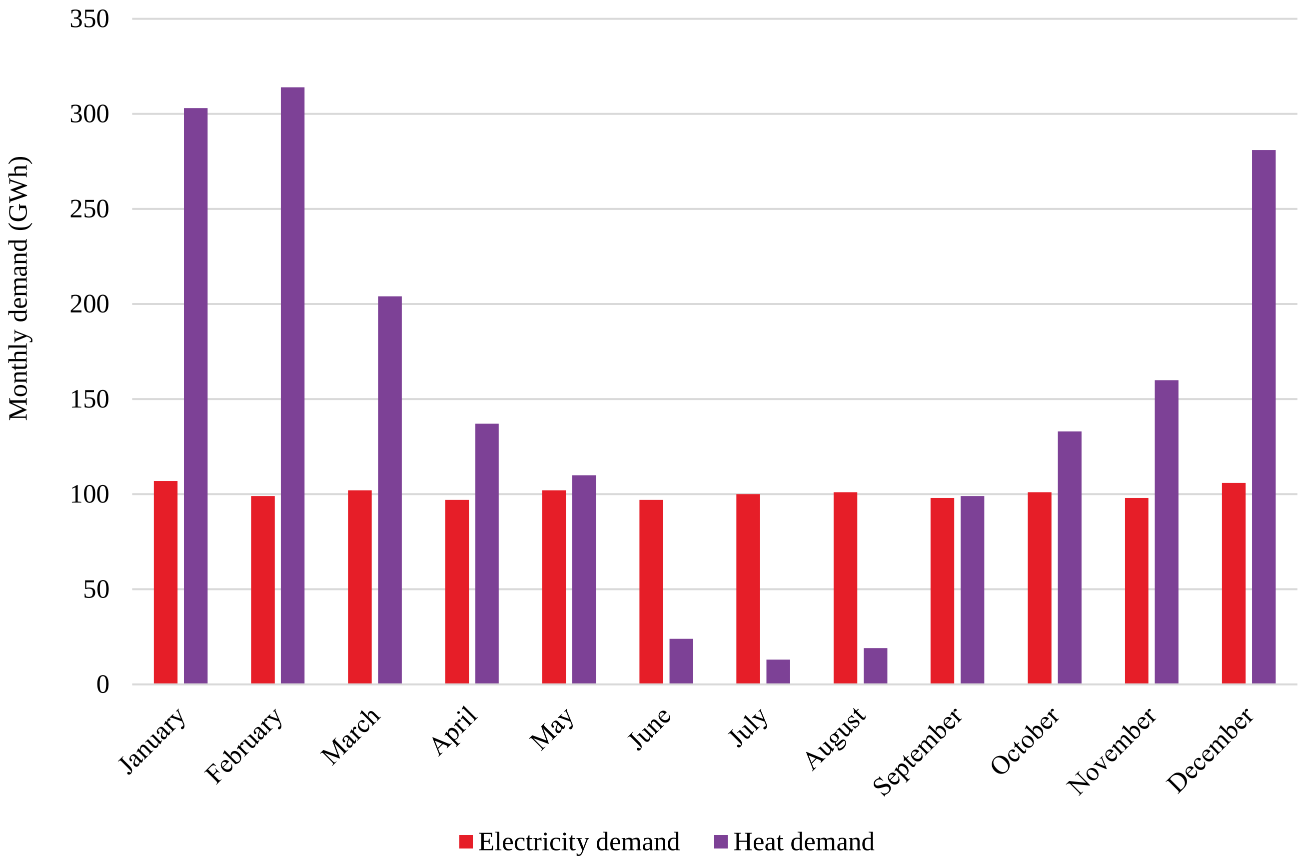
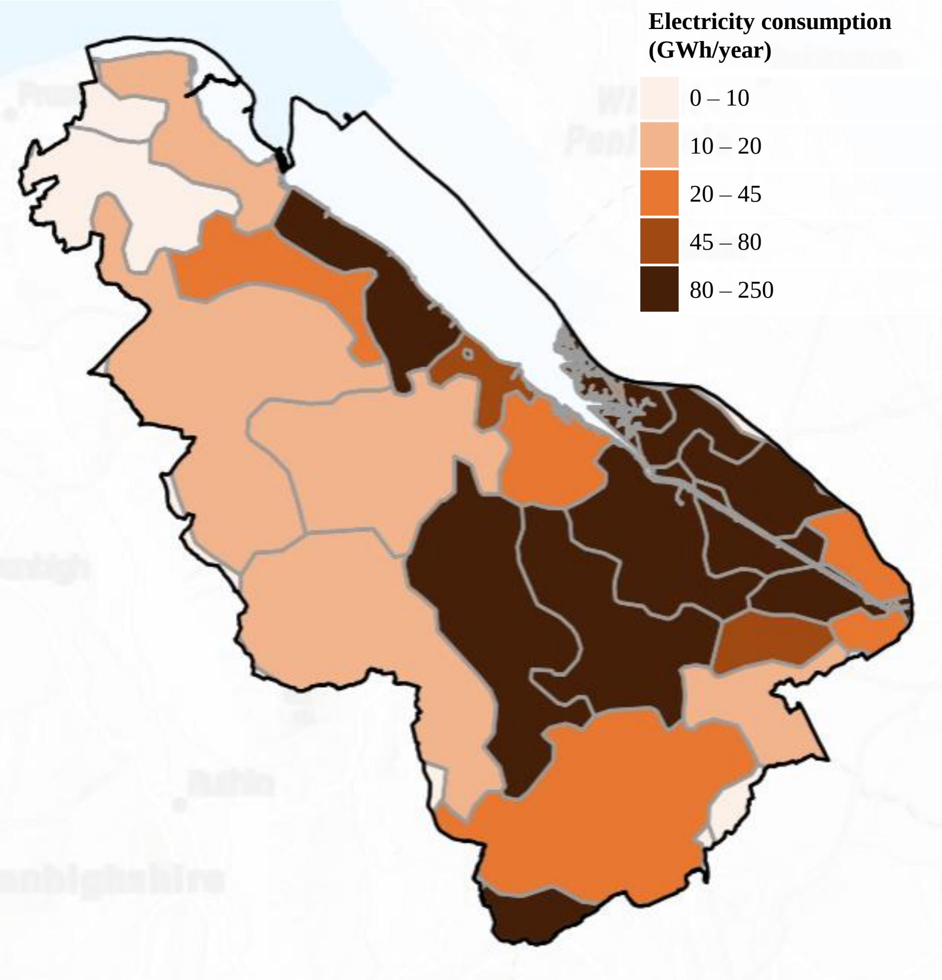


Figure 3.2.10: Monthly buildings energy profile for Flintshire (2023)

Analysis – electricity demand from buildings (GWh/year)



Electricity consumption (total domestic and non-domestic) varied across the area in 2023, except for areas where industrial clusters or larger towns are located (e.g. Deeside, Buckley and Mold) areas with lower population density like Caerwys had lower electricity demands.

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

Sponsors: Delivery partners:

Analysis – heat demand in buildings and industrial energy demand

Heat demand is generally higher in more densely populated locations like Deeside, Mold, and Buckley. These locations are also where most homes and businesses are located, and therefore the higher gas and heat demand.

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

Emissions from industrial activities significantly contribute to Flintshire's carbon footprint, totalling 40 ktCO_2e in 2023[T49]. Detailed analysis and data on emissions from industries are integral to understanding the environmental impact and sustainability challenges posed by this sector.

Flintshire hosts a diverse array of industries that play a fundamental role in its economic vitality. These industries encompass manufacturing, technology, agriculture, and services, each contributing uniquely to the region's economic fabric. The nature of industrial sites in Flintshire varies, with a mix of fragmented sites and industrial clusters.

Across Flintshire, several key industrial sites serve as economic anchors and employment hubs. These sites are strategically located and encompass various sectors, including paper, printing and publishing; chemicals; food and drink; and vehicles. Highlighting these industrial centres provides insight into their significance in driving local economic growth and job opportunities. The largest sectors and companies are highlighted below and in Figure 3.2.18.

Mechanical Engineering

- J Reid Trading Ltd (natural gas)

Vehicles

- Toyota motor manufacturing UK Ltd (Coal)

Paper, Printing and Publishing Industries

- Kimberly-Clark Ltd (natural gas)
- UPM-Kymmene (UK) Ltd (natural gas)
- Essity UK Ltd (natural gas)

Other Mineral Industries

- Knauf Insulation Ltd (natural gas)
- Tarmac Trading Ltd (natural gas)

Chemical Industry

- Synthite Ltd (natural gas)
- TS Resins Ltd (natural gas)

Food, Drink and Tobacco Industry

- Farmers Boy Ltd (natural gas)

Minor Power Producers.

- Culvery Power Ltd (natural gas)

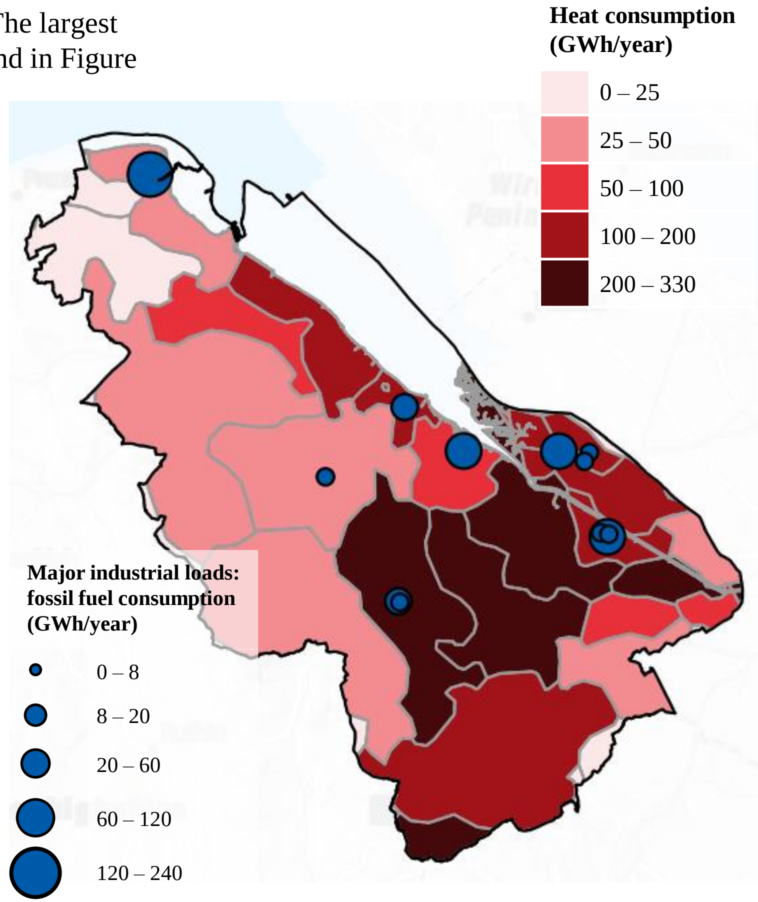


Figure 3.2.12: Major industrial loads (2019) and heat demand (2023) by substation zone across Flintshire. The data is based on meter level gas consumption (MWh/year)

Sponsors: Delivery partners:

Analysis – buildings energy efficiency

The energy efficiency of Flintshire's housing stock varies considerably. On average, properties have below average levels of insulation (e.g. 26% of homes have <100mm loft insulation and 12% had unfilled cavity walls), influencing their overall energy performance. These distinctions are shown in the EPC ratings, with only 35% of properties achieving A-C ratings, relatively high compared to other local authorities in North Wales. There are a higher proportion of homes on the fringes of Flint, Buckley and with EPC A-C ratings. And there are a lower proportion of homes with EPC A-C ratings in and around the Clwydian Range and Dee Valley National Landscape.

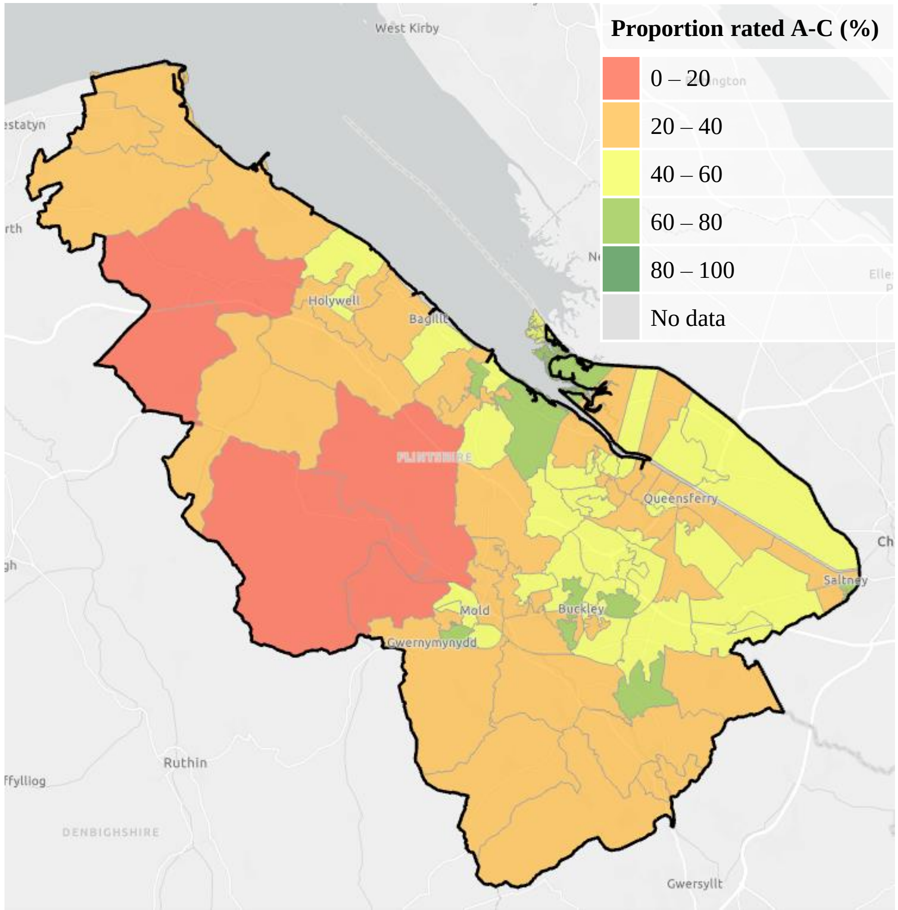


Figure 3.2.13: Proportion of domestic homes by EPC rating in Flintshire by LSOA. (2023)

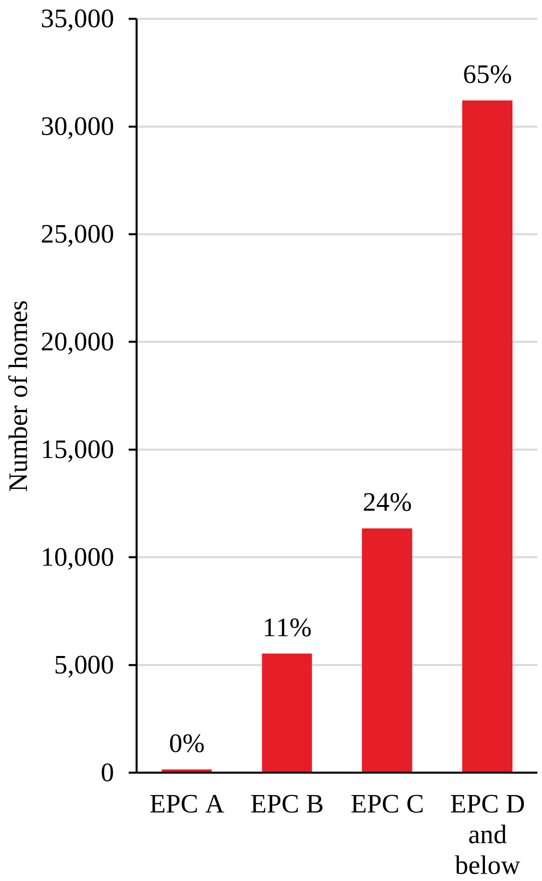


Figure 3.2.14: Energy efficiency of domestic properties across Denbighshire, rated EPC A-C and EPC D and below (2023)

Analysis – transport energy demand

In 2023, transport Flintshire contributed 710 ktCO_2e to the total emissions, accounting for 60% of the overall emissions. The primary sources of these emissions stem from private car usage and HGVs, highlighting the need for sustainable transportation solutions.

Flintshire's proximity to major transportation corridors makes it an attractive hub for businesses in these sectors. This has a significant impact on local employment, fostering economic growth and job opportunities.

HGVs are the main source of transport emissions accounting for over 60% despite only accounting for 29% of mileage due to their higher emissions intensity (gCO2e/km).

In Flintshire, 0.23% of vehicles are electric or hybrid[T40], slightly behind the Wales-wide average of 0.26%[T40]. Flintshire displays a distinctive pattern of car ownership when compared to the national average. 83% of households in the area own cars, with an average of 1.3 cars per household, which is above the national average[T41].

Flintshire County Council has invested in enhancing public transport infrastructure, including the trial of electric buses; improvements to the North Wales metro; development of cycleways; and park and ride schemes aiming to offer residents efficient and sustainable commuting alternatives, reducing reliance on private vehicles.

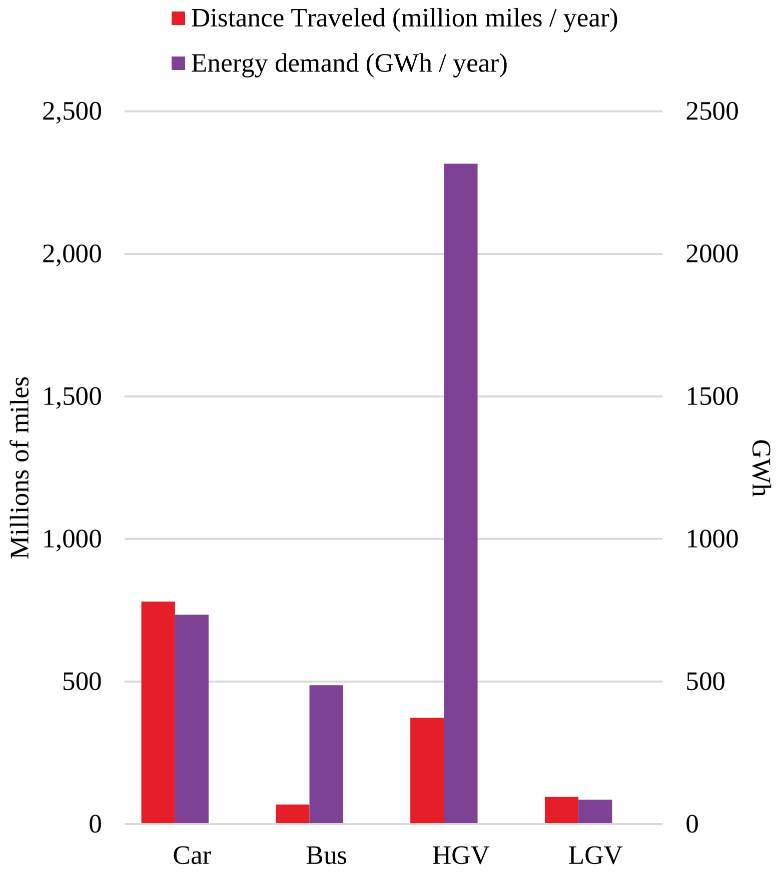


Figure 3.2.15: Total mileage (million miles / year) by vehicle type (2019)

Analysis – transport energy demand

Flintshire's transport landscape varies significantly, influenced by its combination of larger towns along the coast and main roads, and rural areas. More rural regions in the west of the local authority see a reliance on private vehicles due to limited public transport options, longer travel distances to essential services, and the practical necessity of cars. In contrast, more densely populated areas such as Mold, Flint or Deeside feature more robust public transport networks, with residents having the option of buses, cycle networks and trains for daily commuting.

According to the National Chargepoint Registry, there were 53 EV charge points in Flintshire in May 2023[T15]. These points are distributed in areas with high EV concentration and along major transportation routes to facilitate convenient charging for residents and visitors.

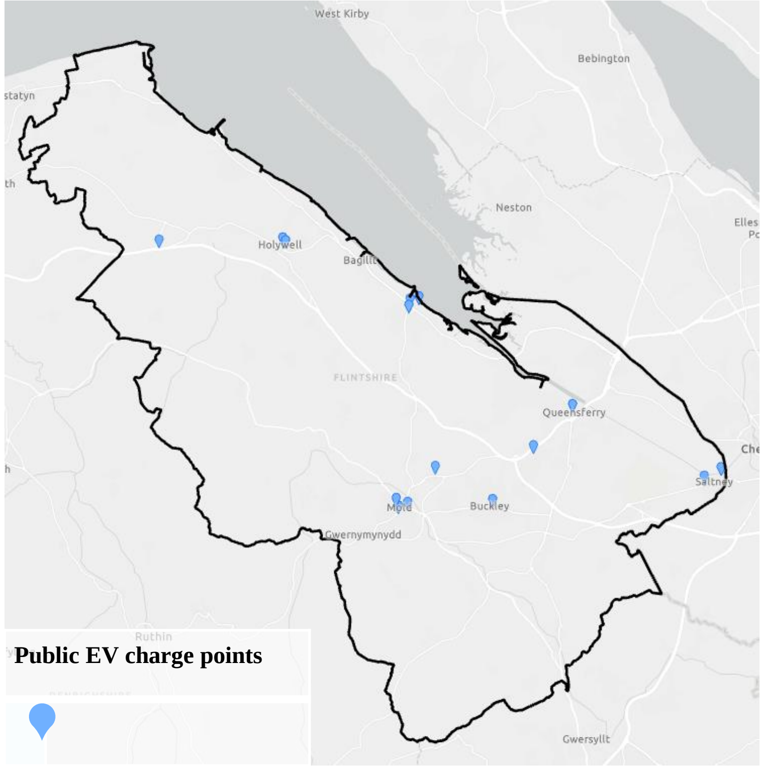


Figure 3.2.16: Public EV chargepoints registered on the National Chargepoint Registry[T16] across Flintshire (date extracted: May 2023)

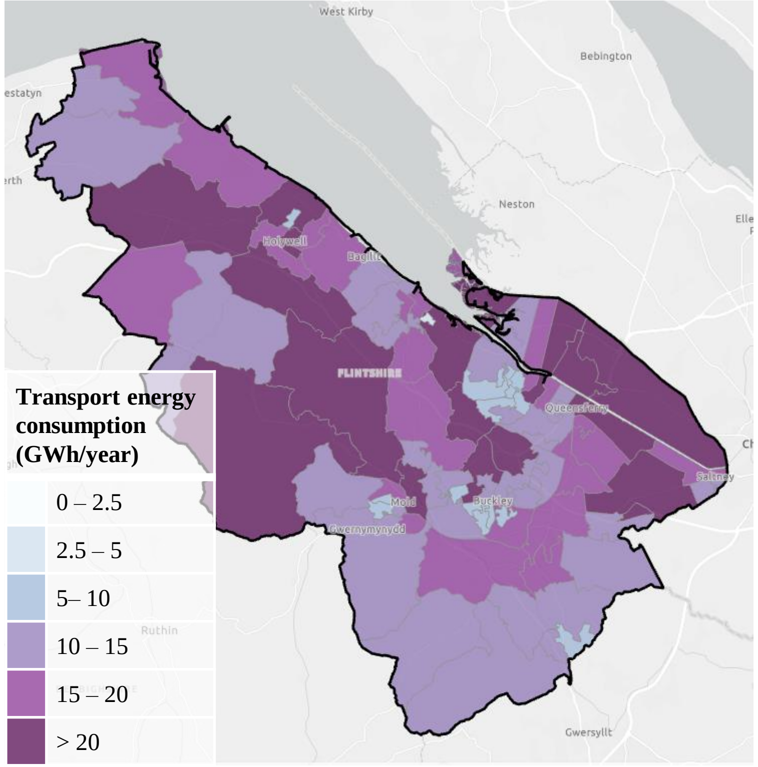


Figure 3.2.17: transport energy consumption (combined total across cars, light goods vehicles (LGV) and heavy goods vehicles (HGV) by LSOA (2019)

3. The current energy system

Analysis – electricity generation in 2023

Currently, Flintshire has the potential to generate a total of 171MW electricity annually. This electricity generation capacity 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.

Onshore wind power: is a prominent renewable energy source harnessed within Flintshire. The region boasts a total 1.8MW of electricity generated annually from wind turbines. Wind energy continues to grow as a reliable and sustainable power source, contributing significantly to reducing carbon emissions. Given local flight zones and areas of outstanding natural beauty, growth of onshore wind within Flintshire is limited.

Solar power: also plays a vital role in the local energy mix. Flintshire harnesses 91.6MW electricity annually from solar panels on rooftops and dedicated solar farms. Solar PV is employed widely in industrial areas for direct use, and this is expected to expand significantly.

In addition to wind and solar, Flintshire utilises various other renewable generation sources, including biomass, energy from waste and biogas facilities. These sources further diversify the energy mix, ensuring reliability and sustainability. To manage increases in renewables and alleviate issues associated with intermittency, several grid-scale battery projects are planned within industrial zones.

In addition to these renewable sources of generation Flintshire generates 35.5MW electricity from non-renewable sources, including gas, and oil. It is anticipated that fossil fuel energy generation will continue to grow as it is a key, cheap resource within industrial zones at the moment.

While Flintshire is a significant contributor to its electricity needs through local generation, it also imports a portion of its electricity to meet the overall demand, totalling 975GWh in 2023. This import ensures a reliable and continuous supply of power.

See overleaf for a map of existing electricity generation in Flintshire.

Analysis – electricity generation (ground-mounted)

Rooftop solar PV

As of 2023, there was a total of 11.6MW of rooftop solar PV capacity across Flintshire, roughly equivalent 4% of buildings (if we estimate that there are 75,200 buildings and rooftop solar PV systems are on average, 4kWp).

This map shows where these systems are located. Across Flintshire, the density of rooftop solar PV per substation is roughly consistent, with an average of 2.5-4.0MW connected at each substation. There is a slightly lower capacity in the areas around Flint, Greenfield and Broughton.

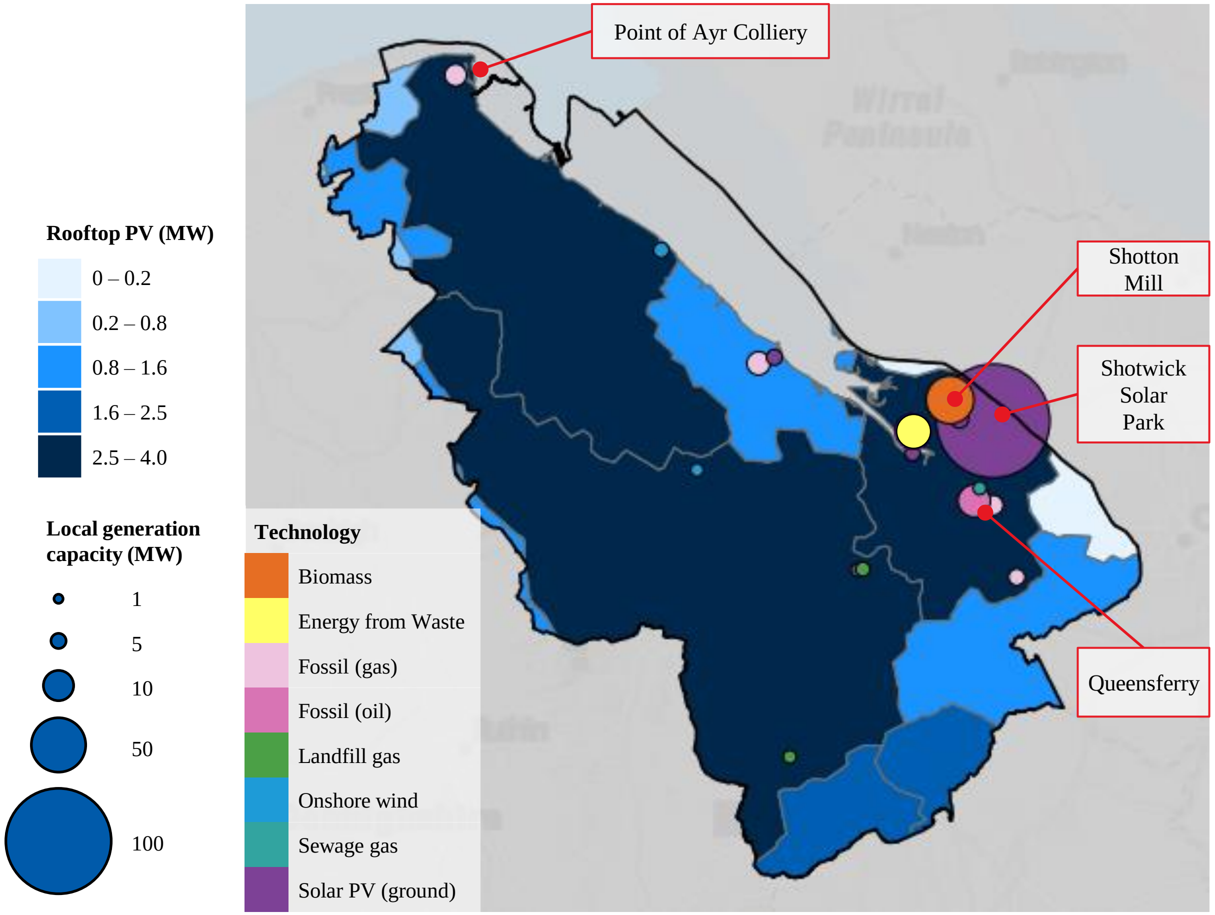


Figure 3.2.16 Local energy generators. Data is based on Energy Generation Wales (2019) and Renewable Energy Generation Database (2019)

Sponsors:
Delivery partners:

Analysis – electricity distribution network

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

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

To illustrate, the maps in Figures 3.1.19 and 3.1.20 show demand and generation headroom at primary substations in Flintshire. Note that substation and LSAO boundaries do not typically align, and the headroom has been distributed proportionally among LSOAs by area

Demand headroom varies across the region significantly with greater room towards the east of the local authority just outside the heavily industrialised areas.

Generation headroom is minimal across most of the county, with some slightly higher capacity in the northwest.

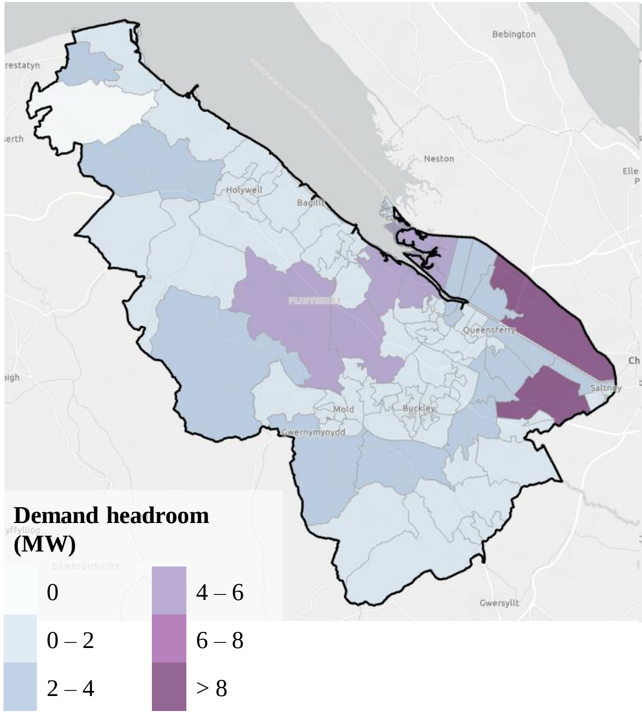


Figure 3.2.17: Electricity demand headroom

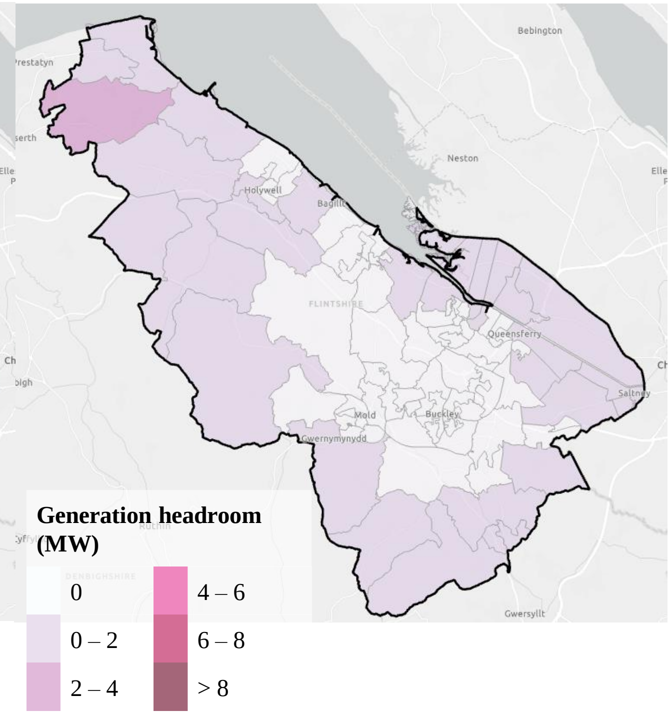


Figure 3.2.18: Electricity generation headroom

Sponsors: Delivery partners:

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

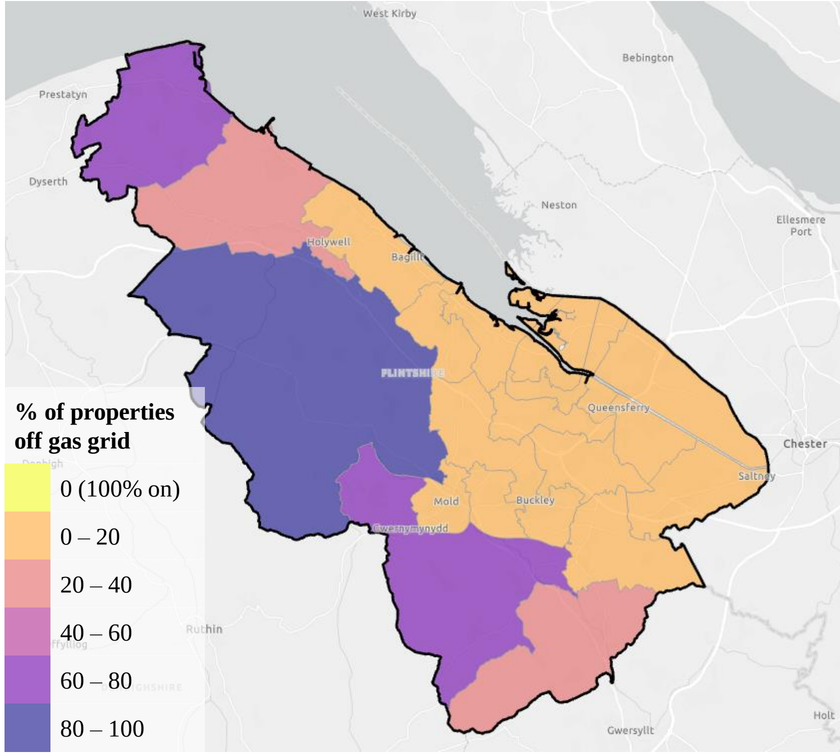


Figure 3.2.19: % of properties that are not connected to the gas distribution network across Flintshire (2023)

18% of properties are not connected to the gas network. This is most prominent in the west and northwest of Flintshire.

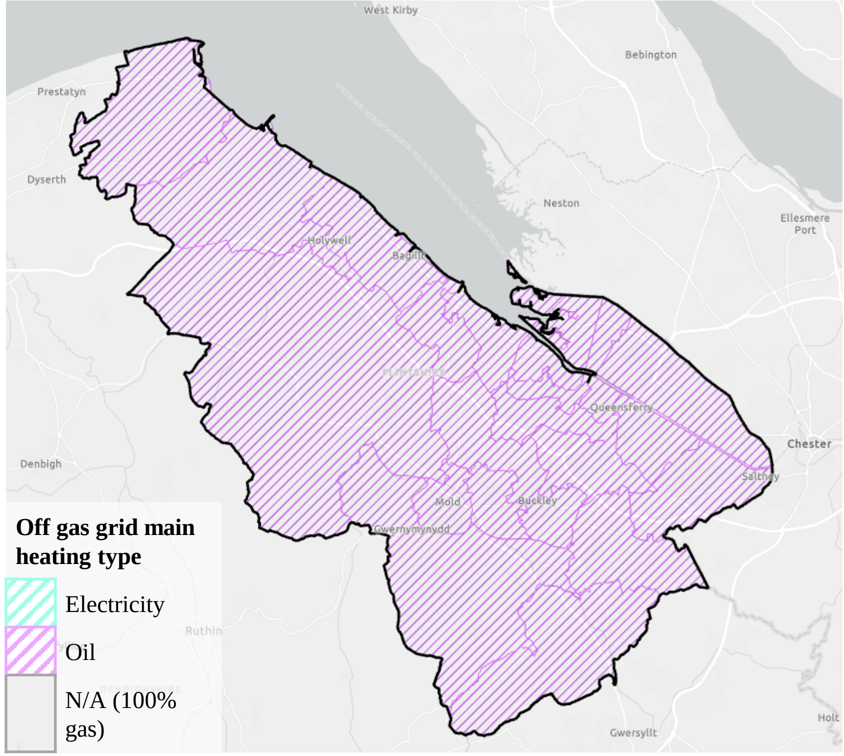


Figure 3.2.20: Main heating type of domestic buildings that are not connected to the gas distribution network across Flintshire (2023)

11% of properties use oil or LPG for heating. There are a small proportion of homes that use direct electric heating (2%). The remainder use biomass, other solid fuels (e.g. coal) or a combination of different fuels.

Sponsors:

Delivery partners:

Technical report

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

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 B7. The outputs helped define the scale of change required to achieve net zero energy system, and to set a level of ambition from which the action plan could be based.

Chapter 4: Future energy system

Scenario analysis

- We defined modelling parameters such as the maximum amount of solar and wind which can be installed in Flintshire.
- 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 low-regret energy system components to consider as high priorities for near-term action.

Deployment modelling

- We modelled the rate of deployment for low-regret 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 GHG emissions, air quality and employment in the local area.

Chapter 5: Action planning

4. The future energy system
Scenario analysis

Methodology - overview

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

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

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

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

What future energy scenarios were chosen?

Using the outcomes of Workshop 2 (Strategic options and priorities workshop), future energy scenarios and their associated assumptions were agreed with the primary stakeholders, ANW representatives and the LAEP technical advisor. To allow for the comparison of results at the national and regional levels, two of the five scenarios were chosen to be tested across all Welsh Local Authorities, and two scenarios were chosen to be tested in all Local Authorities within the region. See Figure 4.0.0 for a description of each scenario and its scope. The final scenario was agreed by Flintshire County Council and was informed by Flintshire County Council's existing principles, strategic objectives and energy priorities.

4. The future energy system
Scenario analysis

Methodology - overview

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 net zero	• Uses the lowest cost and carbon combination of technologies to meet Wales' 2050 net zero target. • Assumes a moderate level of energy demand reduction across the system. • Model is allowed to import and export to the electricity grid, this assumes that the electricity grid is decarbonised and reinforced to allow for the demands, likely to be a combination of offshore wind, hydrogen CCGT, grid-level battery storage, nuclear (these are considered as national assets and outside the scope of the LAEP).
Low demand	• Considers the lowest future energy demand across different sectors. • Explores the impact of energy-reducing initiatives (home fabric improvements) and uptake of active travel and public transport use. • Model finds the lowest cost and carbon combination of technologies to meet predicted future energy demand. • Import and export of electricity as National Net Zero
High demand	• Considers the highest future energy demand across sectors. • Model finds the lowest cost and carbon combination of technologies to meet predicted future energy demand. • Import and export of electricity as National Net Zero
High Hydrogen	• Considers the highest plausible future energy demand across sectors. • Uses a cost- and carbon-optimal range of technologies to meet predicted future energy demand. • Explores hydrogen as a possibility within high temperature industrial processes. • Considers hydrogen for heavy goods vehicles. • Explores the possibility and impact of hydrogen generation and imports.

Figure 4.1.1: Summary of future energy scenarios

4. The future energy system
Scenario analysis

Methodology – modelling parameters

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

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

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

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

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

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

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

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

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

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

4. The future energy system
Scenario analysis

Methodology – optimisation

Once the modelling parameters had been set, we then used the Calliope model to optimise the future supply profiles using the "objective functions" of cost and carbon emissions. This instructs the Calliope model to search for the future supply profile that minimises cost and carbon emissions across the hypothetical year of supply and consumption in 2050 for each scenario. The results suggest the most cost- and carbon-optimised generation profile using a mix of low-carbon technologies that could be used to meet the future energy demand profiles estimated in each future energy scenario.

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

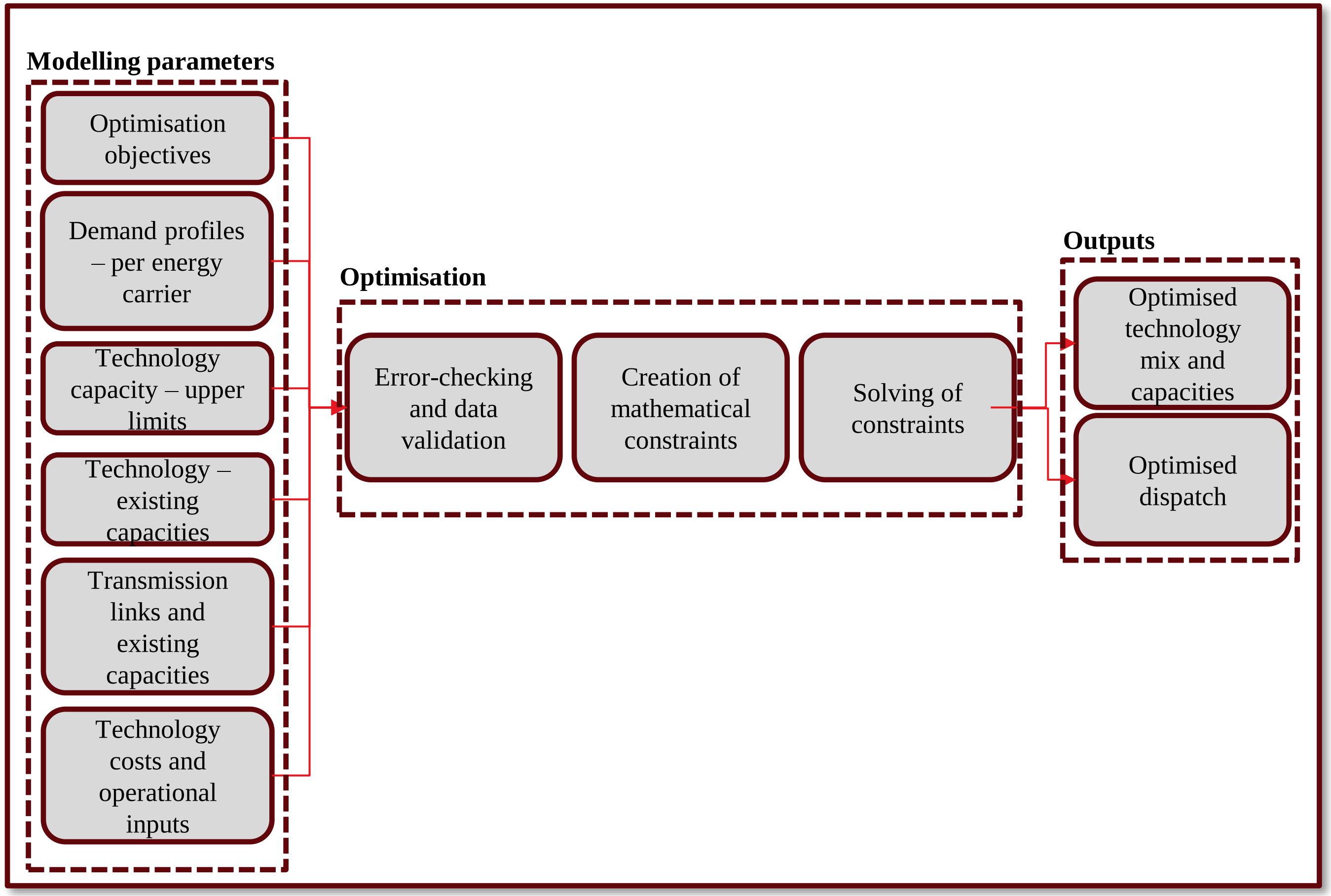


Figure 4.1.2: Optimisation modelling input data and desired outputs

4. The future energy system
Scenario analysis

Methodology - technologies considered

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

Figure 4.0.2 overleaf shows the technologies and carriers (energy vectors) that were modelled for Flintshire's LAEP.

For each technology we collected key information defining costs, GHG emissions, deployment and relationships with other technologies. The key parameters collected are summarised in Table 4.0.0 (see Appendix B7 for more details). Alongside the baseline information collated on demands, existing energy assets and potential renewable locations and capacities, this information was loaded into a database. Automated python scripting was used to handle this data and transform it into formatted model inputs in preparation for running the model. This approach ensuring efficiency and consistency, and minimised opportunities for manual errors.

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

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

Table 4.1.1: Technology parameters

4. The future energy system
Scenario analysis

Methodology - technologies considered

Energy Supply

Energy Imports:
- Electricity import
- Hydrogen import
- Heat networks
- Biomass import

Local electricity generation:
- Ground PV
- Rooftop PV
- Onshore wind
- Canopy PV
- Anaerobic digestion
- Sewage gas
- Hydroelectricity
- Energy from waste
- Landfill gas

Conversion

Heat generation:
- Heat pump
- Biomass boiler (elec)
- Resistance heating

Electricity generation:
- Hydrogen CCGT
- Biomass boiler (heat)

Hydrogen generation:
- Electrolyser
- Methane reformation

Transport:
- Electric car charging
- Hydrogen refuelling

Transmission

Energy transmission:
- Electricity network
- Hydrogen network
- Heat network

Storage

Energy storage:
- Battery storage
- Hydrogen storage
- Heat storage

Demand

Energy demands:
- Electricity demand
- Hydrogen demand
- Heat demand
- Transport demand

Key:

Technology

^ Input Output ^

- Electricity
- Hydrogen
- Heat
- Biomass
- Transport

Figure 4.1.3: Technologies included in optimisation modelling

4. The future energy system
Scenario analysis

Methodology - future energy demand for buildings

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

To produce the scenarios, we chose packages of retrofit measures for each of the 27 archetypes in each scenario. The retrofits are summarised in Table 4.0.1 for domestic buildings and in Table 4.0.2 (overleaf) for non-domestic buildings (see Appendix B3 for more detail). Electricity and heat profiles, generated at the archetype level, were reduced in line with RdSAP-modelled changes to building thermal properties and aggregated to modelling zones.

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

		High demand	Low demand
	Other scenarios this applies to	**National net zero, High hydrogen, High demand**	**Low demand**
DOMESTIC	**Electricity demand**	No change from baseline	5% reduction from smart appliances
DOMESTIC	**Heat demand**	Cost-optimal fabric measures applied to upgrade all buildings below EPC C with insulation measures associated with an EPC C-rated property. 18,300 domestic retrofits will be required.	All buildings below EPC A upgraded with insulation measures associated with an EPC A-rated property. 61,100 domestic retrofits will be required.
DOMESTIC	**New development build rate**	LDP housing targets extrapolated to 2050. 19% increase in number of homes from 2023 to 2050	Average historic build rate applied to 2050. 10% increase in number of homes from 2023 to 2050
DOMESTIC	**New development energy efficiency**	2025 building regulation standard	Net Zero buildings with solar PV and battery storage
DOMESTIC	**Weather profile**	4 days with temperature profiles equivalent to the 'Beast from the East' (extreme weather event in 2018 with -7°C lowest temp) (Appendix B7)	2 days with Beast from the East (-7°C lowest temp) temperature profiles
DOMESTIC	**Interventions for retrofit considered**	See Appendix B7 for details on measures Options dependent on archetype	**High demand interventions**, plus additional measures. See Appendix B7 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 B7 describes the types of retrofits and sources of retrofit costs.

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

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

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

Limitations

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

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

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

		High Demand	Low Demand
	Other scenarios this applies to	**National Net Zero, High hydrogen, High demand**	**Low demand**
NON-DOMESTIC	**Electricity demand**	No change from baseline	5% reduction from smart appliances
	Heat demand	Cost-optimal fabric measures applied to upgrade all buildings with a rating of EPC C and below with insulation measures associated with EPC C-rated properties.	All buildings below EPC A upgraded with insulation measures associated with EC A-rated properties.
	Employment site allocation	LDP employment land allocations/jobs projection (proxy) extrapolated to 2050. 51% increase in commercial floorspace from 2023 to 2050.	LDP employment land allocations/jobs projection (proxy) extrapolated to 2050. -20% decrease in commercial floorspace from 2023 to 2050.
	Weather profile	4 days with temperature profiles equivalent to the 'Beast from the East' (extreme weather event in 2018 with -7°C lowest temp)	2 days with Beast from the East (-7°C lowest temp) temperature profiles
	Interventions for retrofit considered	**Same as domestic**, plus MEV/MVHR ventilation	**Same as domestic**, plus MEV/MVHR ventilation

Table 4.1.3: Assumptions for non-domestic buildings in each future energy scenario

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)[T12] to determine transport demand across Flintshire. 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 4.0.3 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 to account for modal shifts. The selection of growth factors varied based on the specific scenario considered. Table 4.0.4 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.

	High demand, Low demand		High hydrogen	
Vehicle type	**Electric (mileage)**	**Hydrogen (mileage)**	**Electric (mileage)**	**Hydrogen (mileage)**
Cars	100%	0%	94%	6%
Buses	85%	15%	70%	30%
Vans	100%	0%	83%	17%
Heavy Goods Vehicles	86%	14%	45%	55%

Table 4.1.4: Assumptions for vehicle fuel type in each future energy scenario

4. The future energy system
Scenario analysis

Methodology – future energy demand for transport (continued)

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

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

4. The future energy system
Scenario analysis

Methodology– future energy demand for industry

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

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

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

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

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

Limitations

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

Methodology – maximum potential capacities for renewable generation

The maximum theoretical amount of renewable resource (onshore wind, ground-mounted PV, and rooftop PV) was included in the energy model as the sum of the baseline capacity (discussed previously in Chapter 3) and the 2050 renewable resource (discussed below) for each technology.

2050 renewable resource – onshore wind and ground-mounted PV

The maximum available resource (upper limit of renewable generation capacity) was calculated using local authority-specific renewable and low carbon energy assessments (RLCEA) and/or local development plans (LDP). These areas are shown in Figure 4.0.3. A full breakdown of sources and associated shapefiles used during the mapping exercise is presented in Appendix B5.

Overlapping areas were calculated to ensure capacities were not double-counted.

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

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

2050 renewable resource – rooftop PV

Maximum available new resource for rooftop PV capacity was estimated using roof-area at the LA- and substation-level. Further information can be found in Appendix B5.

Pipeline projects

Pipeline projects were compiled using the REPD[T23] and ECR[TN24] datasets. Where relevant, Local Authority projects which have had planning permission granted (not necessarily an accepted grid connection) were included in the dataset.

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

Seasonality and daily fluctuations

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

4. The future energy system
Scenario analysis

Methodology – maximum potential capacities for renewable generation

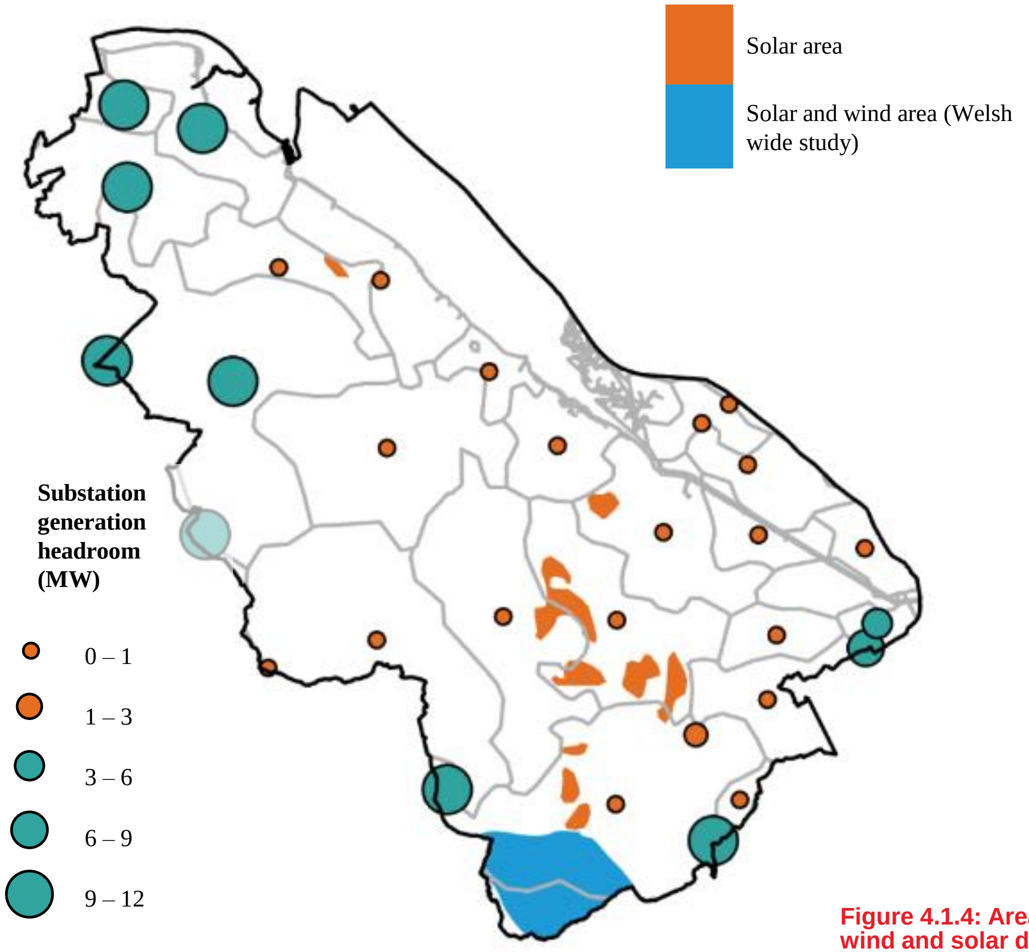


Figure 4.1.4: Areas suitable for wind and solar development

Figure 4.1.4 shows the location of different land packages that could be suitable for ground-mounted solar PV, onshore wind or both, and the generation capacity that is available in each substation zone. This overlay helps to highlight the locations where there is renewable potential and where there is available capacity, which would make conditions more favourable for development. This is discussed in more detail in Chapter 5: action planning, where we introduce the different “priority focus zones” across Flintshire that are ranked highly based on defined criteria for different low carbon technologies, including ground-mounted solar PV and onshore wind.

	Maximum theoretical capacity (MW)	Equivalent land area (km²)
Ground-mounted solar PV	565	10.6
Onshore wind	2	0.2

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 4.0.4 illustrates the flow of electricity between these substations in the model.

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

Primary substation

Each modelling zone was part of a primary substation service area. The capacity of the primary substation[x] 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.

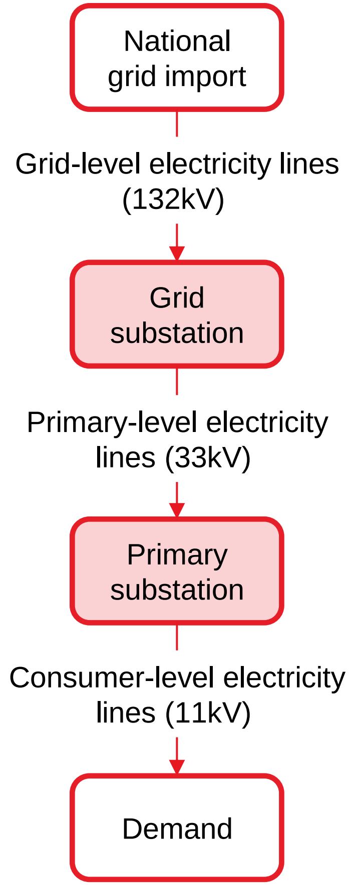


Figure 4.1.5: Modelled electricity flow for each zone

4. The future energy system
Scenario analysis

Methodology – gas infrastructure

We assumed that in all future energy scenarios for 2050, there is no longer a demand for gas, coal and other fossil fuels, as this demand has been replaced by renewable forms of energy. Gas blending was also excluded because we modelled the 2050 scenario, and we assumed the network will be fully hydrogen at this point.

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

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

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

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

Exclusions

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

	Low hydrogen	High hydrogen
Scenario application	National net zero, Low demand, High demand	High hydrogen
Industry	High-grade heat met by hydrogen (low-grade heat met by electricity)	High- and low-grade heat met by hydrogen
Transport	Proportion of vans and HGVs use hydrogen	Proportion of vans and HGVs use hydrogen
Domestic / commercial heat	Hydrogen not considered for domestic/commercial heat	Hydrogen not considered for domestic/commercial heat

Table 4..1.6: Summary of assumptions related to hydrogen demand applied to future energy scenarios

4. The future energy system
Scenario analysis

Methodology – heat networks

What are heat networks?

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

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

How were heat networks modelled?

To determine which buildings should be supplied by heat networks rather than decentralised heat pumps in a future, optimised energy system, Arup used its proprietary HeatNet tool to assess where networks could offer a lower levelised cost of heat (LCoH) than decentralised heat pumps. The tool builds a digital representation of the local road network and uses a specialised algorithm to evaluate the combination of pipework routes and connected heat loads that maximises the amount of connected demand while minimising pipework length and maintaining a LCoH lower than the value for decentralised ASHPs. The LCoH is evaluated through a built-in discounted cashflow model. 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 of heat pumps selected by the Calliope optimisation at each substation. This was carried through capacities and energy analysis but was not carried through to grid upgrade requirements. Thus, the grid upgrade requirements presented herein can be seen as a worst-case scenario, as heat networks (often able to use higher-temperature heat sources and consequently often more efficient than decentralised heat pumps) may lighten the electrical demand.

Sponsors: Delivery partners:

Methodology – heat networks

Mapping heat sources

To capture the full potential of heat networks, location-specific waste heat sources, their temperature and their supply potential were mapped across Flintshire for including in the model. Figure 4.0.5 shows the waste heat sources identified in Flintshire. This includes waste heat generated by national assets, since the waste heat is a locally available resource. In addition to these sources, hydrogen boilers were made available to the model at industrial sites expected to transition to hydrogen in the future, and unlimited 'location agnostic' heat pumps (i.e. plant that can be installed largely regardless of location – like ASHPs) with lower COPs were made available without requiring networks to route to specific locations.

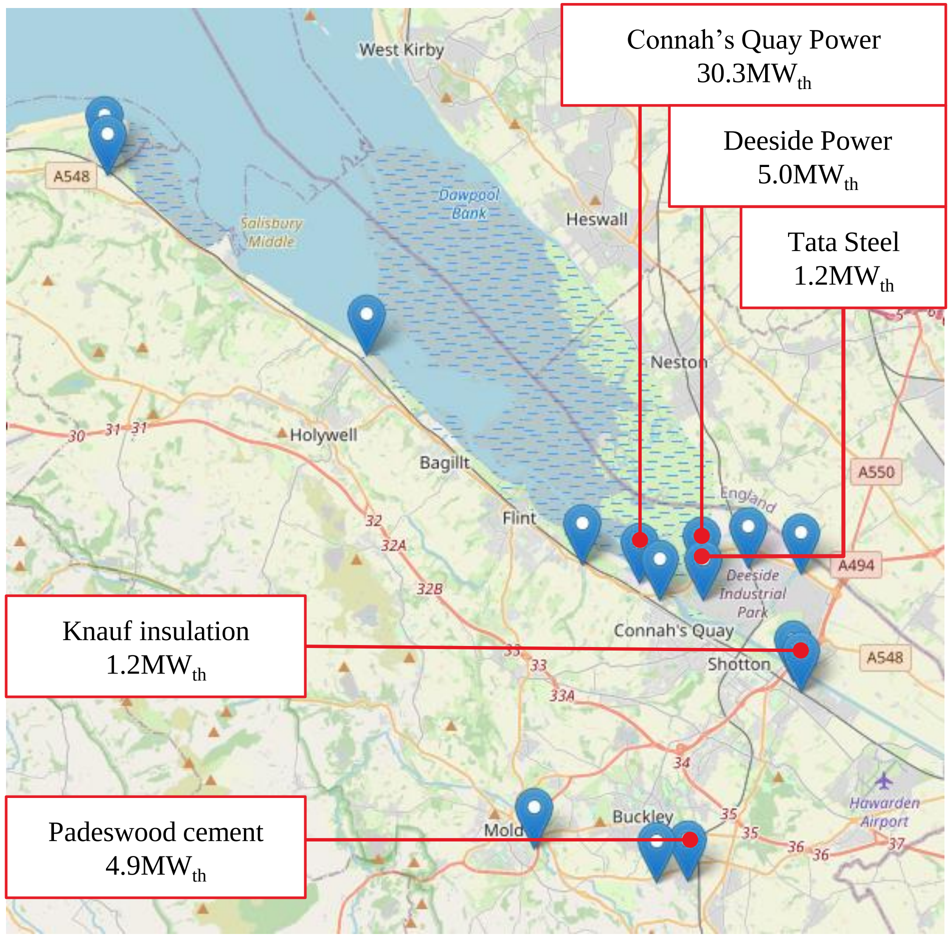


Figure 4.1.6: Heat sources identified, with top five sites named and capturable heat output noted in MW

Sponsors:

Delivery partners:

Technical report

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

Analysis

Sponsors:

Delivery partners:

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

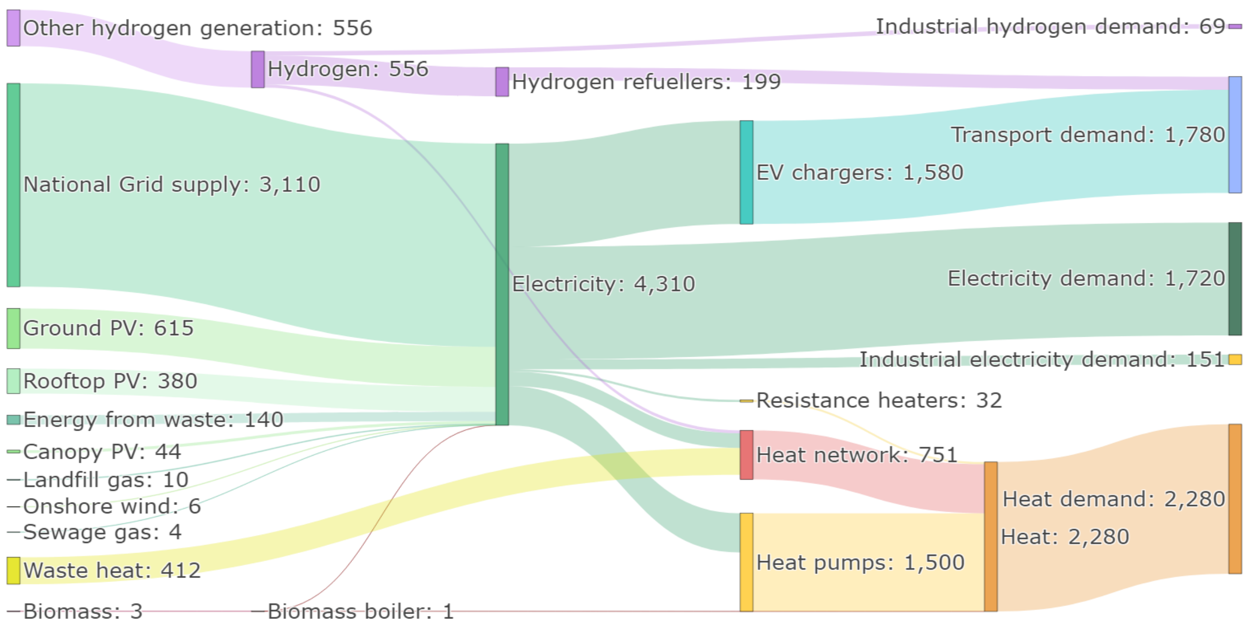
Figure 4.1.0 is an output from our modelling and shows a potential future energy system for Flintshire under the National Net Zero scenario. This energy system results from modelling to create the most cost and carbon optimal system. We ran the model for four scenarios to support our decision making. This optimisation modelling informs the deployment pathways as well as the action plan. The National Net Zero scenario (shown below) aligns with trends in both the High and Low Demand scenarios, as shown in the comparison presented in Figure 4.0.0. Note that this Sankey diagram does not present the final plan for Flintshire's future energy system.

Hydrogen generation /import expected to be required for some transport and industry demand

Electricity supply from the national grid could increase threefold as electricity becomes the primary vector for heat and transport demand

Local renewable generation could provide 28% of electricity, driven by growth of all forms of solar PV and energy from waste

Waste heat is a by-product of industrial processes



Some industrial heat processes are expected to be met through hydrogen use

The transport sector could be almost fully electrified, with some contribution from hydrogen refuellers

Heat demand could grow 25%+ and be met entirely through heat pumps and waste heat delivered through heat networks. ~50% less input energy supply is required (compared to 2019) to provide the increased amount of heat demand in 2050

Figure 4.2.1: Annotated Sankey diagram showing energy flows under the National Net Zero scenario (GWh in 2050)

Sponsors:

Delivery partners:

Low Demand scenario – annual energy flows (GWh, 2050)

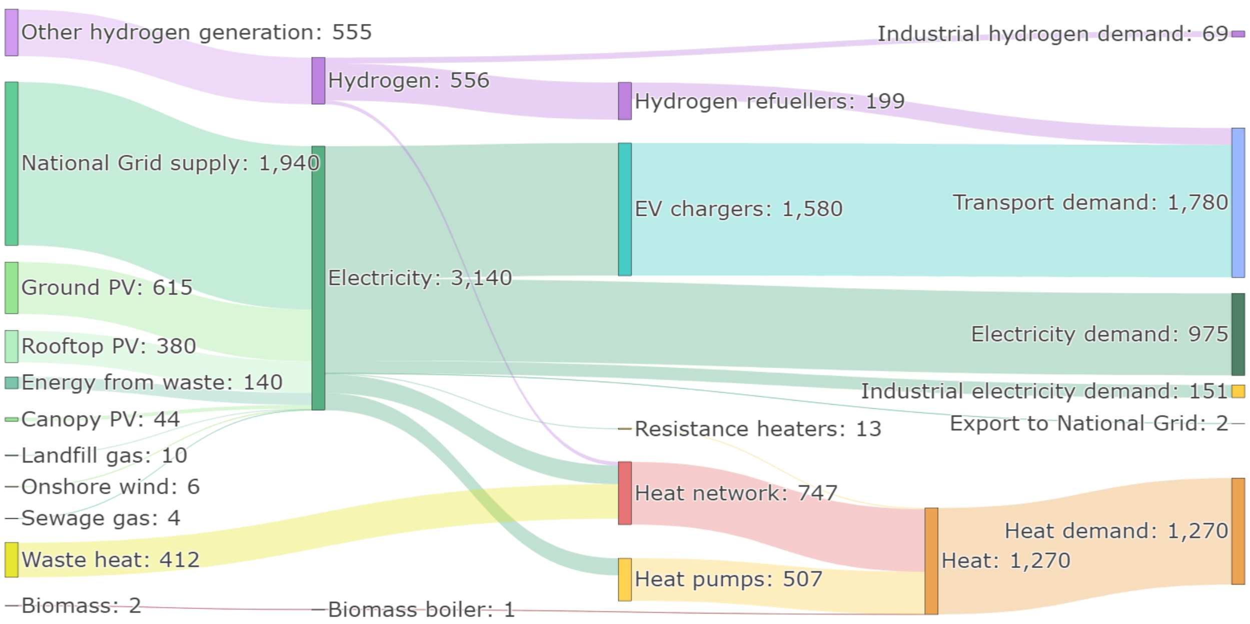
Figure 4.1.1 is an output from our modelling and shows a potential future energy system for Flintshire under the Low Demand scenario. This energy system results from modelling to create the most cost and carbon optimal system. We ran the model for four scenarios to support our decision making. This optimisation modelling informs the deployment pathways as well as the action plan. Note that this Sankey diagram does not present the final plan for Flintshire's future energy system.

Hydrogen generation /import expected to be required for some transport and industry demand

Electricity supply from the national grid could double as electricity becomes the primary vector for heat and transport demand

Local renewable generation could provide 38% of electricity, driven by growth of all forms of solar PV and energy from waste

Waste heat is a by-product of industrial processes



Some industrial heat processes are expected to be met through hydrogen use

The transport sector could be almost fully electrified, with some contribution from hydrogen refuellers

Heat demand could shrink by ~30% and be met entirely through heat pumps and waste heat delivered through heat networks. ~70% less input energy supply is required (compared to 2019) to provide the amount of heat demand in 2050

Figure 4.2.2: Annotated Sankey diagram showing energy flows under the Low Demand scenario (GWh in 2050)

4. The future energy system
Analysis

High Demand scenario – annual energy flows (GWh, 2050)

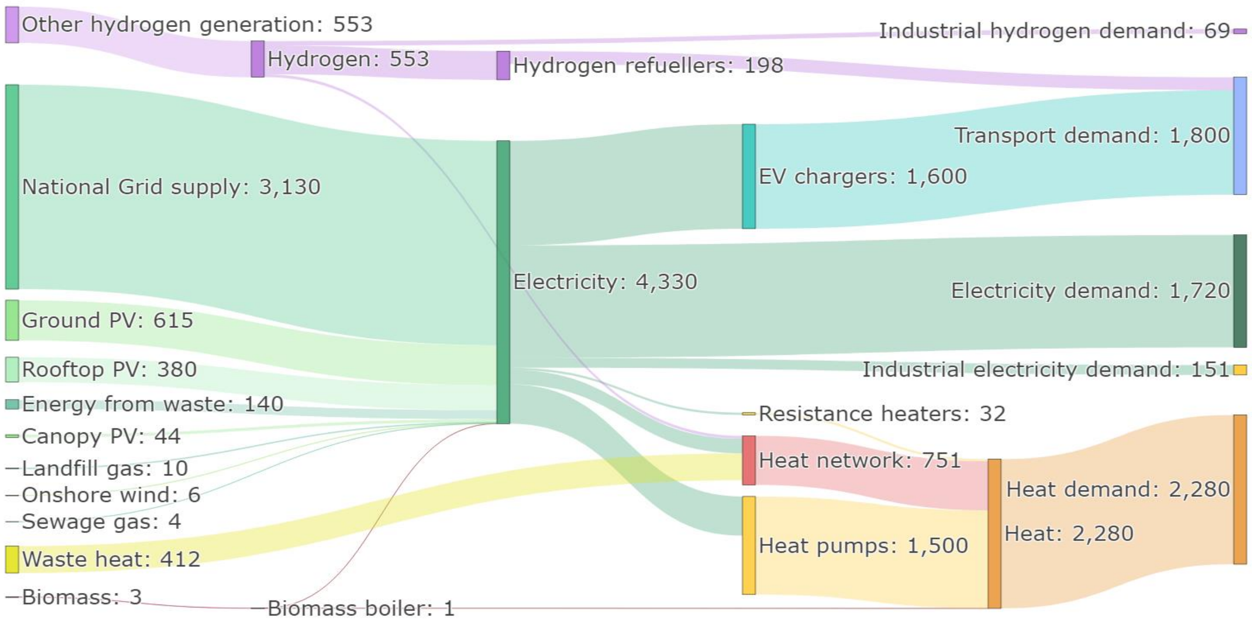
Figure 4.1.2 is an output from our modelling and shows a potential future energy system for Flintshire under the High Demand scenario. This energy system results from modelling to create the most cost and carbon optimal system. We ran the model for four scenarios to support our decision making. This optimisation modelling informs the deployment pathways as well as the action plan. Note that this Sankey diagram does not present the final plan for Flintshire's future energy system.

Hydrogen generation /import expected to be required for some transport and industry demand

Electricity supply from the national grid could increase threefold as electricity becomes the primary vector for heat and transport demand

Local renewable generation could provide 28% of electricity, driven by growth of all forms of solar PV and energy from waste

Waste heat is a by-product of industrial processes



Some industrial heat processes are expected to be met through hydrogen use

The transport sector could be almost fully electrified, with some contribution from hydrogen refuellers

Heat demand could grow 25%+ and be met entirely through heat pumps and waste heat delivered through heat networks. ~50% less input energy supply is required (compared to 2019) to provide the increased amount of heat demand in 2050

Figure 4.2.3: Annotated Sankey diagram showing energy flows under the High Demand scenario (GWh in 2050)

Sponsors: Delivery partners:

High Hydrogen scenario – annual energy flows (GWh, 2050)

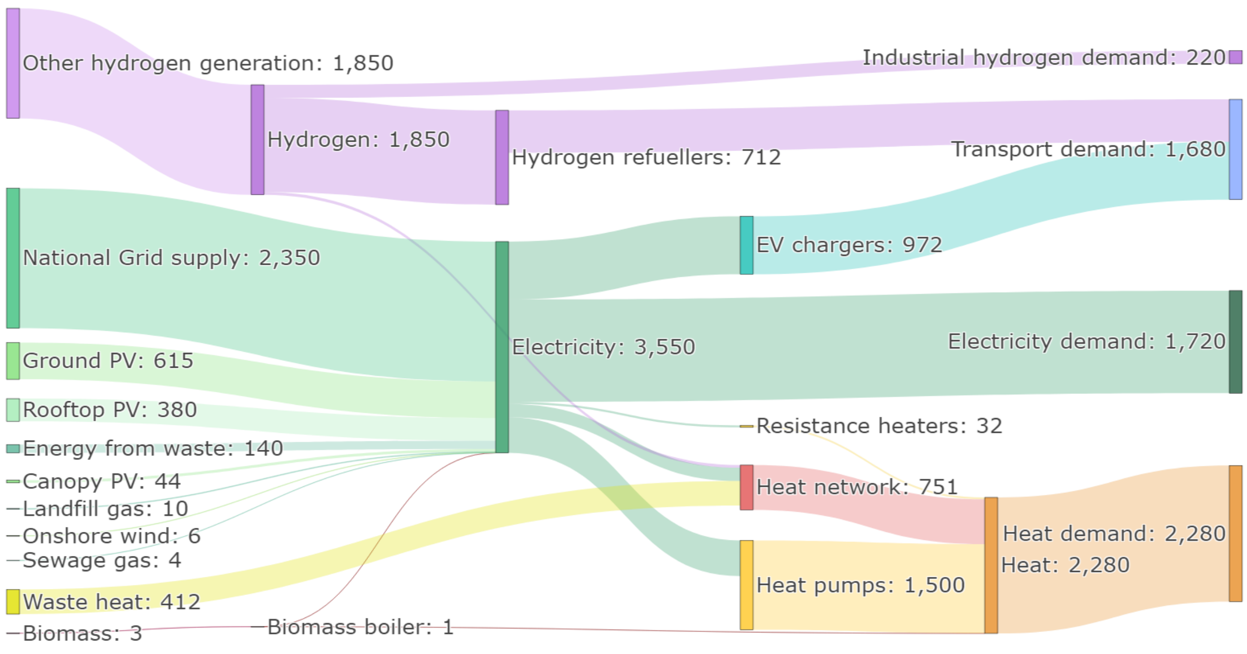
Figure 4.1.3 is an output from our modelling and shows a potential future energy system for Flintshire under the High Hydrogen scenario. This energy system results from modelling to create the most cost and carbon optimal system. We ran the model for four scenarios to support our decision making. This optimisation modelling informs the deployment pathways as well as the action plan. The High Hydrogen scenario (shown below) aligns with trends in the High Demand scenarios, as shown in the comparison presented in Figure 4.0.0. Note that this Sankey diagram does not present the final plan for Flintshire's future energy system.

Hydrogen generation/ import expected to increase significantly with a 3-4 times amount of supply than in any other scenario.

Electricity supply from the national grid could double as electricity becomes the primary vector for heat

Local renewable generation could provide 34% of electricity, driven by growth of all forms of solar PV and energy from waste

Waste heat is a by-product of industrial processes



Both industry and transport expected have a greater demand met through hydrogen supply. 42% of transport demand met through hydrogen refuellers.

The transport sector is likely to be electrified for passenger vehicles and LGVs

Heat demand could grow 25%+ and be met entirely through heat pumps and waste heat delivered through heat networks. ~50% less input energy supply is required (compared to 2019) to provide the increased amount of heat demand in 2050

Figure 4.2.4: Annotated Sankey diagram showing energy flows under the High Hydrogen scenario (GWh in 2050)

4. The future energy system
Analysis

Comparing future energy scenarios

Table 4.1.0 provides an overview of the variations in energy components observed in the optimisation modelling results across future energy scenarios, benchmarked against the baseline results.

Optimisation modelling shows ground-mounted, rooftop solar and onshore wind generation consistently increasing across all scenarios; contributing to meeting both Flintshire's energy demand but also exporting in times of surplus to the National Grid, and serving broader energy needs. In contrast, biomass generation sees a decline across all scenarios, likely due to a reduced dependency resulting from the enhanced output of solar and wind farms. Hydrogen is incorporated into the energy mix in all scenarios, sustaining Flintshire's industrial and transport demands.

Transport demand decarbonises, primarily due to the supply of electricity through EV charge points. Hydrogen also contributes to this demand, albeit to a lesser extent.

Heat demand is predominantly catered for by heat pumps, a trend that is consistent across all scenarios. While heat networks and other technologies contribute to this demand, their usage is comparatively less.

Energy system components	Baseline (GWh)	National Net Zero (GWh)	High Demand (GWh)	Low Demand (GWh)	High Hydrogen (GWh)
Ground-mounted PV	77	615 ↑			
Rooftop PV	11	380 ↑			
Onshore wind	6	6 →			
Sewage gas	1	4 ↑			
Biomass	715	3 ↓		2 ↓	3 ↓
Hydrogen import	0	556 ↑	553 ↑	555 ↑	1,850 ↑
Import from Grid	975	3,110 ↑	3,130 ↑	1,940 ↑	2,350 ↑
EV chargers	3	1,580 ↑	1,600 ↑	1,580 ↑	972 ↑
Refuellers	0	199 ↑	198 ↑	199 ↑	712 ↑
Heat pumps	15	1,500 ↑		507 ↑	1,500 ↑
Heat networks	0	751 ↑		747 ↑	751 ↑
Resistance heaters	40	32 ↓		13 ↓	32 ↓
Biomass boilers	356	1 ↓			

Table 4.2.1: Comparison across the scenarios

4. The future energy system
Analysis

Electricity generation and consumption

Figure 4.2.5 shows monthly averages for one year for optimised generation and consumption of electricity to show what balancing could look like in the High Demand scenario.

A future electrical energy system will look somewhat different from today. On the consumption side there will be much greater demand for electricity for transport, ancillary demand and industry. As heat pumps become the primary heat source, heat demand will require electrical energy and this introduces an element of seasonality to the consumption profile - 13GWh in July vs 154GWh in January.

The seasonal electricity consumption profile will be directly out of phase with increased local renewable generation provided by solar PV (fewer sunshine hours in the winter). As such, the winter months will require a much greater proportion of electricity imported from the national grid – 418GWh in January vs 151GWh in July.

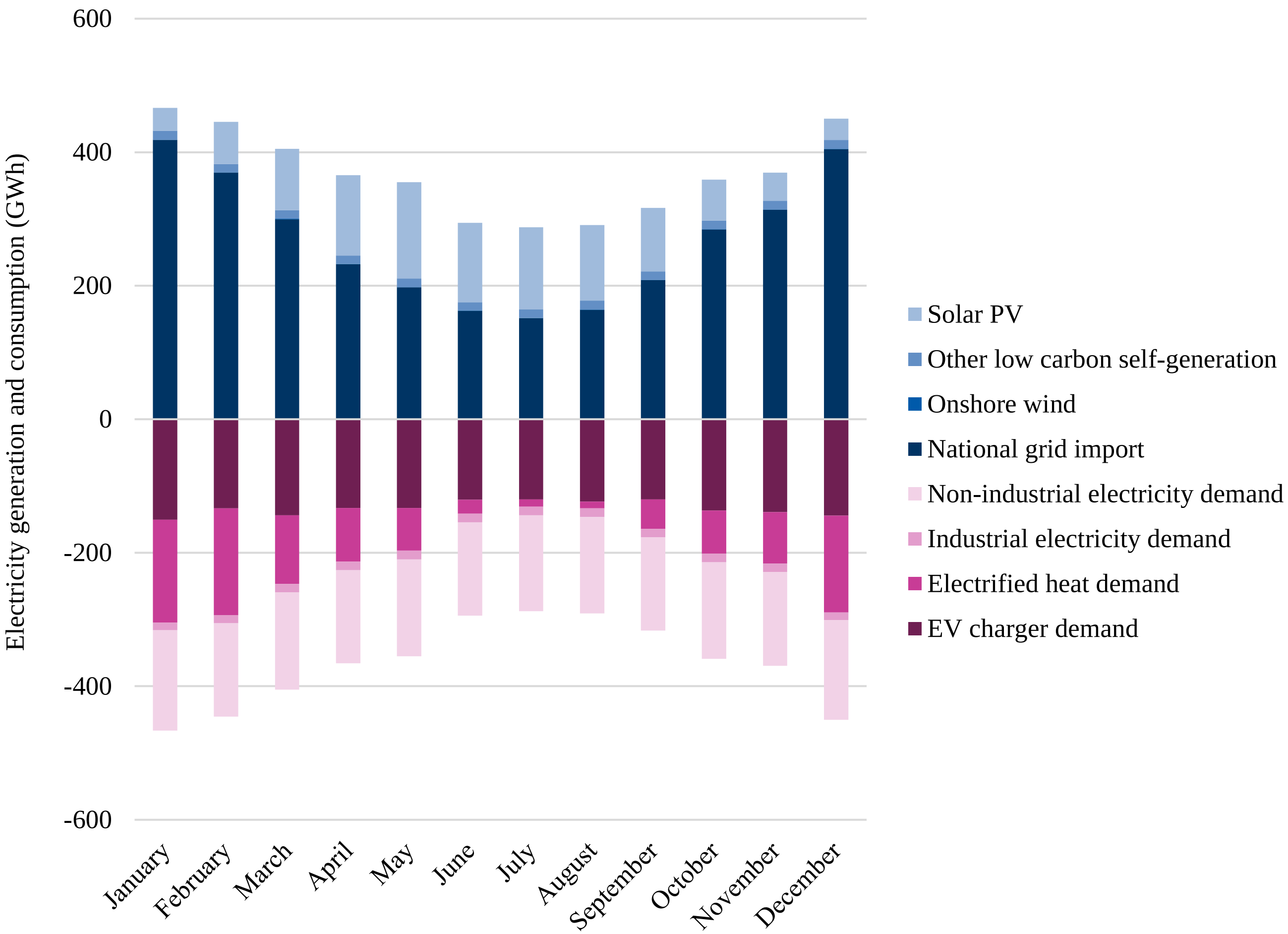


Figure 4.2.5: Monthly electricity generation and consumption in the High Demand scenario

Comparing future energy scenarios - Buildings

Figure 4.2.6 shows the different technologies that are deployed to meet heat demand in homes and commercial properties in 2050, compared to 2023. In 2023, gas boilers and oil/LPG boilers were the most common heating technology installed. In all scenarios, all gas boilers have been replaced by heat pumps with a small number of resistance heaters. Heating systems are generally set up with thermal stores which can help to reduce peak demand by storing heat when there is less demand on the electricity grid and release it when there is high demand. Storage also reduces GHG emissions and costs by making sure energy is used when it's cheaper and when there is a higher proportion of renewables on the grid. 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.

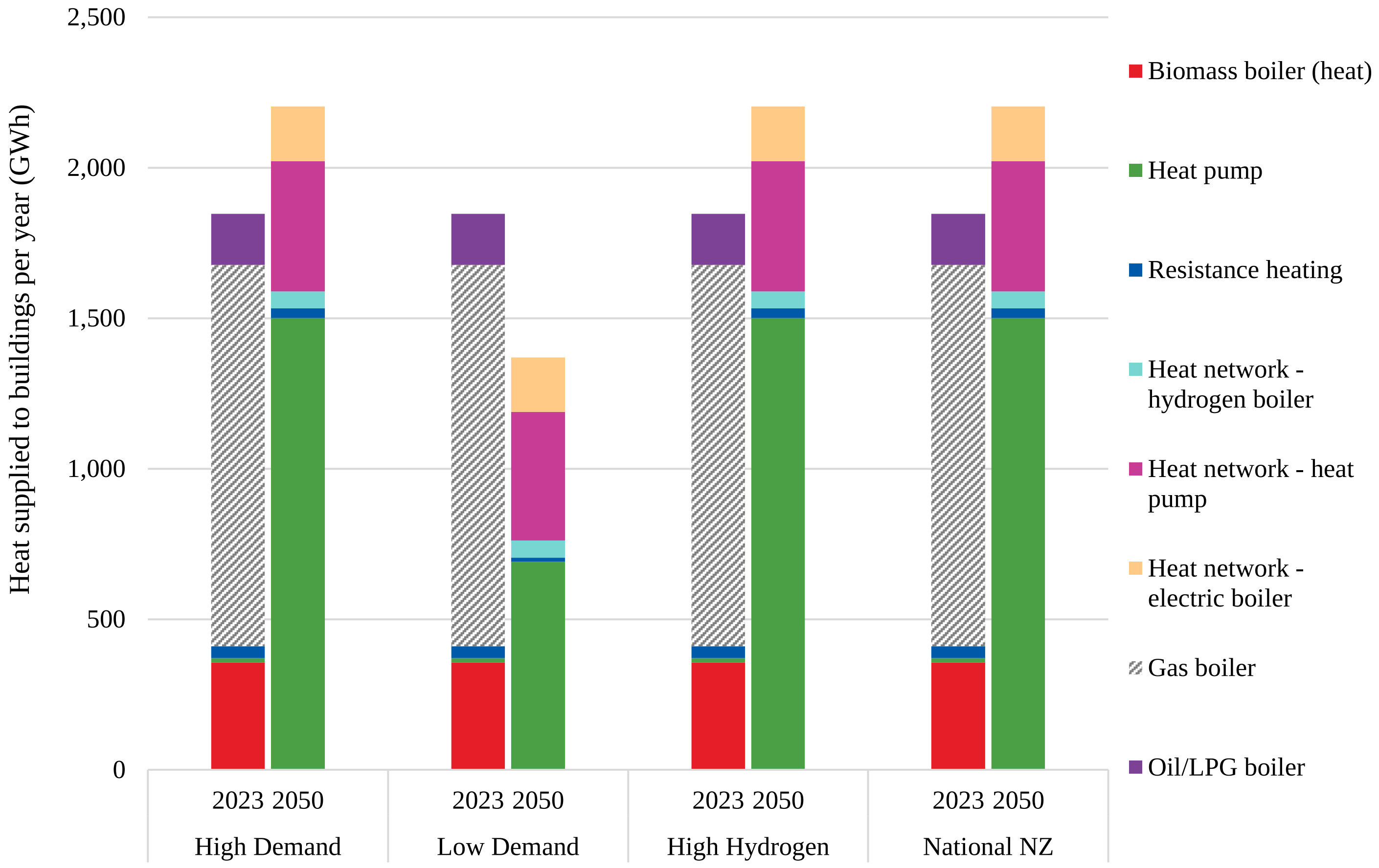


Figure 4.2.6: Proportion of heat supplied to buildings by technology in 2050 for each scenario

4. The future energy system
Analysis

Comparing future energy scenarios - Buildings

Table 4.2.2 shows the total number of energy efficiency measures 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.

Metric	Unit	Baseline	High demand	Low demand
Existing homes	#	71,236		
Domestic - cavity Wall insulation	#		3,732	3,732
	% of total homes		5%	5%
Domestic - floor insulation	#		5,480	56,952
	% of total homes		8%	80%
Domestic - roof insulation	#		12,831	12,831
	% of total homes		18%	18.%
Domestic - solid wall insulation	#			14,579
	% of total homes		0%	20%
Domestic - triple glazing	#			61,128
	% of total homes		0%	86%

Table 4.2.2: Proportion of homes with insulation measures

Comparing future energy scenarios - Buildings

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.

Low Demand: best practice insulation upgrades to improve the heat loss value to the typical efficiency of an EPC C/A.

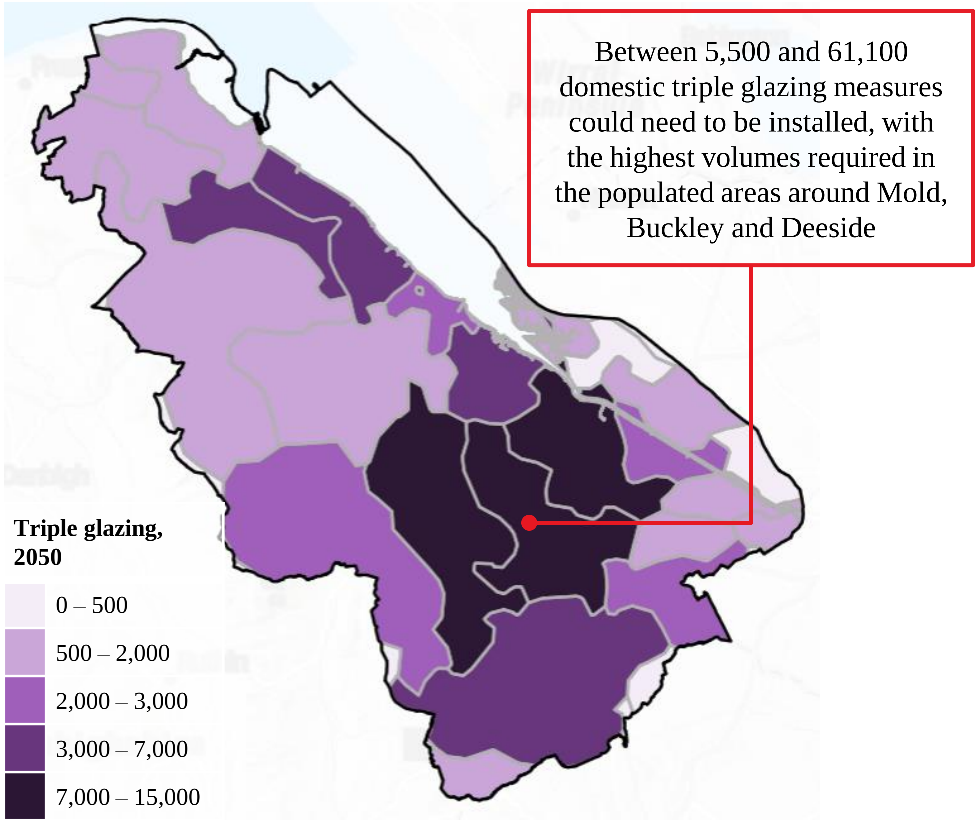


Figure 4.2.7: Map showing the number of additional triple glazing fittings completed by 2050 by substation zone in the Low Demand scenario

Comparing future energy scenarios - Buildings

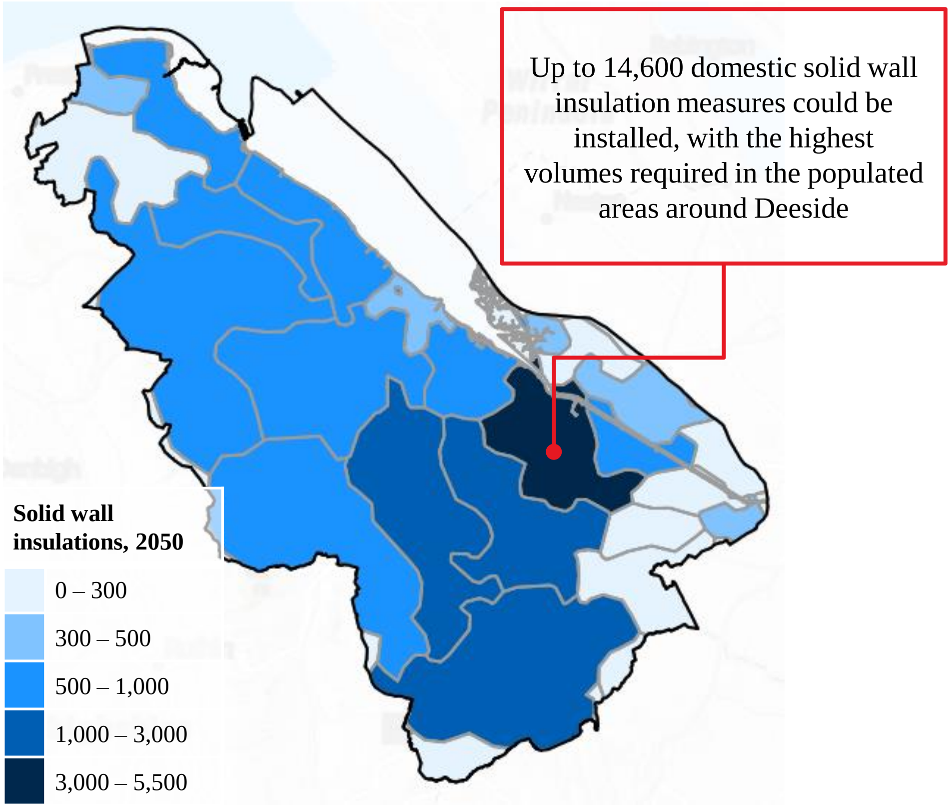


Figure 4.2.8: Map showing the number of solid wall insulation measures fitted by 2050 by substation zone in the Low Demand scenario

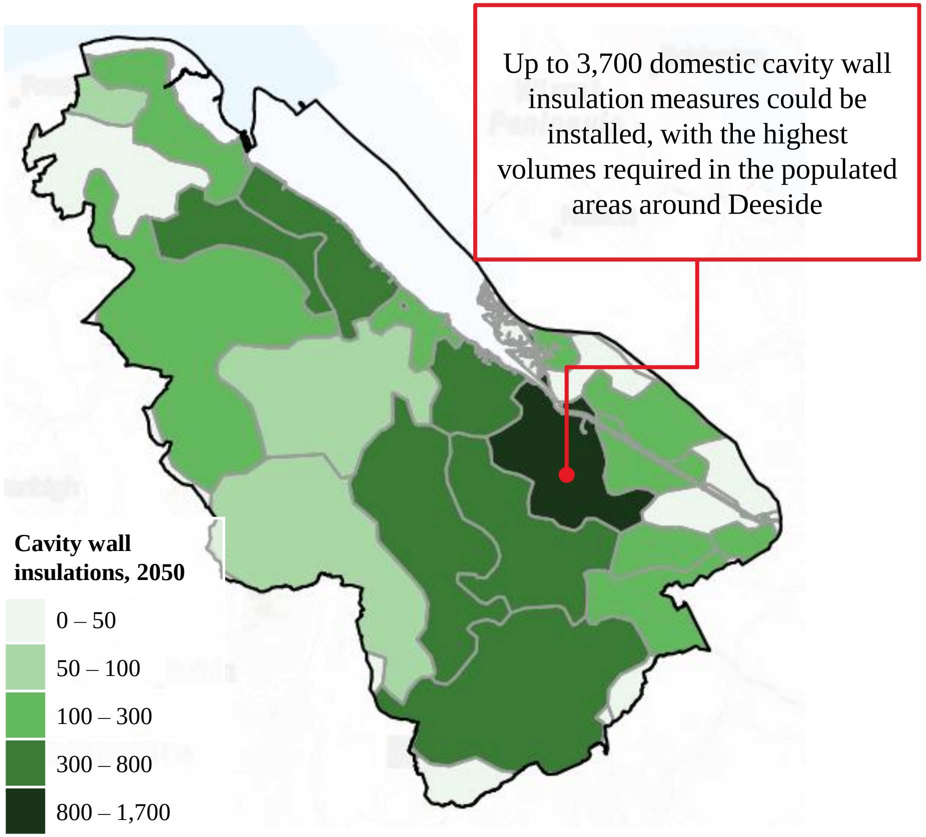


Figure 4.2.9: Map showing the number of additional cavity wall insulation measures fitted by 2050 by substation zone in the Low Demand scenario

Comparing future energy scenarios - Buildings

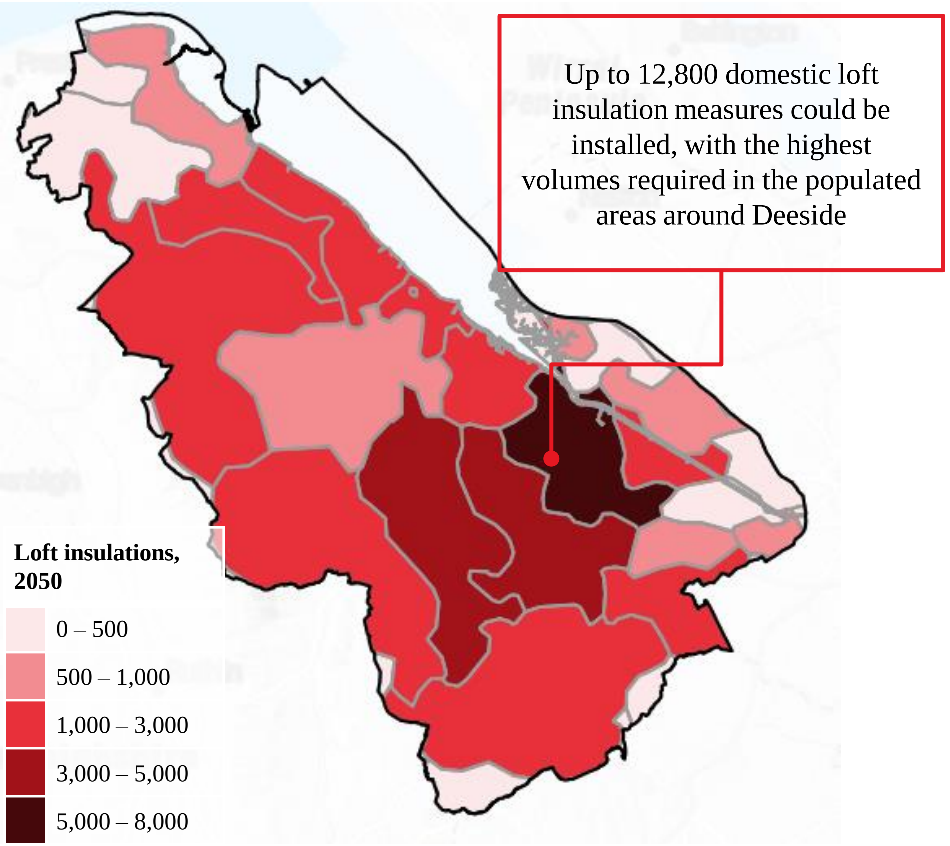


Figure 4.2.10: Map showing the number of additional loft insulation measures fitted by 2050 by substation zone in the Low Demand scenario

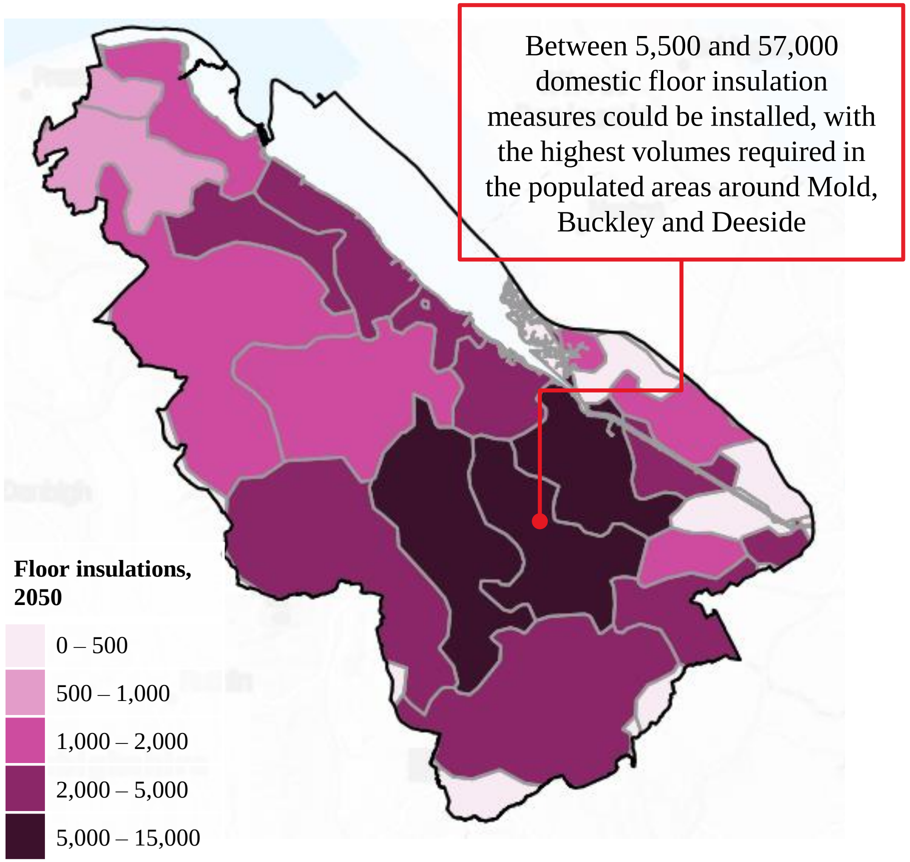


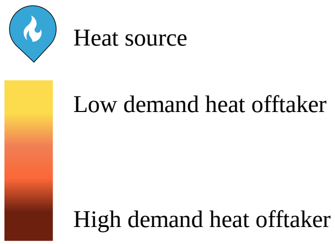
Figure 4.2.11: Map showing the number of additional floor insulation measures fitted by 2050 by substation zone in the Low Demand scenario

Comparing future energy scenarios - Heat networks

This section will analyse potential heat networks in the LA, under high demand scenario.

Potential heat network opportunity areas have been identified where heat networks may be able to deliver heating at lower cost than individual air source heat pumps (ASHPs).

Unsurprisingly, there are numerous potential waste heat providers across the county. These have been highlighted with the blue markings in Figure 4.1.12, and align with the industry and commercial hotspots. This essentially forms a linear network stretching from Saltney in the South to Greenfield in the North with a branch covering the Deeside industrial zone and a separate branch catering for Buckley and Mold. Potential offtakers have been highlighted in yellow, orange and red (depending on the size off the heat offtaker). The offtakers are a mix of commercial, public sector and domestic buildings.



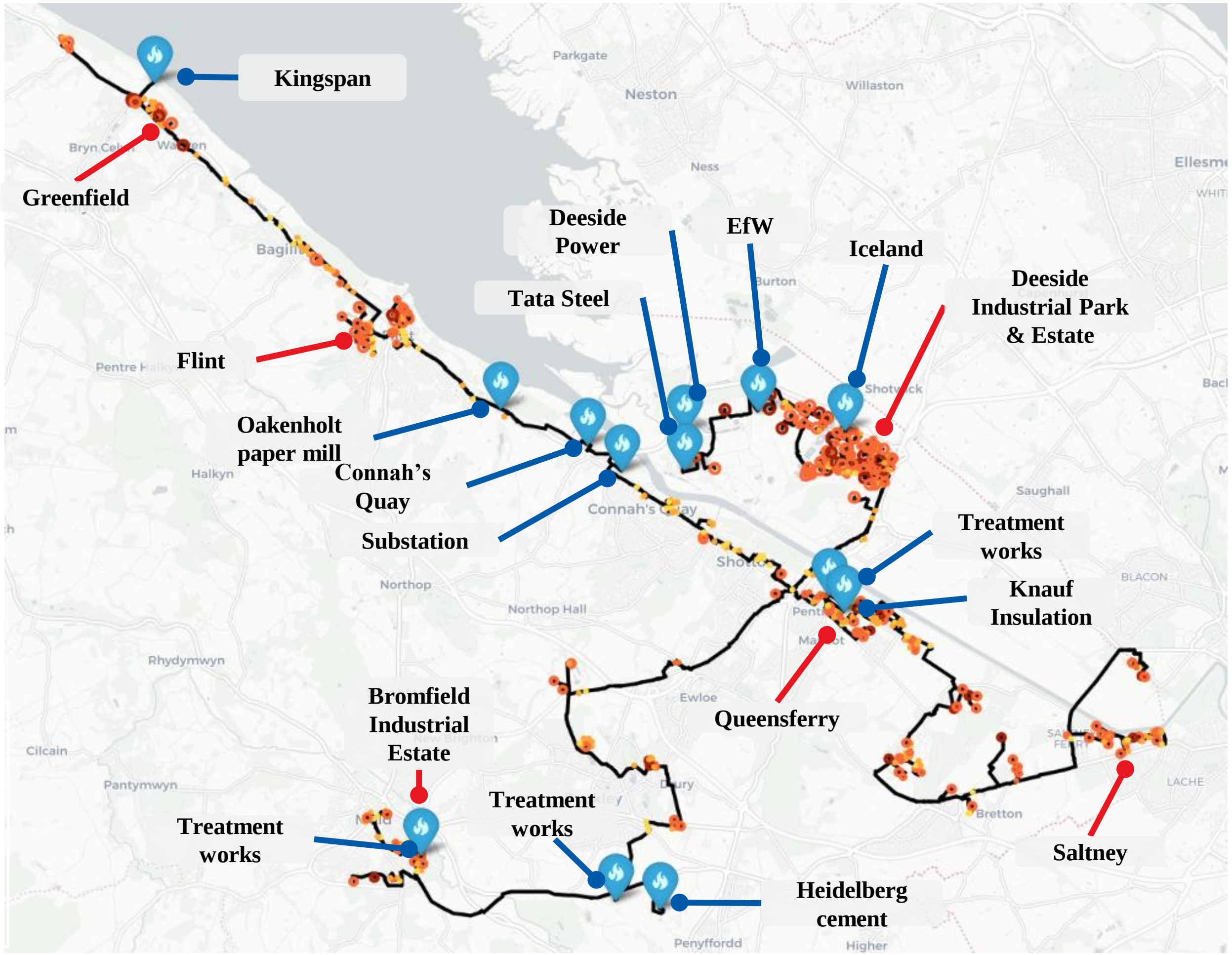


Figure 4.2.12: Map of identified zones for heat network potential in a high demand scenario

Comparing future energy scenarios - Transport

Figure 4.1.12 shows the total number of vehicle miles covered in one year by vehicle type and scenario.

- Car mileage could decrease by 1% in the Low demand scenario and increases by 6% in the High demand scenario based on National Grid's Future Energy Scenarios. This reflects the assumption that people choose to take public transport or use active travel where possible, rather than using their car for all journeys taken.
- Across the three scenarios, 71-88% of mileage is covered by electric vehicles and 12-29% 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 against 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.

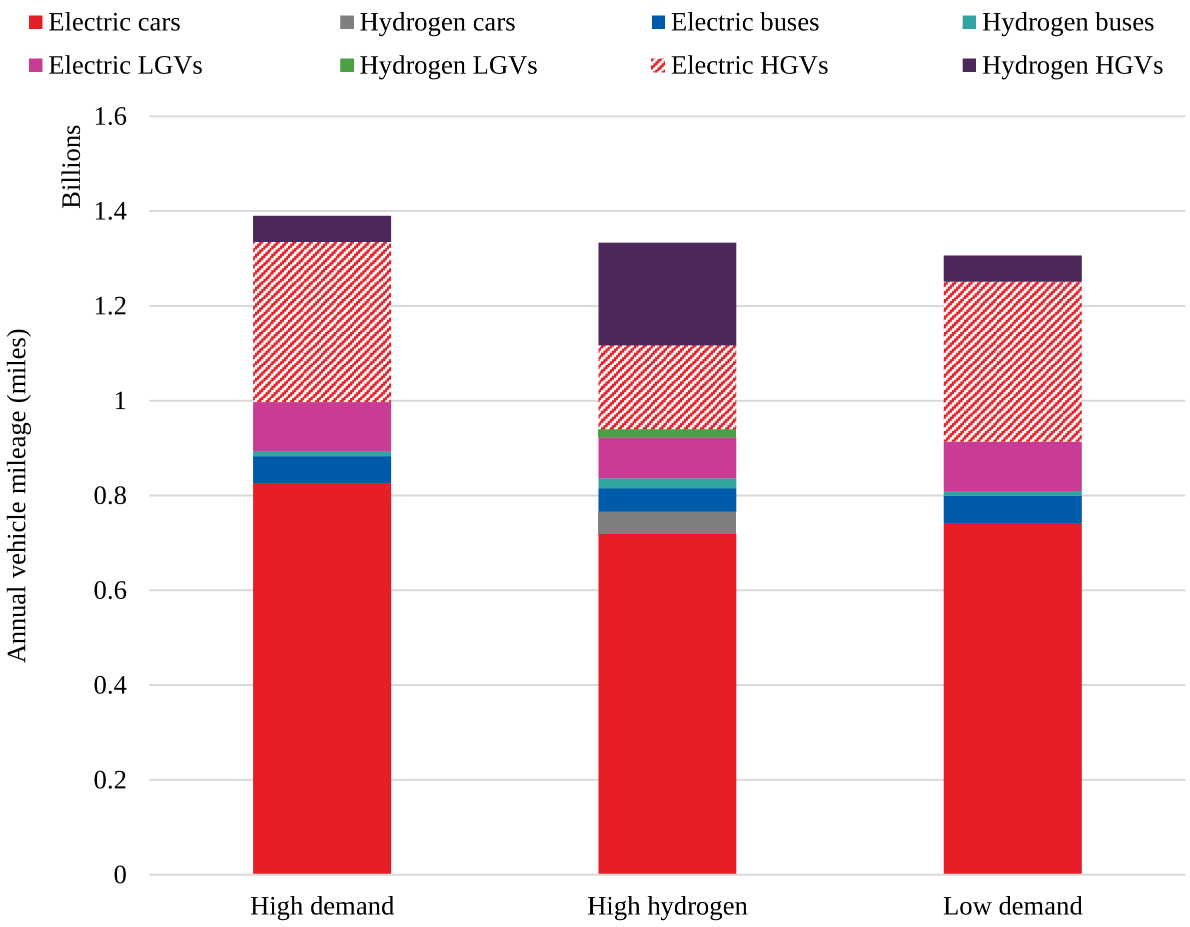


Figure 4.2.13: Total annual vehicle miles by scenario and vehicle type

4. The future energy system
Analysis

Comparing future energy scenarios - Onshore renewables (electricity generators)

Our modelling points to an extensive build out of ground solar PV and rooftop solar PV as the most cost- and carbon- effective way to meet projected energy demands. Across all scenarios, all the land identified as potentially suitable for ground PV was used.

Onshore wind is limited within Flintshire due to restrictions from flight paths over the county, as well as areas of outstanding natural beauty. We, therefore, don't see a build out at all of onshore wind from the current baseline levels.

Solar carports, batteries and energy from waste pick up the small remainder of potential 2050 energy generation.

We see a reduction in the number of different generation technologies being deployed as fossil fuel powered generators are phased out.

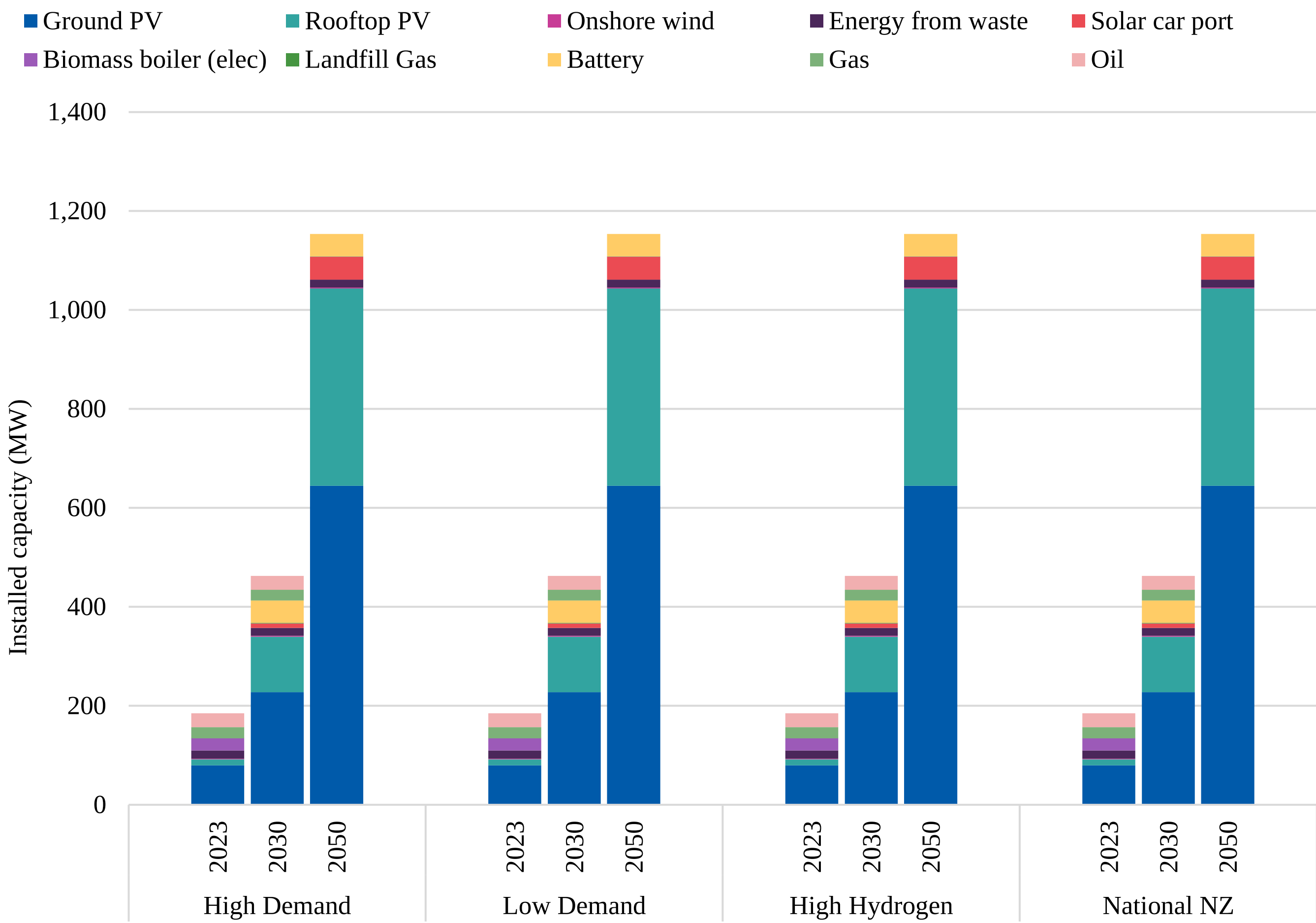


Figure 4.2.14: future capacity of onshore renewables in each scenario

Comparing future energy scenarios - Onshore renewables (electricity generators)

Table 4.1.2 details the maximum theoretical capacity of various generating technologies, taking into account land type and other constraints. Also shown, is the percentage of the theoretical maximum that the modelling suggests needs to be built in order to cover the 2050 energy demands.

It is anticipated that all technologies will either need to be built out to their theoretical maximum or be retired.

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.

Renewable technology	Baseline capacity (MW) (2023)	Total theoretical capacity across scenarios in 2050 (MW)	Additional capacity indicated across scenarios (MW)	Percentage of total maximum theoretical capacity across scenarios (%)
Ground-mounted solar PV	80	565	645	100%
Rooftop solar PV	12	387	399	100%
Onshore wind	2	2	2	100%
Canopy Solar PV	0	46	46	100%
Biomass boiler (elec)	0	25	25	100%
Energy from waste	16	16	0	100%
Battery	0	45	45	100%
Sewage gas	0.2	0	-	n/a
Landfill gas	1	0	-	n/a

Table 4.2.3: Existing and maximum future capacity of onshore renewables

Comparing future energy scenarios - electricity infrastructure - upgrades

The model optimises each future energy system by considering the most cost- and carbon-optimal supply profile to meet demand in each substation zone, solving this problem for three hour intervals over the course of one year. In some cases, the marginal cost of upgrading and connecting an additional unit of capacity to the substation is less than the marginal cost of installing an additional unit of battery or thermal storage capacity to reduce peak demand enough that the upgrade wouldn't be needed. Figure 4.1.14 shows the degree of upgrades required in the High Demand scenario, which explores a future scenario where electricity demand is high because of limited rollout of demand reduction measures and consumer behaviour changes.

28 of the 30 primary substations across Flintshire are likely to require some form of upgrade. The level of upgrade could vary from 0.5MW at some substations to over 90MW at others. 80% of the upgrade in capacity across all 30 primary substations, will be needed from the following 11 primary substations:

1. Connah's Quay (91 MW)
2. Buckley (63 MW)
3. Greenfield (50 MW)
4. Bromfield (43 MW)
5. Deeside Industrial Park (43 MW)
6. Queenferry (38 MW)
7. Flint (30 MW)
8. Caergwrle (25 MW)
9. Shotwick (21 MW)
10. North Wales Paper (20 MW)
11. Holway Road (19 MW)

This modelling considers up to the primary substation; there will be further upgrades required to the 11kV network out from the substations which is not included within the modelling.

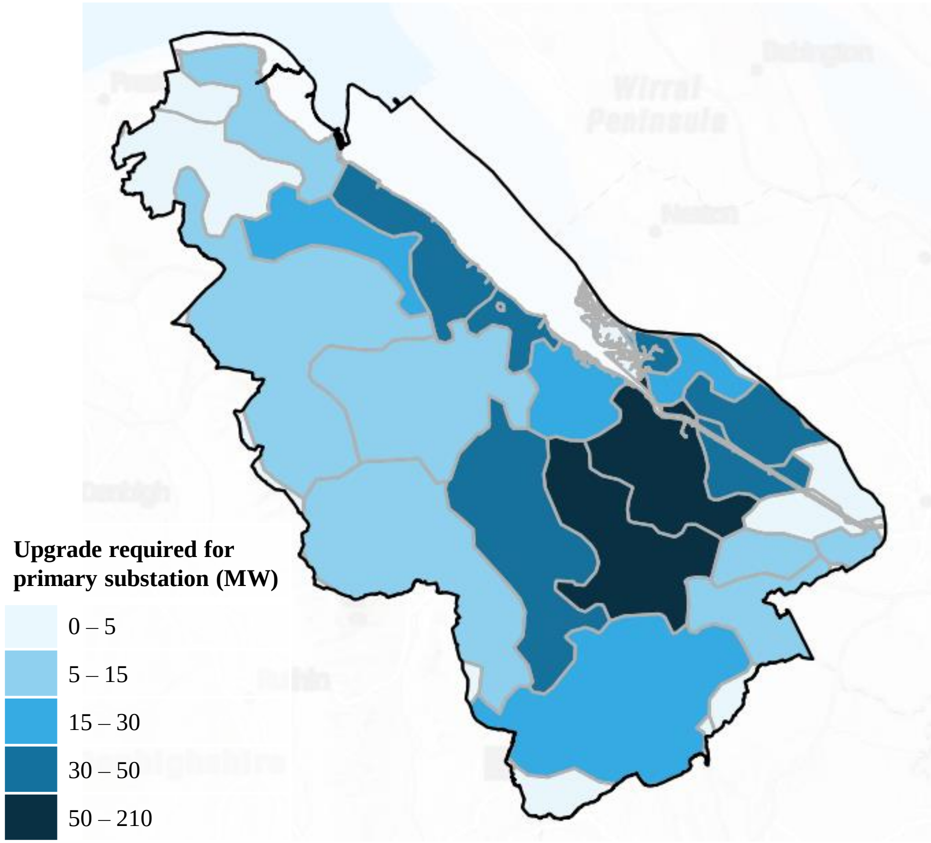


Figure 4.2.15: Map of electricity network upgrades in the high demand scenarios

4. The future energy system
Analysis

Uncertainties and limitations

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

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

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

Table 4.1.3 (overleaf) summarises the impact of key sensitivities and uncertainties on the future energy system scenarios.

4. The future energy system
Analysis

Uncertainties and limitations

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

Table 4.2.4: Impact of key sensitivities on the future local 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 undertake modelling at a 1-hour timestep, we can estimate what the expected impact would be. We have also observed how the system changes when we remove the electricity import. The diagram in Figure 4.1.15 demonstrates what we have found over the multiple model runs that we have undertaken.

What does the model always do?

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

How does the timestep influence the system?

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

What does the model do if electricity imports are restricted?

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

Figure 4.2.16: Trends from optimisation model runs

Sponsors:

Delivery partners:

Technical report

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

Deployment modelling

4. The future energy system
Deployment modelling

Methodology

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

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

Figure 4.2.0 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 4.2.0 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 B7.

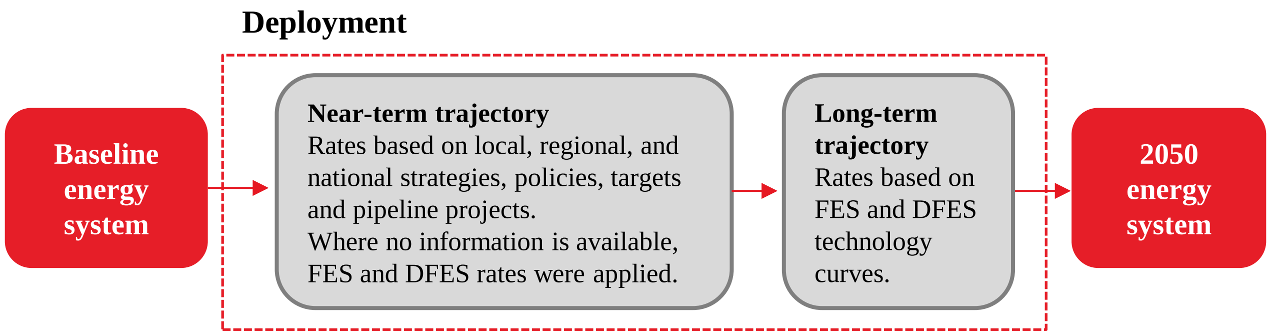


Figure 4.2.0: Deployment model overview of assumptions used to determine rates

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)

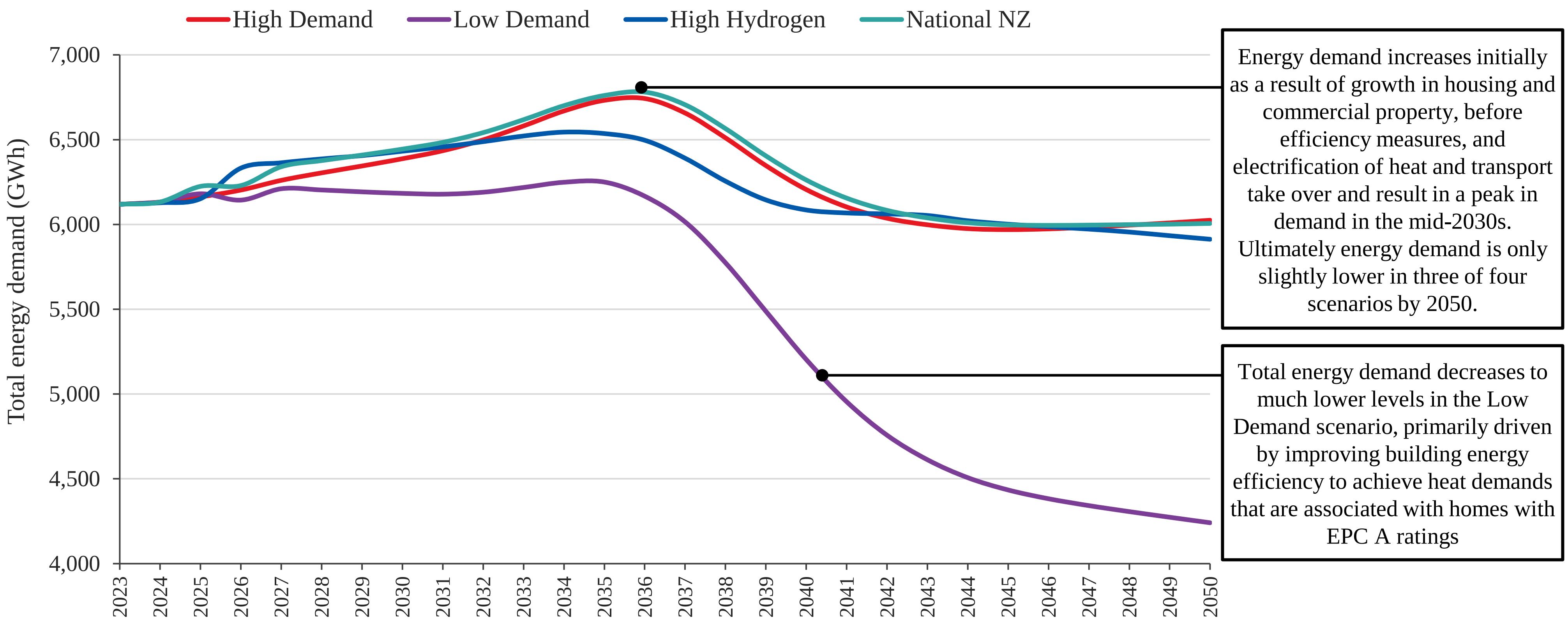


Figure 4.3.1: Change in total energy demand by scenario (GWh)

Energy demand from buildings (GWh)

Buildings energy demand increases overall because the evidence assumes an increase in the number of homes and commercial buildings between now and 2050. However, the average heat demand decreases from approximately 13,000 to 11,000 kWh_{heat}/home and commercial buildings 100 to 77 kWh_{heat}/m^2.

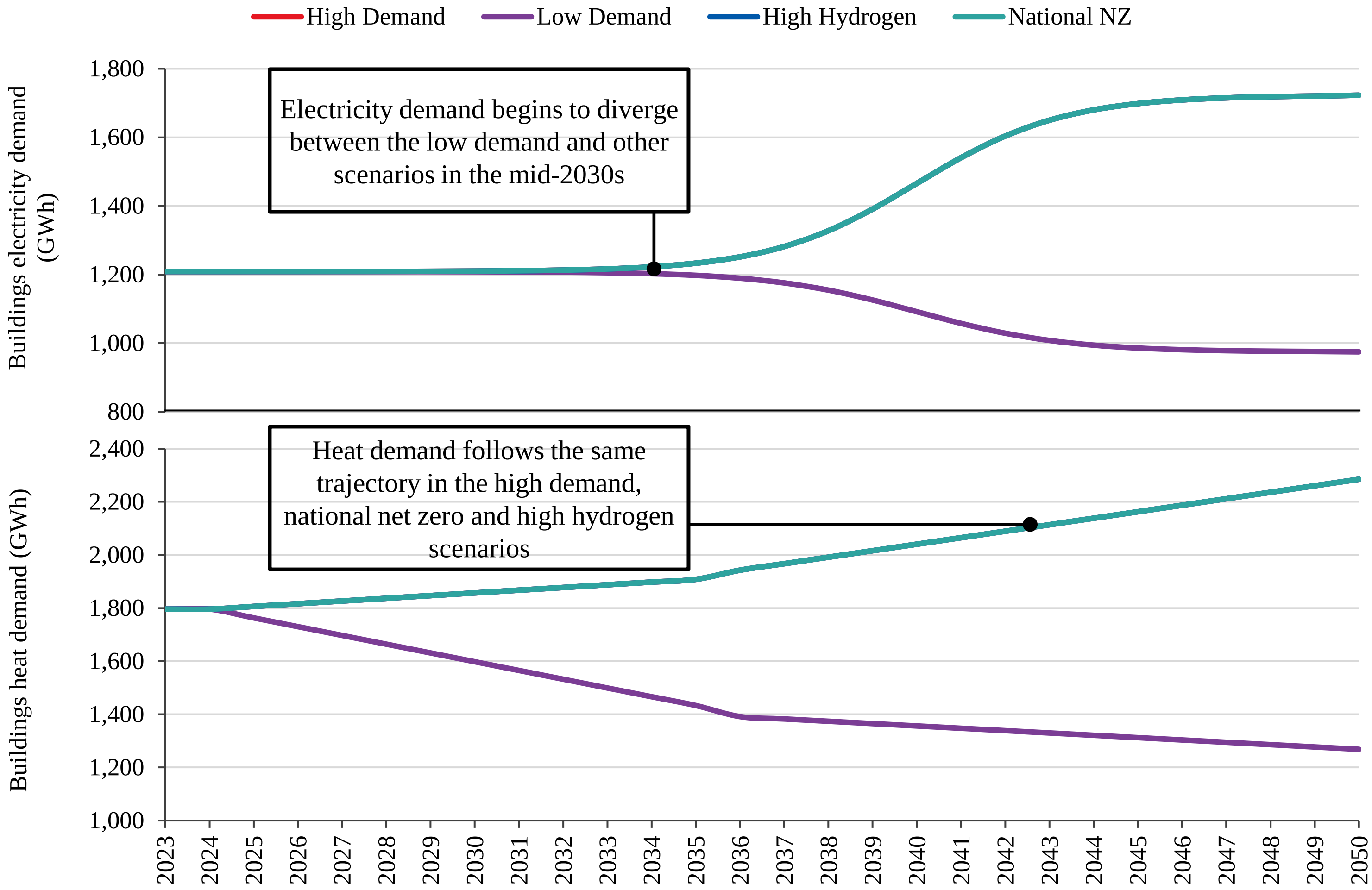


Figure 4.3.2: Projected electricity and heat demand for buildings in each scenario

Energy demand from transport (GWh)

The high demand scenario sees the greatest switching to electric vehicles early on, and therefore the greatest reduction in energy demand. However, as the levels of vehicle electrification increases in the low demand and national net zero scenarios the energy demand trajectories begin to align. The high hydrogen scenario ultimately sees the greatest reduction in energy demand thanks to the greater efficiencies of hydrogen fuelled HGVs compared to electric.

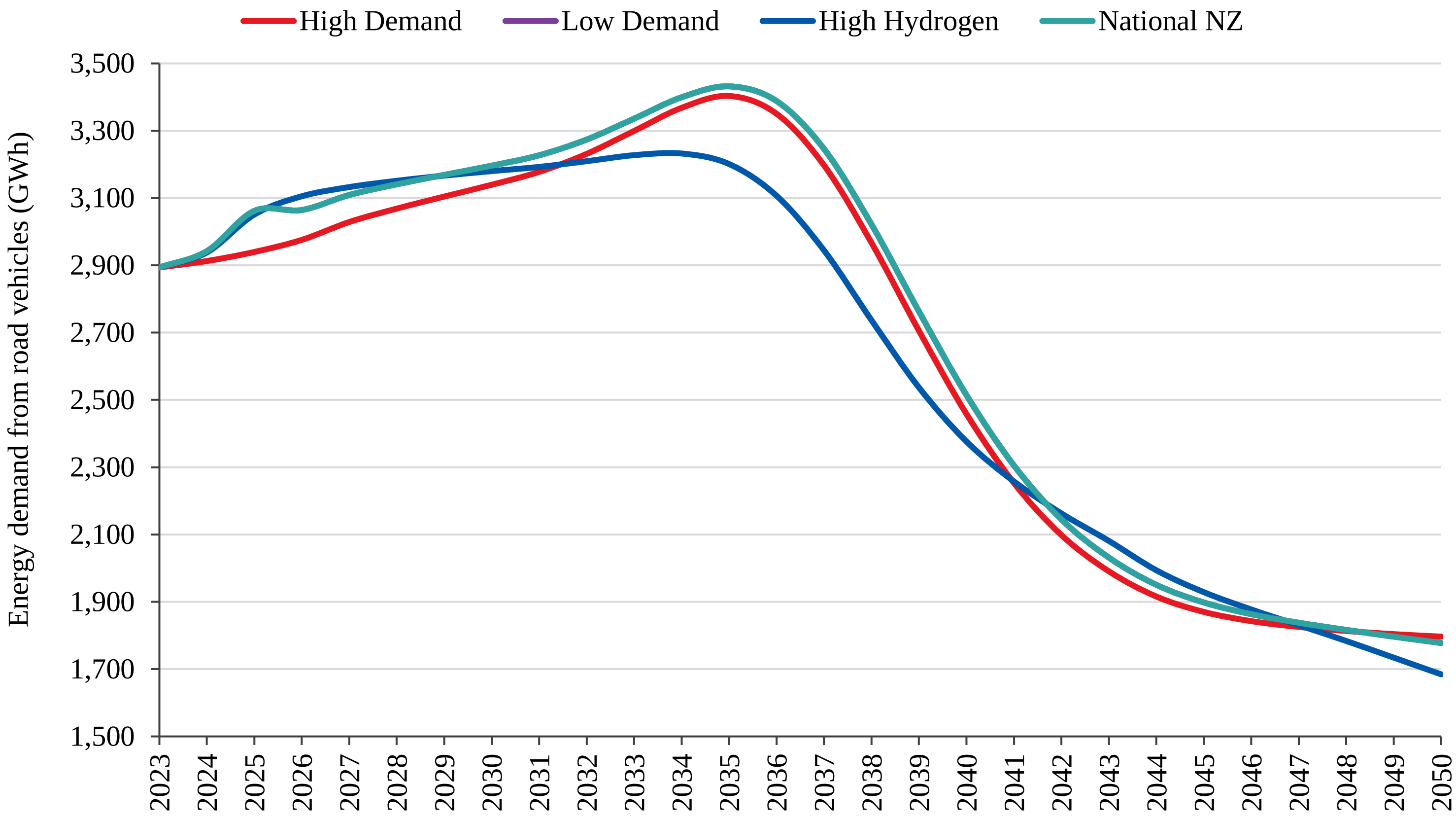


Figure 4.3.3: Projected energy demand from road vehicles by scenario

4. The future energy system
Deployment modelling

Summary of deployment for low-regret energy system components

Our deployment model helps us to think about where we are now and where we need to get to, providing 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 take into account every factor, some of the things that will impact deployment include:

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

*According to the National Charge Point Registry[M43] as of May 2023. Refers to individual charge points, and assuming 4kWp per charge point

**Assuming 4kWp per roof

***Renewable generation capacity is shown for technologies where current installed capacity is >5MW

Measure	2023	By 2030	By 2050
Additional homes with insulation measures (#)	13,00 homes with EPC A-C (35%)	Up to 25,000 homes retrofitted	Up to 61,100 homes retrofitted
Buildings with heat pumps installed (#)	700	Up to 14,600	Up to 95,300
EV charge points (#)*	220	Up to 8,430	Up to 63,840
Buildings with rooftop solar PV (#)**	2,900 (12 MW)	28,000 (112 MW)	99,700 (399 MW)
Ground-mounted solar PV capacity (MW)	80 MW	228 MW	645 MW
Other renewable capacity (MW)***	44 MW	73 MW	110 MW

Table 4.3.2: Summary of deployment of various technologies between 2023, 2030 and 2050

Impact on GHG emissions

Figure 4.2.4 compares projected GHG emissions for each future energy scenario (see Chapter 4. The future energy system (methodology) for a description of scenarios). The "Do Nothing" scenario assumes that Flintshire continues operating as it is today, with no further action beyond what is already current mandatory UK and Wales GHG emission reduction targets. However, this does not reach the net zero target. Any change can largely be attributed to the forecasted decarbonisation of the electricity grid. By considering external factors such as committed policy and other decision points, the deployment pathways for each scenario help us to prioritise actions that we might deliver in the next five years. It also highlights the systemic changes that will be needed to achieve the scale and pace of change that is indicated.

Scenario	2030	2040	2050
Welsh Gov targets	-63%	-89%	-100%
National Net Zero	-33%	-77%	-96%
High Demand	-34%	-78%	-96%
High Hydrogen	-34%	-72%	-95%
Low Demand	-35%	-77%	-97%
Do Nothing	-32%	-33%	-33%

Table 4.3.3: % GHG emissions reduction for each scenario compared to the Welsh Government emissions reduction targets

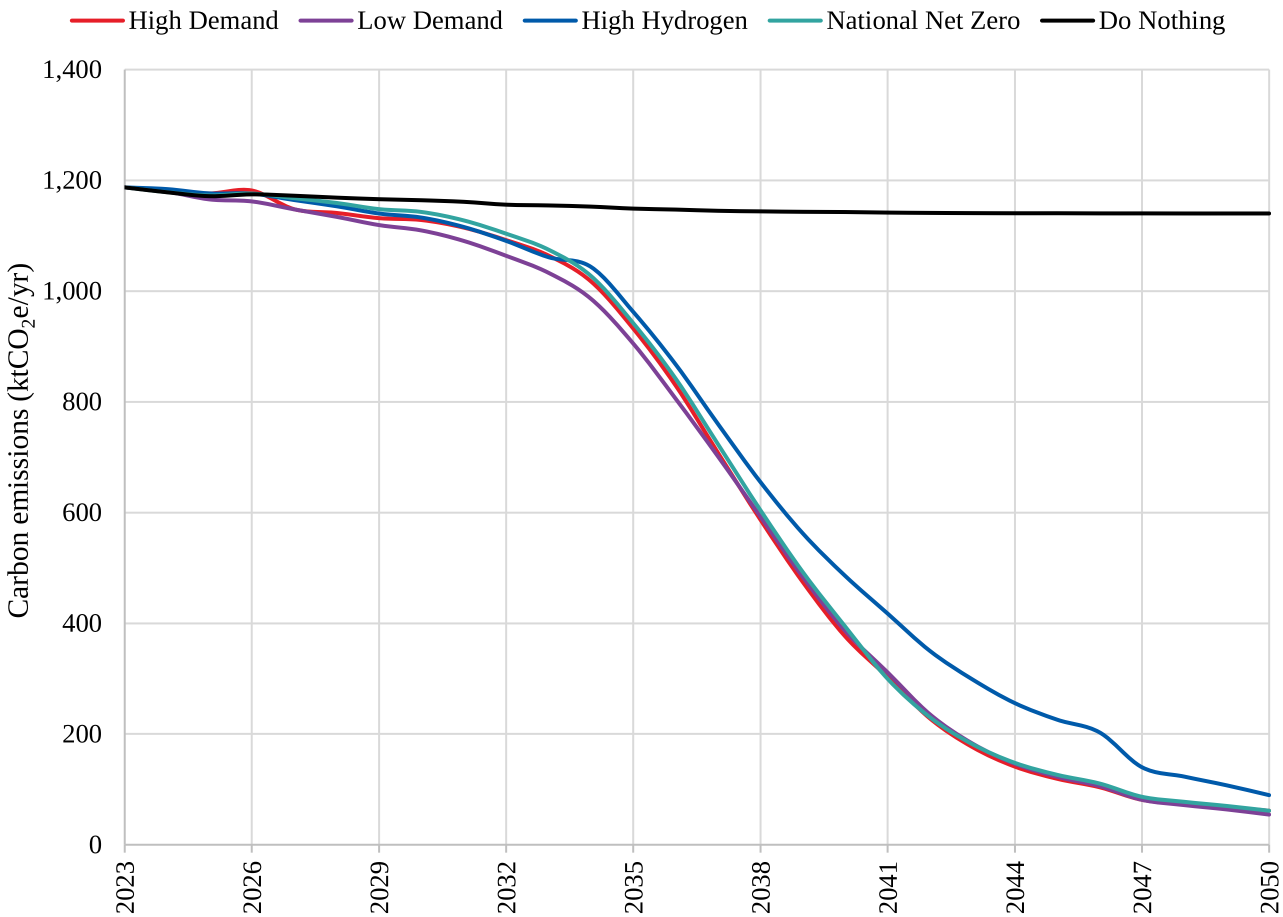


Figure 4.3.4: GHG emissions (ktCO2e) over time for each scenario compared to the Do Nothing scenario

4. The future energy system
Deployment modelling

Impact on employment

Reducing the amount of energy we use and using renewable energy can have wider benefits so it is important that they are understood to support decisions that impact the future of the energy system. The benefits realised can be economic, social and environmental. For example, for every £1 invested in energy efficiency measures, the NHS can save £0.42 (amounting to annual savings of £1.4 billion in England alone)[T35].

Employment impacts

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

Method

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

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

Results

Table 4.2.3 are presented in Full-Time Equivalent (FTE) so that employment impacts can be measured for the lifetime of the project or plant and duration. For example, a job that lasts 1 year for a project where plant lifetime is 10 years would count at 1*1*0.1 = 0.1FTEs over the duration of the project.

Both cumulative gross jobs added, and net additional jobs have been estimated. Net additional jobs are estimated by subtracting the gross jobs by the 'Do Nothing' scenario to net off jobs created if the money were invested in similar ways to what it is today.

Metric	Do Nothing	National Net Zero	High Demand	Low Demand	High Hydrogen
Energy change (GWh, relative to 2023)	0	-113 (-2%)	-94 (-2%)	-1,878 (-31%)	-206 (-3%)
Employment impacts between 2023-2050 relative to Do Nothing scenario (net FTE)	0	7,178	7,194	7,325	8,760

Table 4.3.4: Summary of economic impacts for each scenario: employment impacts and air quality activity costs. Figures shown relate to the period 2023 – 2050. Air quality activity costs are presented using 2022 prices and are not discounted

Impact on air quality

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

Method

We used the Green Book supplementary guidance for air quality[T50] activity costs from primary fuel use and the transport sector to estimate the air quality cost for each year (2023 to 2050) for each scenario. Activity costs simplify evaluating the effects of air pollution by estimating the value of changes to air quality per unit of fuel consumed. Table 4.2.4 provides a summary of the activity costs used in 2023 for the fuel types included in this analysis. The activity cost for electricity was assumed to vary over time; the costs for all other fuels were assumed to remain constant. Appendix B8 provides additional details on the derivation and assumptions for each of these costs. Air quality activity costs are presented using 2022 prices and are not discounted.

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

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

Table 4.3.5: Air quality activity cost factors

4. The future energy system
Deployment modelling

Impact on air quality

Results

Activity costs presented in Table 4.3.6 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 National Net Zero scenario.

Metric	Do Nothing	National Net Zero	High Demand	Low Demand	High Hydrogen
Cumulative air quality activity costs between 2023-2050 (£'million) (2022 prices)	£0	£1,200m	£1,177m	£1,198m	£1,170m
Change in greenhouse gas (GHG) emissions (ktCO2e, relative to 2023)	-47	-1,126	-1,125	-1,133	-1,097

Table 4.3.6: 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

4. The future energy system
Deployment modelling

Investment requirements

High levels of investment will be required to achieve the scale of change required to achieve a net zero energy system. Table 4.2.6 overleaf shows the estimated capital investment (CAPEX) required to build out the critical system components for net zero, that were identified in our scenario analysis. These costs are presented as absolute figures and should be weighted against a suitable counterfactual to understand the additional investment required.

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

The total capital investment requirements between now and 2030 are estimated to be from **£3 billion to £10 billion**, which is mostly invested in building retrofit and energy efficiency, heat decarbonisation and rooftop solar PV.

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

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

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

4. The future energy system
Deployment modelling

Investment requirements

	Indicative CAPEX (£m) to 2050	Basis for CAPEX estimate	Party responsible for CAPEX	Dependencies on other investments
1. Maximise energy efficiency of buildings	£320 – 4,540m	Cost of deep retrofit interventions	Local authority, housing associations, building developers, public	Supply chain
2. Ground-mounted solar PV	£240m	Equipment costs	Local authority, housing associations, building developers, public, renewable energy providers	Electricity network
3. Maximise rooftop PV	£430m	Build out of rooftop PV	Local authority (owned buildings), housing associations, building developers, public, renewable energy providers	Electricity network, potential structural costs
4. Decarbonise transport	£140 - 290m	Build out of EV chargers	Local authority, building developers, public	Electricity network
5. Decarbonise heat	£885 – 1,050m	Heat pump build out costs, heat network decarbonisation cost	Local authority, housing associations, building developers, public, heat network developers	Electricity network, energy efficiency
6. Electricity network reinforcement	£90m	Electricity network reinforcement costs will depend on the extent of network upgrades which will be needed across the LV, HV and EHV networks, requiring a more detailed analysis by the DNO.		
Project costs (incl contingency, prelims, professional and development costs etc) could be 50% of capital costs above				

Table 4.3.7: Indicative investment requirements

Sponsors:

Delivery partners:

Technical report

Chapter 5: Action planning (stages 6-7)

5. Action planning

Overview

Figure 5.0.0 shows the process followed to develop the complete LAEP and routemap to transition the local energy system in Flintshire.

Energy propositions

Identifying priority focus zones

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

Creating energy propositions

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 Flintshire'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 Flintshire, 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 6 energy propositions that form the framework for Flintshire'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 describe the collective effort required to deliver the ambitions and near-term energy propositions set out in Flintshire's LAEP.

Figure 5.1.1: Overview of the approach taken to develop the near-term recommendations for the LAEP

5. Action planning
Energy propositions

Identifying priority focus zones

Prioritising energy system components

Table 5.1.1 shows our approach to prioritise low-regrets energy system components in Flintshire to take forwards when identifying priority focus zones for their deployment. We consulted primary and secondary stakeholders across the county and asked:

- Is the energy system component deployed in all scenarios?
- Is this component a strategic priority identified by stakeholders during engagement?
- Does this energy system component align with the wider objectives that have been set for Flintshire's LAEP (described in Figure 5.0.1)?
- Is this energy system component identified as a priority area in North Wales's energy strategy?

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

	Outcome certain / clear	Outcome less certain / clear
Short term (0-5 years)	Onshore wind Rooftop PV EV chargers (public, private and commercial) Ground mounted PV Anaerobic digestion	EV chargers (domestic) Retrofit Biomass boilers Exporting to grid
Longer term	National grid supply Electrical network infrastructure Battery storage Heat pumps Blending hydrogen in to gas grid Small scale electrolysers	Heat networks Hydrogen infrastructure Electrolysers Hydrogen imports from abroad Tidal lagoons Active travel shift Energy from waste Hydrogen for heating

Table 5.1.1: Summary of feedback from workshop 5 (pathway prioritisation) – "prioritising energy system components"

Flintshire's energy propositions in more detail

Scaling zero carbon buildings

Supporting and deploying energy efficiency measures across the county to reduce energy demand and costs.

Ensuring buildings are safe, healthy and low carbon in operation and design.

Decarbonising transport

Enabling the rollout of ultra low/zero carbon vehicles across the county and transitioning to a zero carbon council fleet.

Promoting active and sustainable travel within the region.

Increasing local renewable generation

Investigating opportunities for local and community ownership of renewables, providing low cost, clean energy to residents.

Supporting future green business

Encouraging and supporting businesses to adopt low carbon measures and reduce energy costs.

Create an attractive environment for sustainable businesses to make base in Flintshire.

Maturing hydrogen in industry

Exploring the potential for hydrogen within particular sectors and understand the infrastructure requirements for implementation.

Reinforce and transition energy networks

Grid reinforcement will be required to accommodate the shift towards electric vehicles and heating.

Even in a low hydrogen scenario the gas grid will require repurposing for hydrogen within some applications.

Figure 5.1.2: Summary of energy propositions

Identifying priority focus zones

Our "plan on a page" indicates the location and scale of recommended near-term changes required across Flintshire. The map highlights nine modelling zones identified as priority focus zones for the low-regret energy system components included in Flintshire's energy propositions: heat pumps, EV chargers, rooftop PV, ground-mounted PV, onshore wind, and insulation retrofits. To prioritise where each low-regret energy system component should be deployed, each modelling zone was ranked using two or more of the considerations in Table 5.0.0, each weighted by the percentage indicated. A modelling zone was only considered for prioritisation if it was greater than 8% of its primary substation service area[x7].

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

In the map (overleaf), green areas show zones identified as a priority focus zone for at least one energy system component. The callouts indicate the total scale of change required by 2030, according to the deployment model analysis, and indicate either the total capacity (MW) to be installed or the number of homes requiring retrofit and the associated investment figures.

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

Table 5.1.2: Input data and relative weighting factors used in "plan on a page" calculations

Sponsors: Delivery partners:

5. Action planning

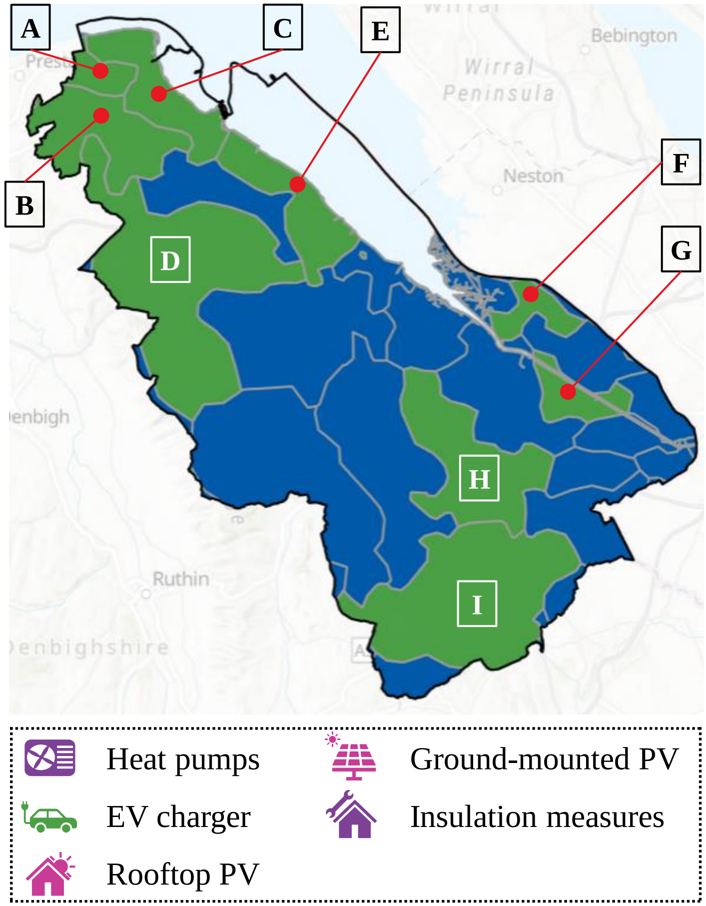


Figure 5.1.3: Flintshire's spatial representation of opportunities, including 2030 ambition and investment (million £) – in Low and High scenarios. Zone boundaries are the modelling zone boundaries.

To support the transformation of the energy system, pilot projects may be useful. The map (left) highlights areas that could provide a useful focus for these pilots. Figure 5.0.3 identifies zones with particularly favourable conditions for specific energy components, making them ideal locations for pilot studies. The summary tables detail key figures for each zone by 2030: **(i)** pilot ambition, **(ii)** required investment for each pilot and **(iii)** total investment for all deployment in the zone, including all energy components and electricity network infrastructure interventions. Ranges show the minimum and maximum results from each future energy scenario. Note: intervention should still be carried out in 'Progress' zones to transition the local area to Net Zero.

	(i)	(ii)	(iii)
A	**Church lane, Prestatyn**		
Insulation measures	140-300 homes	£1.3-23.1m	£3-24m
B	**Graig Fawr**		
Heat pumps	280-480 kW	£210-360k	£3-28m
C	**Point of Ayr Colliery**		
Heat pumps	570-990 kW	£425-740k	£5-36m
Rooftop PV	1 MW	£1.1m	
D	**Holywell**		
Rooftop PV	1.1 MW	£1.3m	£9-69m

	(i)	(ii)	(iii)
E	**Greenfield**		
Insulation measures	370-1,070 homes	£3.4-63.4m	£19-77m
F	**Shotwick**		
EV charger	1 MW	£865k	£18m
G	**Queensferry**		
EV charger	2 MW	£1.6m	£21-64m
H	**Buckley**		
Ground-mounted PV	75 MW	£32.5m	£67-268m
I	**Caergwrle**		
Ground-mounted PV	2.5 MW	£15.2m	£31-141m

Plan on a page (as seen in main report)

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

Plan on a page

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

Figure 0.4 identifies zones with particularly favourable conditions for specific energy components, making them ideal locations for pilot studies. The summary boxes detail the location, opportunity type, potential capacity, required investment for each component, and total investment necessary for both energy component installation and electricity network infrastructure in each zone by 2030. Ranges have been calculated by taking the minimum and maximum results from each future energy scenarios modelled.

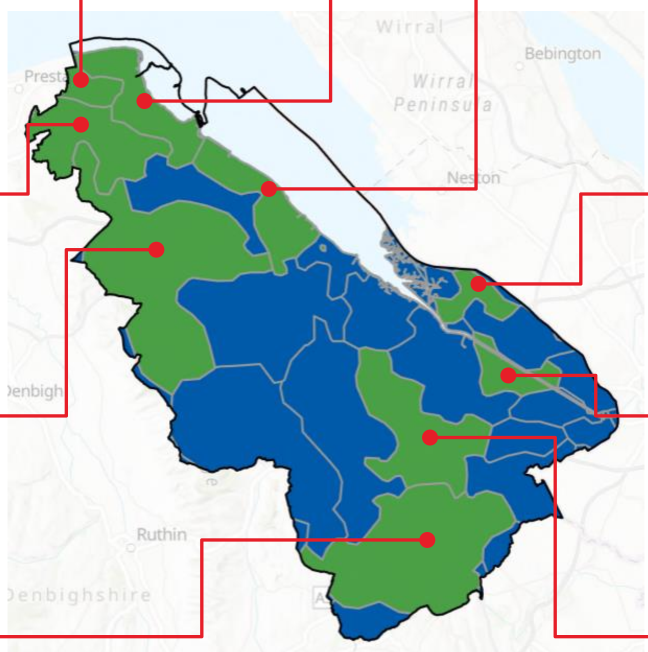
Point of Ayr
Opportunities: Heat pumps | Rooftop PV
Potential: 95-165 units | 1.0MW
Cost: £0.4m-0.7m | £1.1m
Total opportunities cost: £3m-24m

Gronant
Opportunity: Domestic retrofits
Potential: 138-298 homes
Cost: £1.3m-23.1m
Total opportunities cost: £3m-24m

Trelawnyd
Opportunity: Heat pumps
Potential: 47-80 units
Cost: £0.2m-0.4m
Total opportunities cost: £3m-28m

Caerwys
Opportunity: Rooftop PV
Potential: 1.1MW
Cost: £1.3m
Total opportunities cost: £9m-69m

Leeswood
Opportunity: Ground PV
Potential: 35.2MW
Cost: £15.1m
Total opportunities cost: £31m-141m



Greenfield
Opportunity: Domestic retrofits
Potential: 372-1,197 homes
Cost: £3.4m-63.4m
Total opportunities cost: £21m-79m

Shotwick
Opportunity: EV chargers
Potential: 261
Cost: £0.9m
Total opportunities cost: £18m-22m

Queensferry
Opportunity: EV chargers
Potential: 484
Cost: £1.6m
Total opportunities cost: £23m-66m

Buckley
Opportunity: Ground PV
Potential: 75.2MW
Cost: £32.5m
Total opportunities cost: £68m-269m

Figure 5.1.4: Flintshire's spatial representation of opportunities, including 2030 ambition and investment (million £) – in High and Low Demand scenarios. Zone boundaries are defined by primary substation service areas

Sponsors: Delivery partners:

Introduction

National policy indicates a "fabric, worst and low carbon first approach to improve the energy efficiency of the least thermally efficient low-income households in Wales"[T38]. In Flintshire, most homes will need insulation retrofit (discussed here) and heat pump installation (discussed overleaf).

Focus zones for insulation retrofit

We used several factors (Table 5.0.0) to compare each modelling zone's favourability for near-term insulation retrofits. Figure 5.0.4 illustrates the results; the highest-scoring zones are included in Figure 5.0.3 as priority focus areas.

For reference, the zones which are focus zones for heat pump installation (discussed further overleaf) are also highlighted in Figure 5.0.5. 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.

Areas around Prestatyn and Greenfield have been identified as focus zones owing to their higher percentage of domestic properties that fall within areas with a higher index of multiple deprivation. There are approx. 4,900 homes in these substation zones.

Areas, such as Flint, with a higher proportion of properties with EPC A-C ratings are less favourable for insulation retrofits. There are approx. 6,700 homes in this substation zone.

Industrial and commercial zones with few domestic properties are considered less favourable for insulation measures. There are approx. zero homes in this substation zone.

The relative uniformity of focus zone rankings across the county indicates that insulation retrofits need to be considered in most properties.

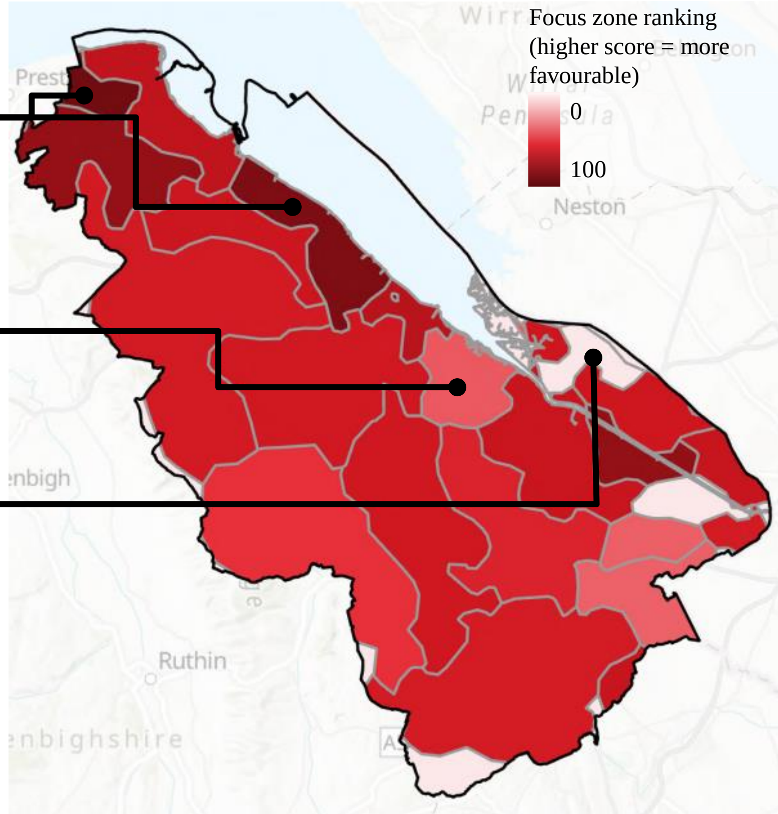


Figure 5.1.5: Focus zone rankings for domestic insulation retrofits by modelling zone

Now: **31,200 homes** rated EPC D or below

By 2030: **Up to 25,000 homes** retrofitted

By 2050: **Up to 61,100 homes** retrofitted

5. Action planning
Scaling zero carbon buildings

Introduction

Focus zones for heat pump retrofit

Electrifying building heat (e.g. via heat pumps) could play a dominant role in decarbonising the buildings sector. We used several factors (Table 5.0.0) to compare each modelling zone's favourability for near-term heat pump retrofits. Figure 5.0.5 illustrates the results; the highest-scoring zones are included in Figure 5.0.3 as priority focus areas.

For comparison, Figure 5.0.6 shows the fraction of homes in Flintshire 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. The most favourable zones for heat pump installations are therefore areas around Caerwys, Nannerch and Trelawnyd in the West and North West. There are approximately 5,700 homes in these substation areas.

For reference, the zones which are focus zones for insulation retrofits, discussed previously, are also highlighted in Figure 5.0.4.

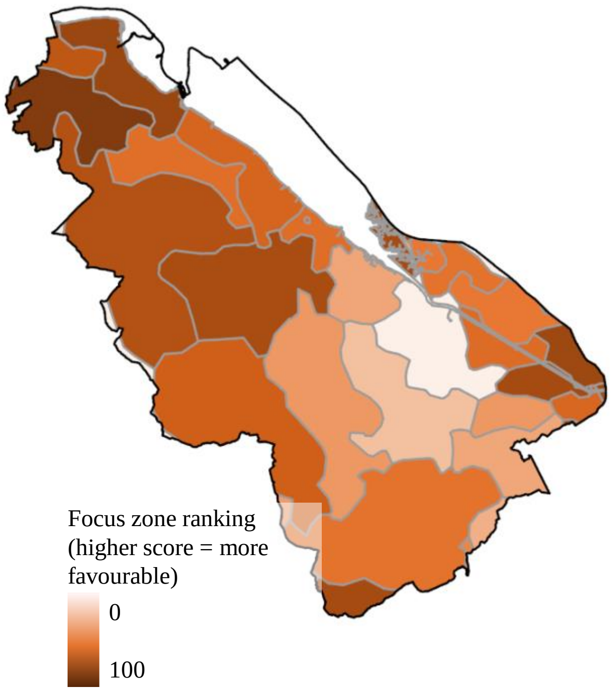


Figure 5.1.6: Focus zone rankings for heat pump installations across Flintshire by modelling zone

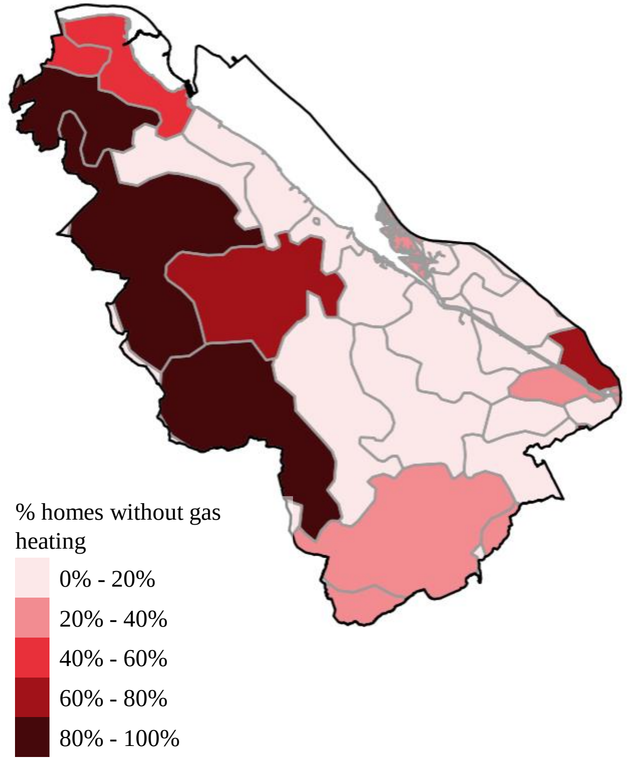


Figure 5.1.7: Baseline fraction of homes without gas heating in Flintshire

Now: **700 buildings** with heat pumps

By 2030: **Up to 14,600 buildings** with heat pumps

By 2050: **Up to 95,300 buildings** with heat pumps

5. Action planning
Scaling zero carbon buildings

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 insulation retrofit varies depending on the package of insulation measures appropriate for each archetype and the desired level of energy efficiency. In the High Demand scenario, the cost of retrofit can vary between £7,200 - £22,200 per household and £49,000 – £147,700 per commercial property. In the Low Demand scenario, the cost of retrofit between £47,250 - £101,500 per property and £89,250 - £381,800 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 heat pumps

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

Funding opportunities

Consider who is going to pay here, for instance, the LA might consider tackling social housing first because of grants, private rented is forced to get a particular EPC, how can we support them. How is the owner occupier supported – UK gov grants for specific income groups/EPCs for retrofit measures and heat pumps.

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

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

Energy system component(s)	Investment (£m) in retrofit and heat electrification between 2023 and 2050
Retrofit (domestic)	£200 – 4,090m
Retrofit (non-domestic)	£125 – 450m
Heat pump	£885 – 1,050m
Heat networks	£370m

Table 5.1.3: Investment costs for the Scaling zero carbon buildings proposition for 2050

5. Action planning
Decarbonising transport

Introduction

The transport proposition for Flintshire covers active travel, public transport, feeds off the transport strategy for Flintshire, EV infrastructure on publicly-owned land. These are the things in the direct control of the Local Authority.

The transport proposition for Flintshire prioritises a reduction in car use as much as is possible through improved provision of active travel routes and public transport. Flintshire is a mix of large towns and some more sparsely populated areas, which means that private car usage 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.

Sponsors:

Delivery partners:

5. Action planning
Decarbonising transport

Focus zones for EV chargers

EV chargers will be required across the local authority, with a fairly constant level of favourability across the county.

Areas with higher demand headroom, such as Deeside industrial estate and Shotwick, have been highlighted as more favourable.

Deeside has been flagged as a less favourable zone due to low levels of demand headroom and lower grading against the Welsh Index of Multiple Deprivation

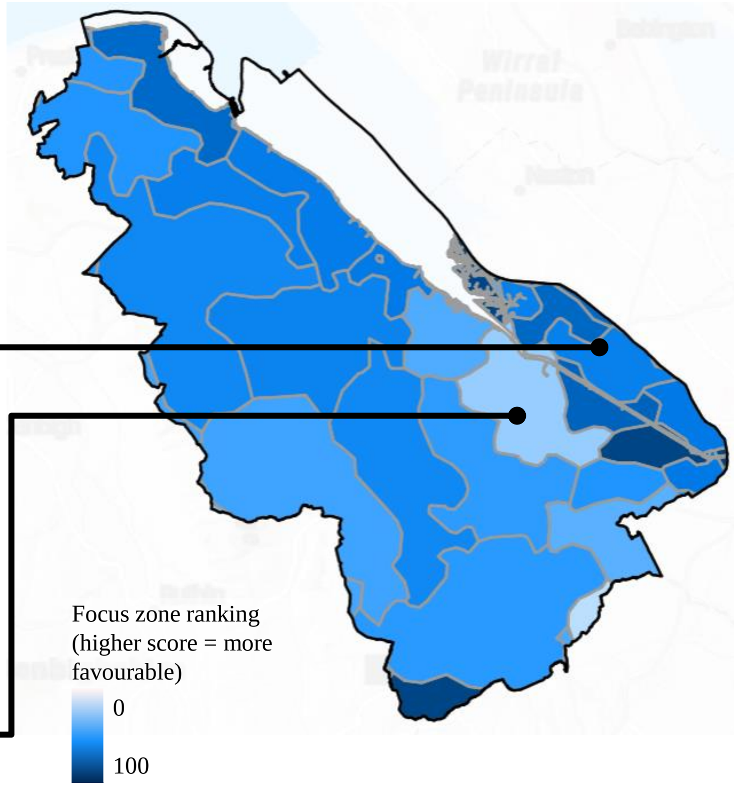


Figure 5.1.8: Focus zone rankings for EV chargers by modelling zone

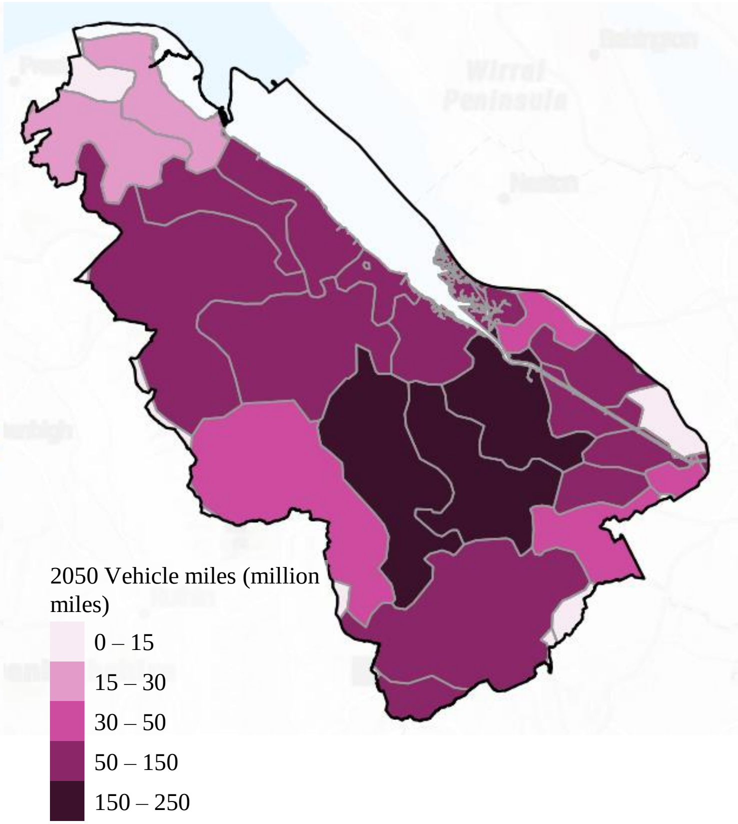


Figure 5.1.9: Future car mileage in 2050 by substation zone

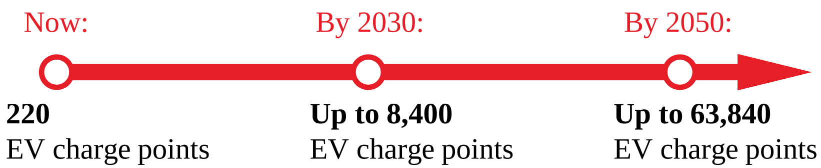
EV charging infrastructure

Predicted EV charge point deployment from Wales' EV Charging Strategy[T44] is that by 2030, there are over 50,000 EV chargers in Flintshire, of which:

- 0.5% are rapid (43kW)
- 7.1% are fast (14.5kW)
- 92.4% are slow chargers (3kW)

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

Our modelling indicates that by 2030, up to 8,400 chargers will need to be deployed to meet future transport demand (shown in Figure 5.0.7).



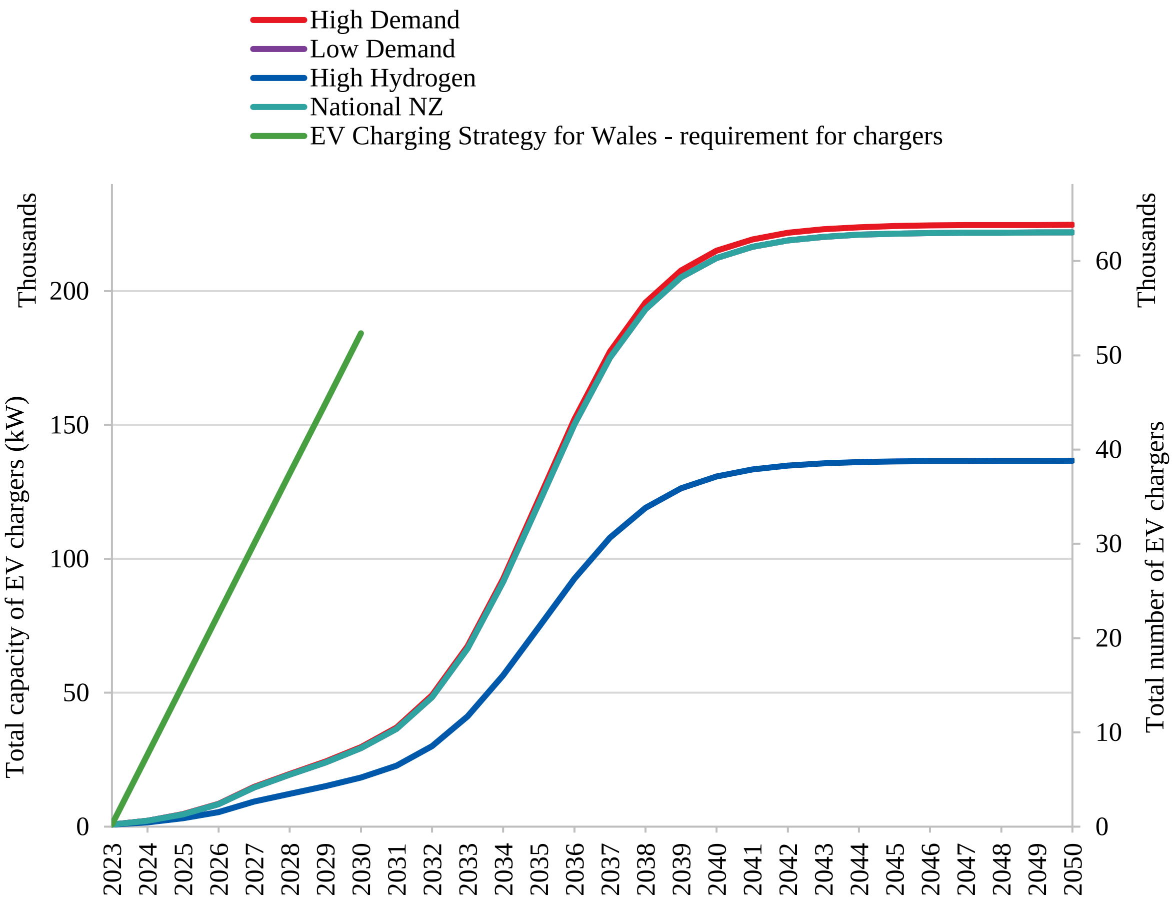


Figure 5.1.10: Capacity and EV chargepoint deployment over time

5. Action planning
Decarbonising 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 (Table 5.0.0) to compare each modelling zone's favourability for near-term installation of EV chargers. Figure 5.0.8 illustrates the results; the highest-scoring zones are included in Figure 5.0.3 as priority focus areas.

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

The maps shown in Figure 5.0.8 and 5.0.9 (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.

Investment requirements

The investment required for EV chargers could be about £290m 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 comp onent(s)	Investment (£m) in retrofit and heat electrification between 2023 and 2050
EV chargers	£140 - 290m

Table 5.1.4: Investment costs for the Decarbonising transport proposition for 2050

5. Action planning

Increasing local renewable generation

Focus zones for local electricity generation

To support Flintshire in getting to net zero, renewables are shown in the scenario analysis to reach the maximum in every model run for this Local Authority.

In the future, the maximum theoretical amount of wind energy isn't expected to be any different to the baseline due to constraints from land use, protected areas and flight paths. We have overlaid this map with the generation headroom, renewables should be prioritised where there is generation headroom in the short-term. Where there is no capacity in the grid for renewables, see the energy networks proposition.

Whilst we recognise this scale of build out to be ambitious, we suggest that the shaded orange areas on the map would be priority locations for the development of solar PV infrastructure.

We suggest that the shaded blue areas on the map would be the possible areas for the development of solar and wind infrastructure. However, in our modelling we have favoured solar PV in these locations due to the lower capital costs.

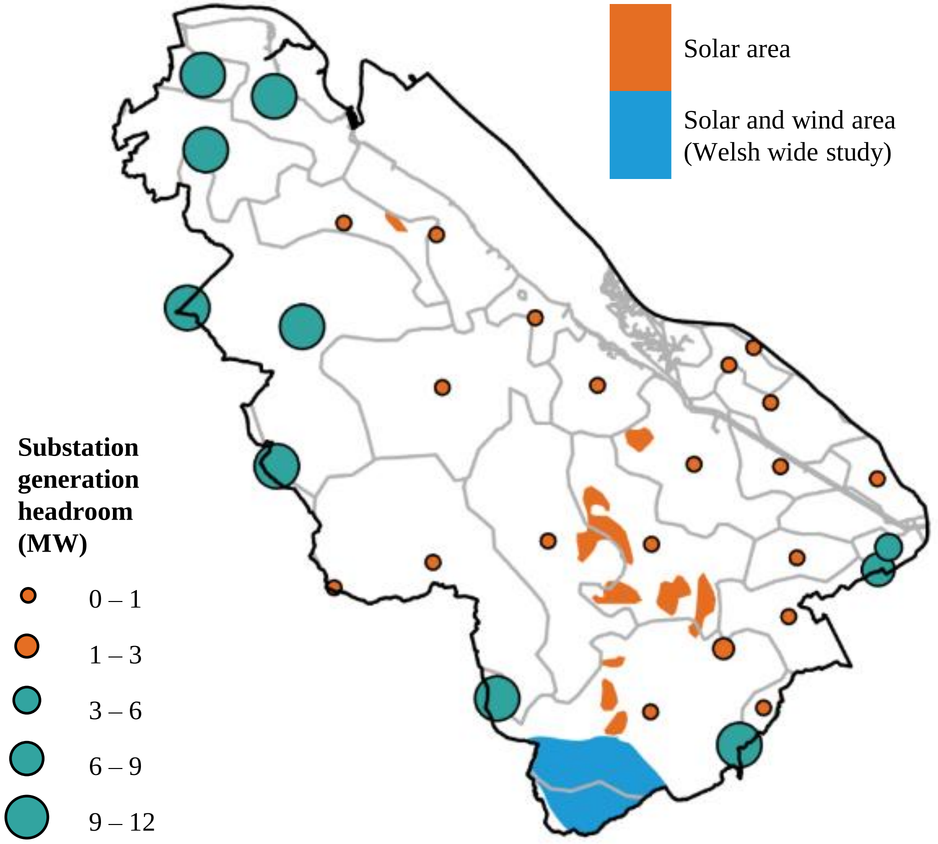


Figure 5.1.11: Areas suitable for wind and ground-mounted solar PV development in Flintshire and substation generation headroom (MW)

5. Action planning
Increasing local renewable generation

Focus zones for local electricity generation

Areas in the Northwest of Flintshire have been highlighted as more favourable locations for rooftop solar panel installations due to the higher generation headroom available.

Buckley has been highlighted as a more favourable location for ground-mounted solar PV based on results from renewable energy assessments, substation upgrades will be required, however.

No additional onshore wind generation is suggested for Flintshire.

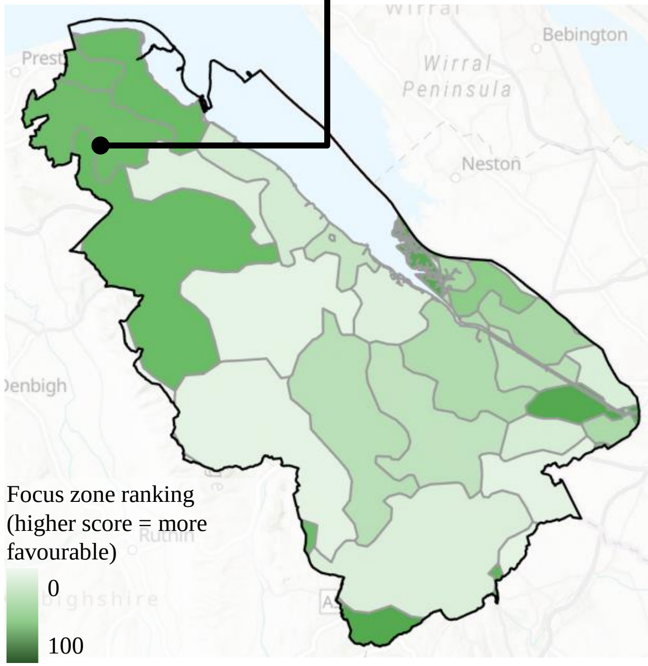


Figure 5.1.12: Focus zone rankings for rooftop solar PV by modelling zone

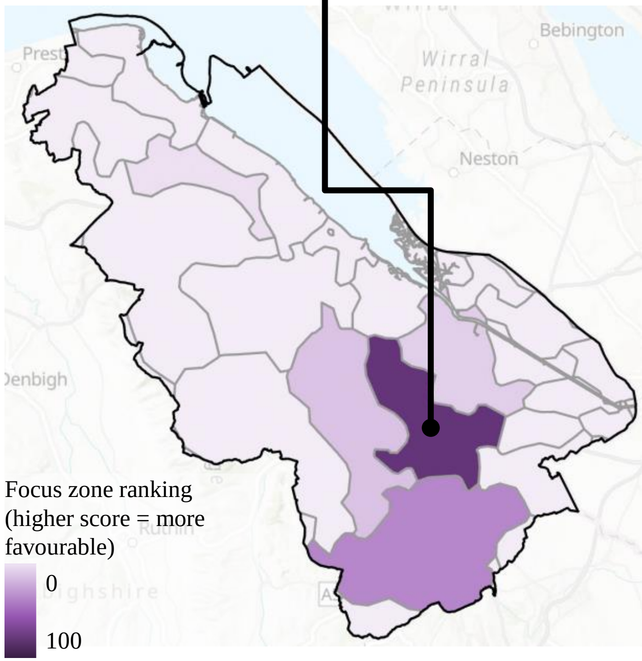


Figure 5.1.13: Focus zone rankings for ground-mounted solar PV by modelling zone

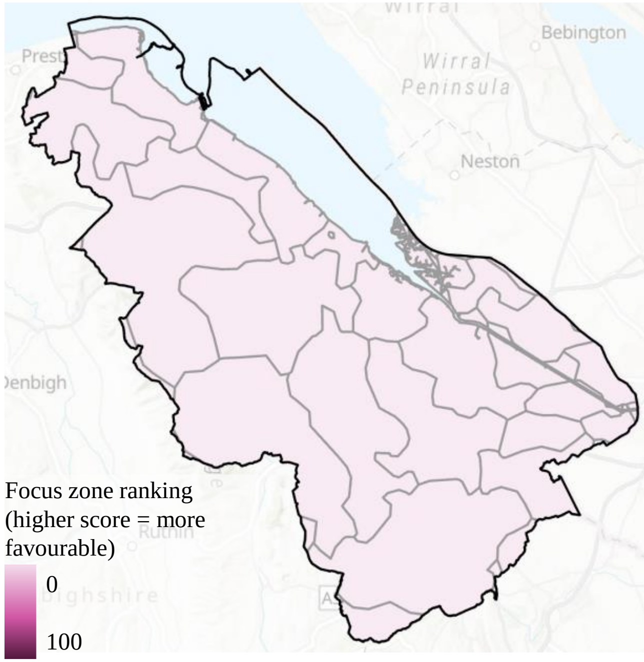


Figure 5.1.14: Focus zone rankings for onshore wind by modelling zone

Focus zones for local electricity generation

Figure 5.1.15 shows all electricity generation projects in the pipeline. There are plans to develop large scale solar PV and battery projects in the Queensferry area, with a smaller such project also in the pipeline for the Saltney area. 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 rooftop solar, ground-mounted solar and onshore wind. These are shown in Figure 5.1.4.

Energy system component(s)	Investment (£m) in renewables between 2023 and 2050
Rooftop solar PV	£425m
Ground-mounted solar PV	£240m
Onshore wind	£0m

Table 5.1.5: Investment costs for the Decarbonising transport proposition for 2050

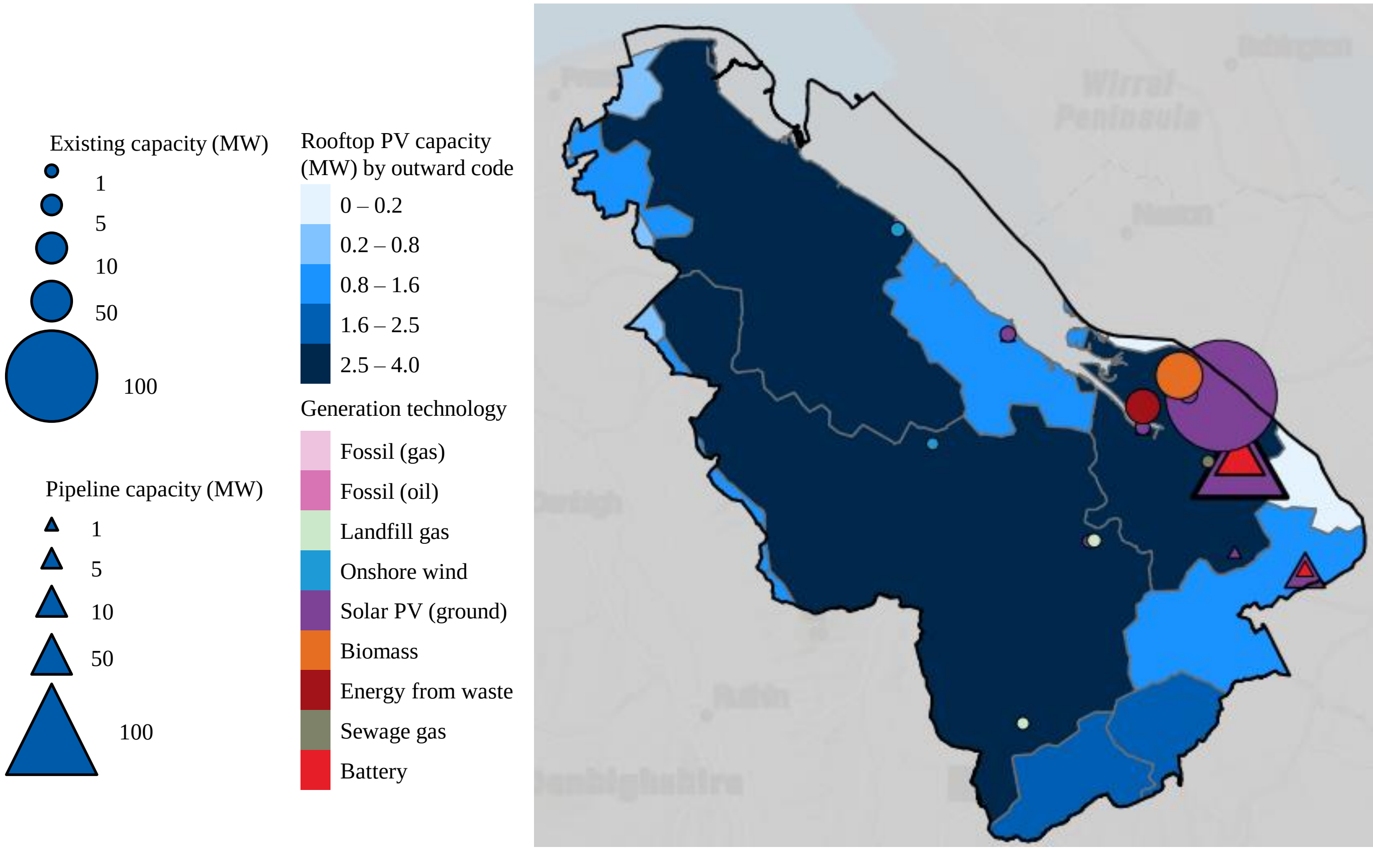


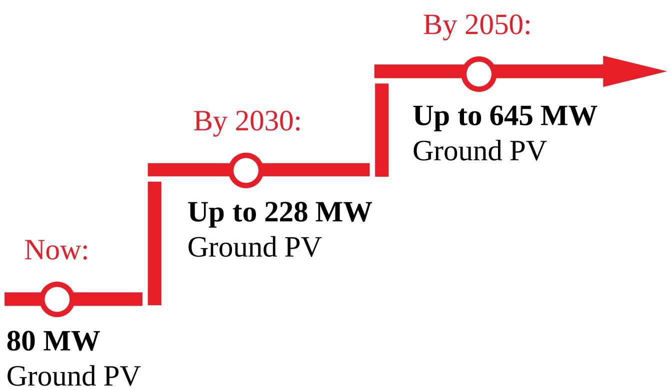
Figure 5.1.15: Electricity generation projects in the pipeline and baseline rooftop solar PV by outward code, investment requirements for priority focus zones for onshore wind and ground-mounted solar PV

5. Action planning
Increasing local renewable generation

Introduction

All scenarios show a shift to electrified heating and transport, which could increase the need to harness renewable electricity sources to meet increasing electricity demand. Figure 5.1.10 shows the range of possible deployment of ground-mounted solar and onshore wind across the scenarios in Flintshire.

Flintshire's Renewable Energy Assessment (2019)[x] was used to understand the amount of land suitable for ground-mounted solar PV and onshore wind. All scenarios indicated an additional 538 MW of ground-mounted solar PV would be needed to meet future energy demand. This maximises the theoretical potential for ground-mounted solar PV in Flintshire.



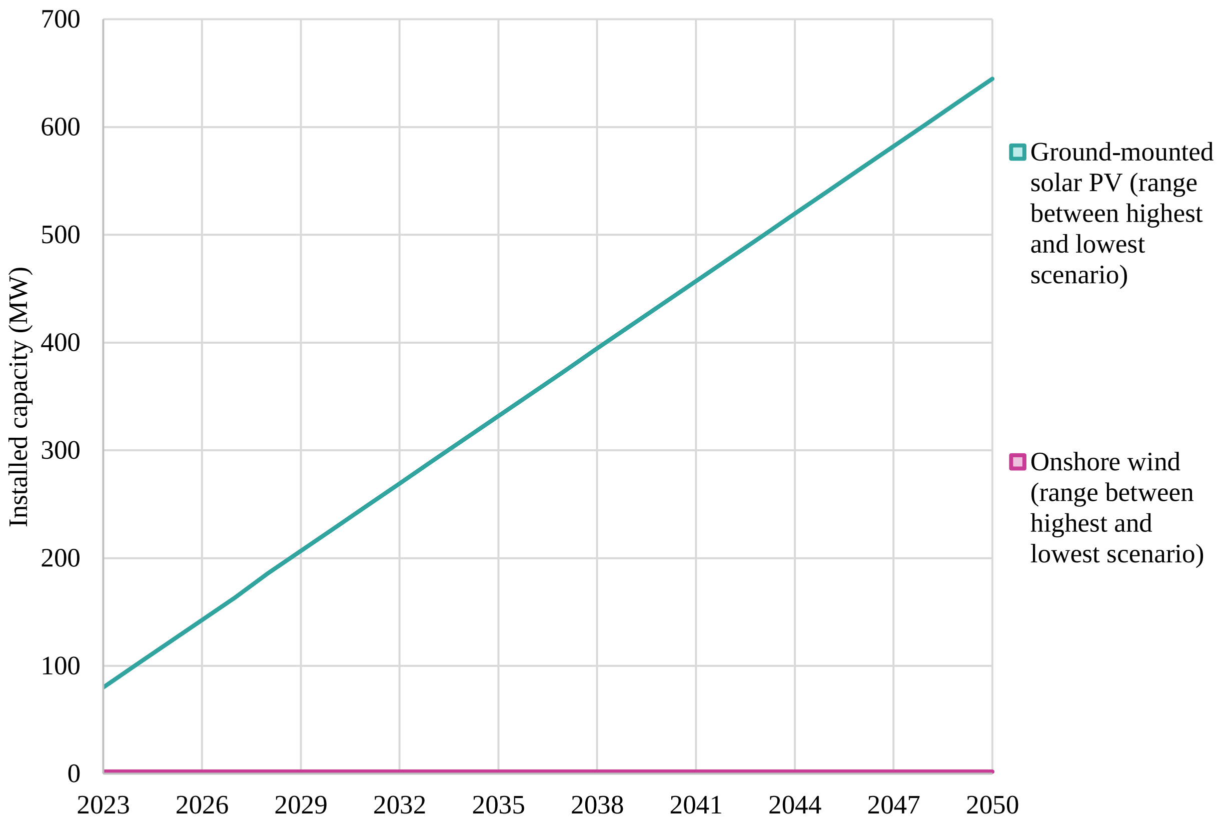


Figure 5.1.16: Summary of scale of renewables deployment across scenarios

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 ED3 will commence in 2028; the exact time period hasn't been announced yet.
- For gas networks: GD2 runs from 2021 to 2026. It was considered whether to extend GD2 to align the two networks. However, it's been announced that GD3 will start in 2026 for a "medium term ex-ante" period. Consideration is being given to the length of GD3.
- Outside of these cycles, a strategic reopener can be submitted to Ofgem to determine if there is sufficient evidence to make a case for additional investments beyond the business plans.

SPEN undertakes an annual modelling, planning and reporting process called Distribution Future Energy Scenarios (DFES) to support business planning, shown in Figure 5.1.15. WWU similarly uses historical data and modelling tools such as Pathfinder to forecast expected demands, resilience and storage needs, and general system operation. While these forecasting tools each incorporate some amount of input from the other network type (for example, DFES considers different options for heat pumps vs hydrogen for heating), they don't typically actively interlink and cross-communicate throughout the analysis processes. Therefore, the whole systems modelling undertaken within the LAEP process can be used as evidence to make strategic changes to the networks.

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

The gas network provides natural gas to 82% of homes in Flintshire. Policy context for hydrogen shifted on 14th December 2023 with a decision to allow blending of 20% hydrogen into the network which will reduce the carbon emissions from the gas network by 7%, however this isn't a zero-carbon solution.

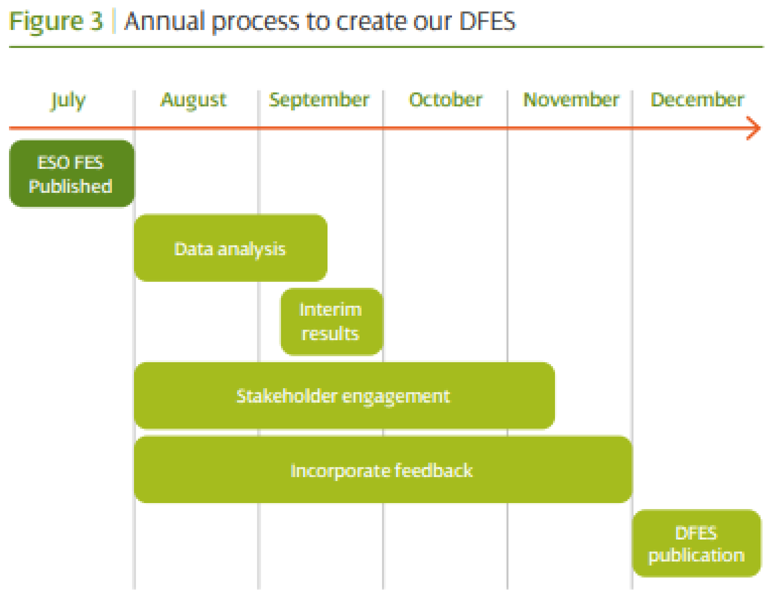


Figure 5.1.17: SPEN's annual DFES process (credit: SPEN)

5. Action planning
Reinforce and transition energy networks

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

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 5.1.16 shows areas where substation upgrades are needed if the rest of LAEP is carried out.

The substation upgrade areas, are those that should be prioritised for investment from the electricity network, considered for hydrogen or 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 28. This equates to a total of 545MW additional capacity.

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

The cost of this is over £3m per year between the baseline and 2050. In total, this amounts to approximately £1,250 per home (in the high demand scenario).

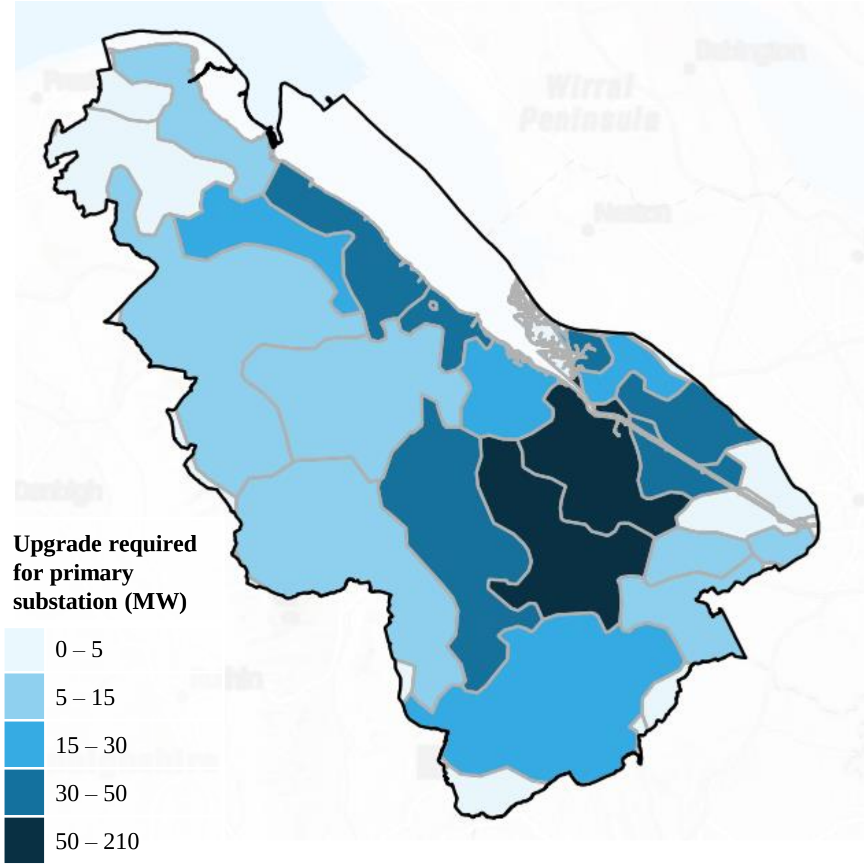


Figure 5.1.18: Map showing where substation interventions will be required by 2050 if the rest of the plan is followed

5. Action planning
Reinforce and transition energy networks

Network transition planning

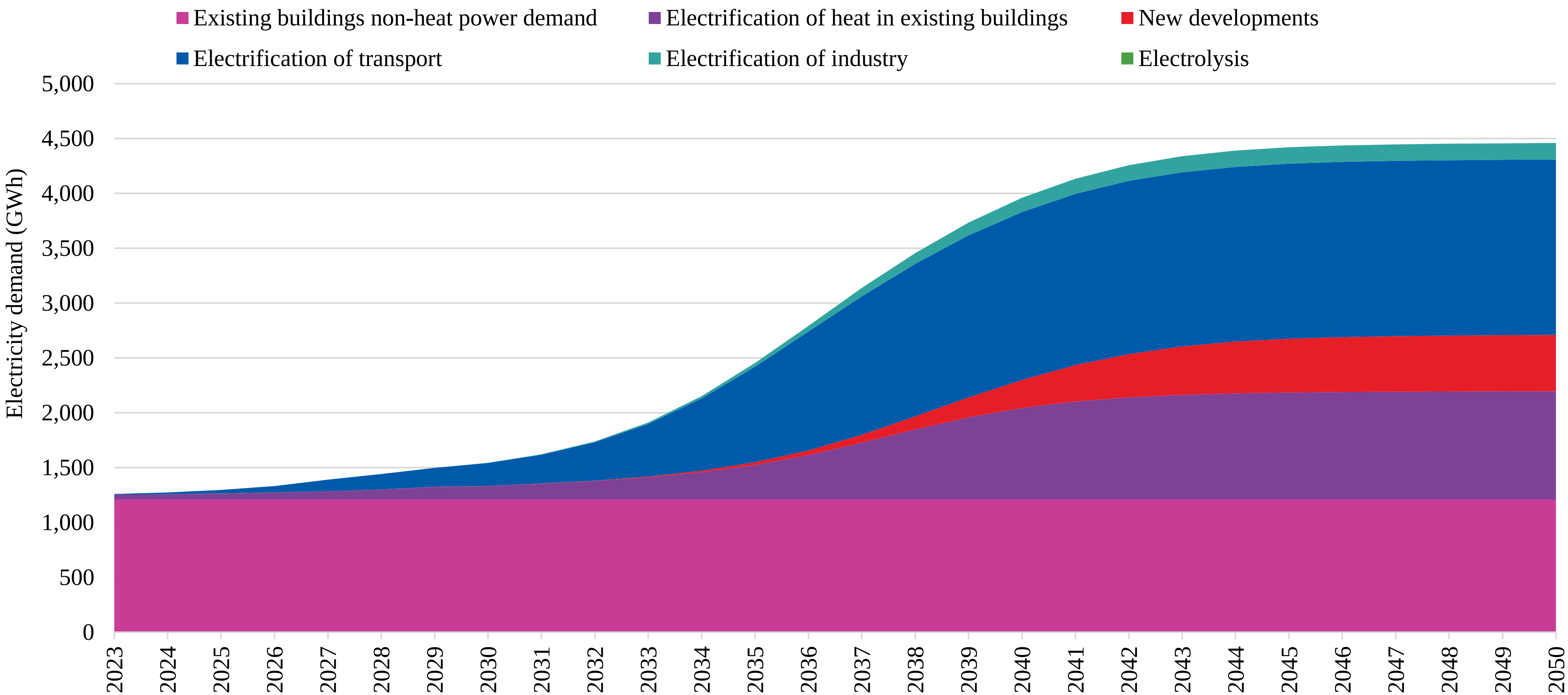


Figure 5.1.19: Projected change in electricity demand by end use between 2023 and 2050 in the High Demand scenario

5. Action planning
Reinforce and transition 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 Flintshire this is 66.57% complete.

Our modelling has shown a demand of up to 220GWh/year for hydrogen in the future from industry and up to 710GWh/year for transportation. These numbers need additional verification with the industry within Flintshire

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 LA is already underway with pilot projects.

The model shows the hydrogen required for industry and transportation is produced via electrolysis could be 0.04MW, supporting far less than 1% if the UK ambition of 10GW[T51] of low carbon hydrogen production by 2030. Hydrogen is currently localised in the model, which means it is used at the point of production, or imported into the system from a national asset.

The investment needed for hydrogen in Flintshire is £107m between now and 2050, mainly for hydrogen refuellers.

5. Action planning
Reinforce and transition 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, the majority of scenarios use the electricity grid as storage, choosing to export when there is excess renewable energy in the system and to import when there is a deficit of renewable energy in the system. Especially since neighbouring local authorities which opt for weather-dependent renewables (e.g. PV and wind) are likely to be generating (and thus exporting) renewable energy at similar times, there is a need for national asset level storage to provide flexibility and resilience in the energy system. This could come in many forms, including batteries, hydrogen storage with CCGT and CCUS, 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 3,130GWh/year of electricity imported in the high demand scenario, this equates to £188million/year.

5. Action planning
Reinforce and transition energy networks

Network transition planning

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

Smart local energy systems

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

Areas to focus on would be those which need substation interventions (see Figure 5.0.16), 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 as a means to avoid reinforcing the electricity network (thus reducing the cost of network upgrades) has nuanced impacts on the reliability and safety of the network which should be carefully considered by each community before implementing this approach.

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

Sponsors:

Delivery partners:

Technical report

Appendices

Appendices
Section A

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.1	1.2
Description	Develop and implement programme of support for off-gas grid homes	Develop programme for retrofit of Council owned buildings
Lead	FCC	FCC
Timescale	2024-2030	2024-2026
Benefits	Reduced emissions from domestic sector, less reliance on fuels with fluctuating prices	Safe, healthy, low carbon homes for those who most need them. Clear plan for needs, investment, and capital across the local authority.
Investment	Staff resources required from planning team	Staff resources required from planning team
Contributing stakeholders	Flintshire County Council	Flintshire County Council

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.3	1.4
Description	Promote rollout of EPCs to all Flintshire residents	Complete existing ECO4 and ORP 2 and 3 funding programmes
Lead	FCC	FCC
Timescale	2024-2026	2024-2025
Benefits	Greater awareness of energy performance of Flintshire's domestic stock, and potential for carbon reduction measures	
Investment	Unknown	
Contributing stakeholders	Local EPC contractors, the public, property owners	

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.5	1.6
Description	Upskill Council planning and regeneration team staff on retrofit of 'heritage' buildings, and novel technologies (e.g. heat pumps and charging hubs)	Develop emissions standards for operation and construction of Council new builds and retrofits
Lead	FCC	FCC
Timescale	2024-2025	2024-2025
Benefits	Greater in-house knowledge for hard to decarbonise areas of the domestic stock	Low energy, low carbon, safe and warm homes for residents, and council staff
Investment	Cost of training	
Contributing stakeholders	Training providers	External advisors

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.7	1.8 (linked to regional action B.1.8)
Description	Explore opportunities to engage with the supply chain to ensure they are adequately aware of the scale of change required for domestic retrofit	Apply lessons learnt from Optimised Retrofit Programme to retrofitting the privately rented and owner-occupied sectors through Welsh Zero Carbon Hwb.
Lead	FCC	Welsh Government
Timescale	2024-2026	2024 - 2030
Benefits	Lower cost and faster build out of decarbonisation and retrofit measures	
Investment		
Contributing stakeholders	Supply chain: producers, sellers, installers of decarbonisation retrofit measures	Welsh Zero Carbon Hwb

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.9 (linked to regional action B.2.1)	1.10 (linked to regional action R.1.4)
Description	Using the learning from other information hubs to develop an information service that provides a trusted source of retrofit and energy efficiency information for consumers. Explore the potential of establishing an advice hub to support regional decarbonisation / low carbon energy initiatives.	Work with Community Interest Companies (CIC) to provide a regional service of wrap around support for residents covering education, behaviour change, energy advice and support.
Lead	Welsh Government	Warm Wales
Timescale	2024-2026	2024-2028
Benefits		
Investment		
Contributing stakeholders		Community Interest Companies (CIC)

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.11 (linked to regional action 3A)	1.12 (linked to regional action 3C)
Description	Provide support and incentives for households to install energy efficiency measures and low-carbon heating systems, ensuring such support is targeted at those in fuel poverty and/or in most need.	Ensure PAS 2035 surveys and a clear plan for retrofit measures are prepared for individual social homes, in accordance with the Welsh Housing Quality Standard (WHQS)[M20].
Lead	RSLs	FCC and RSLs
Timescale	2024-2030	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.13 (linked to regional action 3D)	1.14 (linked to regional action 3C)
Description	Review current support provision to tenants and landlords in the private-rented sector to ensure minimum energy efficiency standards are met. Review enforcement provisions to ensure minimum statutory standards within the sector are achieved.	Explore development of support mechanisms for small to medium-sized enterprises (SMEs) to encourage uptake of energy efficiency improvements to commercial buildings.
Lead	Welsh Government	Business Wales / M-Sparc; North Wales Mersey Dee Business Council
Timescale	2024-2026	2024-2030
Benefits		
Investment		
Contributing stakeholders	Local Authorities	

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.15 (linked to regional action B.1.7)	1.16 (linked to regional action B.5.1 and 3E)
Description	Work with local authorities and regional bodies to determine an approach to coordinated, street-by-street approach to retrofit and the mechanisms for delivery (e.g. governance, resource, finance, policy). Co-ordinate a retrofit plan for all housing tenures which expands on the Optimised Retrofit Programme.	Identify specific local planning constraints (e.g. permitted developments i.e. 3 metre rule for heat pumps, permissive planning for listed buildings, new build regulations) limiting progress to net zero and delivering the LAEPs and work with Welsh Government to resolve these.
Lead	Welsh Government	Welsh Government and Local Authorities
Timescale	2024-2030	2024-2030
Benefits		
Investment		
Contributing stakeholders	Local Authorities, regional bodies	

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Scaling zero carbon buildings

	1.17 (linked to regional action B.5.2)	1.18 (linked to regional action B.1.2 and 3B)
Description	Consider tighter building regulations to support delivery of net zero ready buildings including a consultation on Part L regulations in 2024	Develop and agree an approach and delivery plan for tackling owner-occupied retrofit. Review existing and explore new potential financial mechanisms to support owner-occupiers and building owners seeking to undertake energy efficiency retrofit works.
Lead	Welsh Government	Welsh Government
Timescale	2024-2026	2024-2026
Benefits		
Investment		
Contributing stakeholders	Local Authorities, regional bodies	

Scaling zero carbon buildings

1.19 (linked to regional action E.4.1)

Description	Identify procurement frameworks for renewable technologies which consider local and ethical sourcing of goods and services. Develop national procurement framework, learning from previous ECO 4 roll out and the Optimised Retrofit Programme, to deliver street-by-street retrofit.
Lead	Welsh Government
Timescale	2024-2026
Benefits	
Investment	
Contributing stakeholders	

Appendix A1
Actions and recommendations

Decarbonising transport

	2.1	2.2
Description	Apply pressure to Welsh Government for greater direction for on street EV charging	Explore EV charging technologies for kerbline properties where no off-street options are available FCC
Lead	FCC	2024-2026
Timescale	2024-2025	
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Decarbonising transport

	2.3	2.4
Description	Understand charging facilities potential within town centre regeneration and place making plans, explore SPF and ORCS funding	Ensure commitment to high speed broadband connections for everyone in Flintshire
Lead	FCC	FCC
Timescale	2024-2026	2024-2025
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Decarbonising transport

	2.5	2.6
Description	Lobby for investment in the rail infrastructure to improve service frequency and reduce travel time	Further develop active travel networks and principles, keeping in mind impacts of equalities act FCC
Lead	FCC	2024-2025
Timescale	2024-2026	
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Decarbonising transport

	2.7	2.8
Description	Develop plans for last mile sustainable mobility requirements within the scope of new and improved stations in the North Wales metro programme	Provide public finance options and national standards for EV charging infrastructure.
Lead	FCC	FCC
Timescale	2024-2026	2024-2026
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Decarbonising transport

	2.9	2.10 (linked to regional action 4C)
Description	Release pilot EV charge point locator and costing tool for EV charge points.	Collaborate on opportunities to decarbonise the public sector fleet, public service vehicles, and commercial and industrial fleets and the co-ordination of associated infrastructure design and development across local authority boundaries.
Lead	FCC	ANW and WGES
Timescale	2024-2026	2024-2030
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Decarbonising transport

	2.11 (linked to regional action 4D)	2.12 (linked to regional action 4F)
Description	Work together to deliver the most appropriate electric vehicle public charging infrastructure across the region, aligning with national work being undertaken through Transport for Wales.	Support greater awareness raising of UK Government funding for development of electric vehicle charging infrastructure such as the on-street residential charging scheme.
Lead	ANW; North Wales Corporate Joint Committee; TfW; SPEN	ANW
Timescale	2024-2026	2024-2028
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Decarbonising transport

	2.13 (linked to regional action 4G)	2.14 (linked to regional action R4.1)
Description	Continue to support organisations such as local community car clubs to deliver community-oriented, low-carbon transport infrastructure and services.	Establish a Regional Transport Officer's Group that provides a forum for collaboration and alignment between local and national government in addition to Transport for Wales.
Lead	ANW; WGES	North Wales Corporate Joint Committee
Timescale	2024-2030	2024-2026
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Decarbonising transport

	2.15 (linked to regional action R4.2)	2.16 (linked to regional action R4.3)
Description	Explore opportunities around bus franchising across the region.	Produce the first Regional Transport Plan (RTP) in line with that Welsh Government statutory guidance.
Lead	ANW	ANW
Timescale	2024-2026	2024-2025
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Decarbonising transport

2.17 (linked to regional action T.2.4)

Description	Develop a national procurement framework for EV infrastructure
Lead	Welsh Government
Timescale	2024
Benefits	
Investment	
Contributing Stakeholders	

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.1	3.2
Description	Promote community energy schemes	Continue to rollout renewables in line with REAs, land assessments and constraints mapping
Lead	FCC	FCC
Timescale	2024-2025	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.3	3.4
Description	Facilitate rooftop solar PV uptake in owner-occupied dwellings through knowledge sharing and signposting	Understand local potential for solar carports
Lead	FCC	FCC
Timescale	2024-2027	2024-2026
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.5	3.6
Description	Support SMEs with rooftop solar installation for reducing energy costs	Further explore possibilities for geothermal energy generation within old coal fields, this can build on the work that has been undertaken by the Coal Authority.
Lead	FCC	FCC
Timescale	2024-2027	2024-2027
Benefits		
Investment		
Contributing stakeholders		The Coal Authority

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.7 (linked to regional action G)	3.8 (linked to regional action 2A)
Description	Explore the development of an investment prospectus for renewable developments currently in the pipeline.	Engage with Welsh Government to identify and build on opportunities that Ynni Cymru could provide to North Wales.
Lead	ANW	Ynni Cyrmu and ANW
Timescale	2024-2025	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.9 (linked to regional action 2B)	3.10 (linked to regional action 2D)
Description	Explore how to improve communication of available funding sources for the development and delivery of a range of low-carbon power generation projects (e.g. onshore and offshore wind, solar PV, nuclear, and tidal and marine energy).	Support workstreams in increasing local ownership of energy projects to be delivered in line with proposed guidance on local and shared ownership in Wales.
Lead	ANW	Ynni Cyrmu and ANW
Timescale	2024-2025	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.11 (linked to regional action 2E)	3.12 (linked to regional action 2F)
Description	Explore the potential of establishing an advice hub to support regional decarbonisation / low carbon energy initiatives.	Maximise opportunities for public procurement to support the acceleration of renewable energy generation and secure local economic and social value. Ensure that public procurement strengthens local supply chains / local jobs (social value). Ask the supply chain to deliver against public sector carbon ambitions through procurement frameworks.
Lead	ANW	ANW
Timescale	2024-2026	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.13 (linked to regional action 2G)	3.14 (linked to regional action R2.1)
Description	Maximise opportunities for community benefits funds from energy infrastructure projects (on the distribution network) to support local and regional decarbonisation initiatives, recognising the need to target those communities and areas most impacted by such developments.	Explore the opportunities that Power Purchasing Agreements could provide to energy generation across the region.
Lead	ANW	ANW
Timescale	2024-2030	2024-2026
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Increasing local renewable generation

	3.15 (linked to regional action R2.2)	3.16 (linked to regional action RN.4.1)
Description	Continue to explore the opportunities presented by solar canopies in car parking spaces and the enablers to scale the technology across the region.	Identify and explore opportunities for the development of renewables on public sector owned land.
Lead	ANW and WGES	Welsh Government and Trydan Gwyrdd Cymru
Timescale	2024-2027	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Supporting green business

	4.1	4.2
Description	Promote work undertaken by AMRC where appropriate	Continue to support Deeside Decarbonisation Forum and signpost funding opportunities
Lead	FCC	FCC
Timescale	2024-2026	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Supporting green business

	4.3	4.4
Description	Understand potential for redevelopment plan of Mostyn dock, undertake opportunities mapping	Understand how sustainability can be worked in to Flintshire's digital strategy and potential for data supported decarbonisation
Lead	FCC	FCC
Timescale	2024-2026	2024-2025
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Supporting green business

	4.5	4.6
Description	Look to undertake heat mapping exercise and understand heat network potential	Support SMEs to develop plans to decarbonise and signpost to funding opportunities
Lead	FCC	FCC
Timescale	2024-2026	2024-2030
Benefits		
Investment		
Contributing stakeholders		

Appendix A1
Actions and recommendations

Supporting green business

	4.7
Description	Continue to support town centre place making investment and signpost funding opportunities available to businesses and social enterprises
Lead	FCC
Timescale	2024-2030
Benefits	
Investment	
Contributing stakeholders	

Appendix A1
Actions and recommendations

Maturing hydrogen in industry

	5.1	5.2
Description	Plan for and be aware of upcoming hydrogen project funding opportunities	Develop local strategy to understand local need, requirements, challenges, and opportunities for hydrogen
Lead	FCC	FCC
Timescale	2024-2026	2024-2026
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Maturing hydrogen in industry

	5.3	5.4 (linked to regional action E)
Description	Look to support research into hydrogen co-challenges for local businesses	Support the emerging hydrogen economy, taking account of proposed hydrogen projects across the region.
Lead	FCC	ANW
Timescale	2024-2027	2024-2030
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Maturing hydrogen in industry

	5.5 (linked to regional action N.4.4)	5.6
Description	Publish a Welsh Government carbon intensity standard for hydrogen production based on that of UK Government. This standard can be used as a basis for future permitting by Natural Resources Wales.	Publish findings from North Wales Conceptual Plan for hydrogen infrastructure.
Lead	Welsh Government and NRW	WWU
Timescale	2024-2025	2024-2025
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Maturing hydrogen in industry

	5.7 (linked to regional action N.3.5)	5.8 (linked to regional action N.4.4)
Description	Make the network hydrogen ready. Deliver programme to convert remainder of gas network not covered by the REPEX programme to enable a 100% hydrogen conversion, WWUs sustainability strategy from 2023 identifies a desire to complete this between 2035-2040.	Develop hydrogen and bio-methane projects.
Lead	WWU	WWU
Timescale	2024-2040	2024-2050
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Maturing hydrogen in industry

5.9 (linked to regional action N.4.5)

Description	Develop a more detailed understanding of potential hydrogen transport demand and incorporate this demand within existing network demands. This action will be supported by WWU's innovation project HyDrive.
Lead	WWU
Timescale	2024-2025
Benefits	
Investment	
Contributing Stakeholders	

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.1 (linked to regional action N.1.2)	6.2 (linked to regional action N.2.2 and N.3.3)
Description	Hold regular engagement meetings between Flintshire County Council, SPEN and WWU	FCC and SPEN to work collaboratively to understand future demands (electricity) and use this to influence ED3 Planning and investment from OFGEM.
Lead	SPEN, WWU	FCC, SPEN
Timescale	2024-2030 (on an ongoing basis)	2024-2026
Benefits		
Investment		
Contributing Stakeholders	Flintshire County Council	

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.3 (linked to regional action N.2.1)	6.4 (linked to regional action N.2.3)
Description	Inform local authorities about available data resources by providing access to the DFES report and the resulting NDP (Network Development Plan) via SPEN's Open Data Portal as well as other datasets such as heat maps, network infrastructure & usage. Requests for additional, bespoke reports can also be made via the portal.	Use all relevant outputs from the LAEPs to inform SPEN's DFES (Distribution Future Energy Scenario) Report, in turn SPEN will share the trends and highlights from the DFES with individual LAs.
Lead	SPEN	SPEN
Timescale	2024-2030	2024-2025
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.5 (linked to regional action N.2.4)	6.6 (linked to regional action N.2.5)
Description	Provide low carbon technology (LCT) optioneering services to Local Authorities to support them with site optioneering (cost and timescale) for EV charging, heat pump rollout and renewable generation infrastructure planning.	Co-ordinate Net Zero clinics for Local Authorities to discuss decarbonisation of heat, transport and renewables strategies, and willingly contribute to workshops organised by the Local Authorities for local small-medium enterprises (SMEs).
Lead	SPEN	SPEN and WWU
Timescale	2027-2029	2024-2030 (on an ongoing basis)
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.7 (linked to regional action N.2.6)	6.8 (linked to regional action N.1.3)
Description	Discuss and agree any strategic optimisation opportunities with each Local Authority to continue progressing decarbonisation and economic growth plans.	Plan a method to consolidate the pipelines for all energy-related projects across the electricity and gas/hydrogen networks. This will consolidate all actions planned by electricity and gas/hydrogen networks within an area into one common database. As a starting point, set up ongoing engagement meetings with DataMapWales, NGED SPEN, and WWU to coordinate if and how DataMap Wales may be an appropriate platform to consolidate this information.
Lead	SPEN and WWU	SPEN and WWU
Timescale	2024-2030 (on an ongoing basis)	2024-2030 (on an ongoing basis)
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.9 (linked to regional action N.3.1)	6.10 (linked to regional action N.3.2)
Description	Highlight gas infrastructure opportunities. Support Local Authorities in exploring new opportunities to develop the existing gas networks in advance of 100% transition to existing hydrogen network.	Include new projects from the LAEP in strategic planning process.
Lead	WWU	WWU
Timescale	2024-2030 (on an ongoing basis)	2024-2027
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.11 (linked to regional action N.3.4)	6.12
Description	Share LAEP outputs on DataMapWales, plan how to keep this data up to date and relevant	Raise awareness of SPEN's Flexibility Service procurement to support a smarter system.
Lead	Welsh Government	SPEN
Timescale	2024-2025	2024-2025
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.13 (linked to regional action N.2.7)	6.14
Description	SPEN is already looking at industrial decarbonisation through their partnership in the NEW-ID (North East Wales Industrial Decarbonisation) Project. Any opportunities/benefits identified as part of work on this project will be shared with the affected Local Authorities, including Flintshire.	Explore opportunities for partnership delivery of district heating and cooling networks, using waste heat sources such as mine water.
Lead	SPEN	WG; Coal Authority; WWU
Timescale	2024-2030	2024-2027
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Reinforce and transition energy networks

	6.15 (linked to regional action 5B)	6.16 (linked to regional action R5.1)
Description	Understand the role that micro-grids and other innovative solutions can play in existing industrial clusters such as those in Deeside and Flintshire.	Explore and recognise opportunities that will be made available from the Flintshire/Wrexham investment zone.
Lead	ANW; DDF	North Wales Corporate Joint Committee; DDF
Timescale	2024-2028	2024-2028
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Enabling actions

	7.1(linked to regional action A)	7.2 (linked to regional action D)
Description	Ensure effective alignment between local, regional and national energy strategies, plans and initiatives.	Provide regional support in the delivery of commitments made in the Climate Action Wales public engagement strategy (July 2023) to help citizens take action to reduce demand, improve energy efficiency and use energy in a way which supports our vision.
Lead	ANW	ANW
Timescale	2024-2030	2024-2030
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Enabling actions

	7.3 (linked to regional action I.1.3 and F)	7.2 (linked to regional action R1.2)
Description	Continue to explore and support opportunities for smart local energy systems in the region. Using outputs from the LAEP, map smart local energy system opportunities and identify feasibility/demonstrator projects through engagement with key stakeholders including community energy groups and general public.	Ensure alignment between the scope and function of the new Regional Energy Strategic Planners (RESPs) with Ofgem's policy design. Consultation of the policy design will be published in the summer of 2024 with the RESPs in operation by late 2025/early 2026
Lead	ANW; Ynni Cymru; WG	WG; Ofgem; National Grid ESO
Timescale	2024-2030	2024-2026
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Enabling actions

	7.5 (linked to regional action R1.2)	7.6 (linked to regional action E3.1 and C)
Description	North Wales Corporate Joint Committee to support the Race to Zero campaign and provide oversight on carbon emissions across the region	Lead on developing the skills requirements identified in the Regional Skills Partnership's (RSP's) Green Skills Report and Welsh Government's Net Zero Skills Action Plan. Map and identify skills and labour needs and gaps up to 2050 for retrofit and low carbon new builds; renewable deployment; decarbonised transport and business / industry decarbonisation.
Lead	North Wales Corporate Joint Committee	RSP; WG
Timescale	2024-2030	2024-2030
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Enabling actions

	7.7 (linked to regional action E3.2)	7.8 (linked to regional action E3.3)
Description	Review and develop educational programmes to meet skills needed	Develop a communication strategy to educate, promote skills, training and the need for a supply chain
Lead	Welsh Government	Welsh Government
Timescale	2024-2030	2024-2030
Benefits		
Investment		
Contributing Stakeholders		

Appendix A1
Actions and recommendations

Enabling actions

	7.9 (linked to regional action R1.5)	7.10 (linked to regional action E2.2)
Description	Work with Welsh Government to create a governance structure and performance management framework for the LAEPs to facilitate monitoring of progress and performance of the LAEPs across the Region.	Using the outputs from the LAEPs and REPs, create a national plan which covers the gaps such as national and regional assets.
Lead	ANW; WGES	Welsh Government
Timescale	2024-2025	2024
Benefits		
Investment		
Contributing Stakeholders		

Sponsors: Delivery partners:

Appendix A1
Actions and recommendations

Enabling actions

	7.11 (linked to regional action R1.3)	7.12 (linked to regional action H)
Description	Develop the first regional Strategic Development Plan (SDP). Include policies in the plan that support low carbon building practices and low carbon new builds.	Strengthen the link between research, development and innovation with regards to current and emerging technology and the Energy Strategy priorities.
Lead	North Wales Corporate Joint Committee	Bangor University / M-Sparc; Wrexham University; ANW
Timescale	2024-2028	2024-2030
Benefits		
Investment		
Contributing Stakeholders		

Appendix A2

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

Sponsors: Delivery partners:

Appendix A2

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
Deployment modelling – National, regional and local policies applied

Local proposed and committed policies	Source
New jobs over the plan period (2015-2030)	Flintshire LDP 2015-2030
Hectares of employment land	Flintshire LDP 2015-2030
New homes over plan period (2015-2030)	Flintshire LDP 2015-2030
New homes in Tier 1 locations (Main Service Centres listed on page 47 of LDP)	Flintshire LDP 2015-2030
New homes in Tier 2 locations (Local Service Centres listed on page 47 of LDP)	Flintshire LDP 2015-2030
New homes in Tier 3 locations (Sustainable Settlements listed on page 47 of LDP)	Flintshire LDP 2015-2030
New homes in Tier 4 locations (Defined Villages listed on page 47 of LDP)	Flintshire LDP 2015-2030
New homes in Tier 5 locations (Undefined Villages listed on page 47 of LDP)	Flintshire LDP 2015-2030
New homes on Northern Gateway Mixed Use Development Site	Flintshire LDP 2015-2030
New hectares of B2/B8 employment land at Warren Hall Development Site	Flintshire LDP 2015-2030
New hectares of B1 and B2 employment land at Warren Hall Development Site	Flintshire LDP 2015-2030
New commercial hub at Warren Hall Development Site	Flintshire LDP 2015-2030
New employment land allocation at Chester Aerospace Park, Broughton	Flintshire LDP 2015-2030

Appendix A3
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.
Certainties	A fact that is definitely true or an event that is definitely going to take place. In terms of a local energy system, certainties include funded projects, etc.
Demand	Local energy demand that the local energy system needs to meet.
Demand headroom	The difference between the electrical capacity of a substation, and the electricity demand at the substation at the time of peak demand.

Appendix A3
Glossary of terms

Term	Definition or meaning
Deployment modelling	A model investigating rates by which to deploy specific technologies between the baseline year and 2050 to achieve the end state developed by the optimisation model for each scenario. The model considers broader plan objectives and local, regional, and national strategic priorities, policies, and targets to help us to define a suitable level of ambition and inform an action plan.
Dispatchable energy generation	Energy generation that can turn on and off (i.e. isn't controlled by the weather) – this is likely to be gas turbines of some sort.
Distribution network	Takes energy from transmission network and delivers it to users via pipes or wires at low pressure / voltages.
Electricity network	Interconnected infrastructure which consists of power stations, electrical substations, distribution lines and transmission lines. The network delivers electricity from the producers to consumers.
Electrolyser	A piece of equipment that uses electricity to split water into hydrogen and oxygen.
Energy Proposition	A proposition is an energy component with a scale and a timescale. For instance, X MW of wind turbine to be built in 5 years, 10,000 buildings to retrofit with XX by 2030, or a pilot project such as hydrogen storage innovation. These are typically near term, low regrets energy components that are needed in future energy systems (it is likely that these appear in all scenarios).
Energy System Component	A term used to describe anything that can have a direct impact on energy demand and/or the way energy is supplied. E.g. installing retrofit measures can reduce overall heating demand, increasing solar PV capacity can change the supply mix and the way that the energy system operates.
Focus zone	A modelling zone which has been identified as an area in which to target near-term installation, upgrade, retrofit, or other activities related to a specific energy system component.
Generation	Local generation – size below 100MW.
Generation headroom	Generation headroom in a local authority's electricity distribution network refers to the remaining primary substation capacity at the time of peak generation, crucial for maintaining a stable and reliable power supply to meet the community's needs
Grid electricity	Electricity that is supplied by the electricity network.

Appendix A3
Glossary of terms

Term	Definition or meaning
Grid substation	The physical equipment comprising a substation with a 132kV-33kV transformer(s) connecting the grid-level, extra high voltage electricity lines to the primary-level, high voltage electricity lines. The grid substation facilitates connection with the national grid.
Heat network	A distribution system of insulated pipes that takes heat from a central source and delivers it to a number of domestic or non-domestic buildings.
Heat pump	A piece of equipment that uses a heat exchange system to take heat from air, ground or water and increases the temperature to heat buildings.
Hydrogen	A flammable gas that can be burned, like natural gas, to generate heat or power vehicles. The by-product is water only, no carbon.
Infrastructure	Local energy distribution infrastructure, includes storage assets if these are at grid level.
Landfill gas	Gases such as methane that are produced by micro-organisms in a landfill site that can be used as a source of energy.
Lever	We use the term policy levers to refer to the 'governing instruments' (Kooiman, 2003) which the state has at its disposal to direct, manage and shape change in public services.
Local energy system	The distribution level energy system, excludes the transmission and national assets.
Longer-term options	The likely outcome of these is less certain and dependent upon actions and decisions being made that are not under our control, e.g. a national policy or the capability / availability of a technology.

Appendix A3
Glossary of terms

Term	Definition or meaning
Major industrial load	The power demand of industrial sites in the 2019 NAEI Point Sources data are large enough to be classified as major industrial loads. Sites that aren't included in this database are likely too small to have a significant impact on the energy system singlehandedly.
Methane reformation	Process of producing hydrogen by heating methane from natural gas and steam, usually with a catalyst. Produces carbon dioxide as a by product.
Microgeneration	Small-scale generation of heat and electricity by individuals, households, communities or small businesses for their own use.
Modelling zone	A specified area in our modelling which is the smallest level of granularity for analysis. The zones are used through energy modelling, deployment modelling, and mapping. Zones were created by intersecting the Local Authority boundary with the primary substation service area boundary, as described in the "Methodology - electricity and gas network infrastructure" section of the Technical Report. *May also be called "zone" or "substation zone" in the reports.*
National Asset	National infrastructure (can be supply or demand and the accompanying transmission / distribution infrastructure) – defined as over 100MW, unless it produces heat which can only be used locally this is generally excluded from LAEP particularly the modelling.
National grid	A generic term used in the reports referring to the electricity network serving Wales, including both the transmission and distribution networks and facilitating the flow of electricity between neighbouring areas or regions. *May also be called generically "grid" in the reports.*
National Net Zero	The National Net Zero modelled in the LAEP. Details of assumptions are in the methodology section.
Natural Heritage	This includes features which are of ecological, geological, geomorphological, hydrological or visual amenity importance within the landscape, and which form an essential part of the functioning of the natural environment and natural assets of RCT.

Appendix A3
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 ANW, a group of primary substations acting together to serve one area).

Appendix A3
Glossary of terms

Term	Definition or meaning
Programme	A series of projects, usually with a theme, that is run collectively.
Project	Strategic scale projects being implemented or planned for implementation in the local energy system that will significantly affect local demand or local supply.
Quick win projects	Very short-term actions, certain as no major blockers.
Renewable Energy Guarantees of Origin (REGO) Agreement	A scheme that tells consumers what proportion of their electricity comes from renewable sources.
Resistance heating/ heater	Generate heat by passing electrical currents through wires.
Scenario	A scenario is a set of assumptions for a particular end point (usually 2050) which are modelled in our optimisation model. We modelled 5 different scenarios to see what was common across the scenarios and therefore is a “no regrets” measure, and what changed between the modelled scenarios.
Sensitivities	Sensitivities of a specific scenario can be tested – for instance to test the impact of increasing electricity/hydrogen prices on the scenario. Testing a sensitivity is when you change one thing multiple times to assess the impact on the cost/carbon.
Sewage gas	A mixture of gases generated in sewer systems, used in a reciprocating gas engine to produce heat and electricity.
Solar PV	Convert solar radiation into electricity using photovoltaic (PV) cells.
Strategic objective	Strategic objectives are purpose statements that help create an overall vision and set goals and measurable steps to achieve the desired outcome. A strategic objective is most effective when it is quantifiable either by statistical results or observable data. Strategic objectives further the vision, align goals and drive decisions that impact change.

Appendix A3
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	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.
Wind power	Harnessing the kinetic energy of wind to turn a turbine to generate electricity.

Appendix A4
Units of measure

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

Appendix A4
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.

Appendix A5
Bibliography

Sponsors: Delivery partners:

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)	✓	
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.
Storage		
Electrical	X	
Thermal	X	
Other	X	
Land use, land use change and forestry	X	LAEP focused on energy system and associated emissions, rather than all sources of territorial emissions.

Appendix B2
Emission factors

Technology	Value	Units	Notes
Biomass	0.0119	kgCO2e/kWh	DESNZ, 2023 (Average of 4 biomass fuels: wood logs, wood chips, wood pellets, grass/straw)
Sewage gas	0.0002	kgCO2e/kWh	DESNZ, 2023 (Biogas - Biogas)
Organic matter	0.0002	kgCO2e/kWh	DESNZ, 2023 (Biogas - Biogas)
Natural gas	0.1843	kgCO2e/kWh	DESNZ, 2023 (Gaseous fuels - natural gas, Gross CV)
Oil/LPG	0.2413	kgCO2e/kWh	DESNZ, 2023 (Average of LPG and Fuel Oil, Gross CV)
Diesel	0.2391	kgCO2e/kWh	DESNZ, 2023 (Liquid fuels - Diesel (average biofuel blend), Gross CV)
Petrol	0.2217	kgCO2e/kWh	DESNZ, 2023 (Liquid fuels - Petrol (average biofuel blend), Gross CV)
Landfill gas	0.0002	kgCO2e/kWh	DESNZ, 2023 (Biogas - Landfill gas)
Waste incineration	0.0380	kgCO2e/kWh	Tolvik, 2021 (https://www.tolvik.com/published-reports/view/uk-energy-from-waste-statistics-2021/)
Coal	0.3226	kgCO2e/kWh	DESNZ, 2023 (Coal - Industrial, Gross CV)

Grid electricity carbon factor source	FES 23 (average scenario)

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

Sponsors: Delivery partners:

Appendix B3
Buildings – domestic archetypes

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

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

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

Appendix B3

Buildings – non-domestic archetypes

Archetype	Description	Age	Wall	Roof	Floor	Window	Heat demand (kWh/m^2)	Electricity demand (kWh/m^2)	Cooling demand (kWh/m^2)
12	Office unit	Pre-1930	Uninsulated solid wall	Other premises above	Uninsulated solid floor	Double glazing	73.8	95.1	28.0
13	Retail	After 1930	Insulated cavity wall	Other premises above	Uninsulated suspended floor	Double glazing	95.1	117.0	28.0
14	Hotel / hostel	After 1930	Insulated cavity wall	Insulated flat roof	Uninsulated suspended floor	Double glazing	120.9	117.6	30.0
15	Leisure/sports facility	After 1930	Insulated cavity wall	Insulated flat roof	Uninsulated suspended floor	Double glazing	181.3	72.4	40.0
16	Schools, nurseries and seasonal public buildings	Pre-1930	Uninsulated solid wall	Uninsulated pitched roof	Uninsulated suspended floor	Double glazing	127.7	41.0	0.0
17	Museums / gallery / library / theatre	Pre-1930	Uninsulated solid wall	Part insulated pitched roof	Uninsulated suspended floor	Double glazing	107.3	59.7	0.0
18	Health centre/clinic	After 1930	Uninsulated cavity wall	Part insulated pitched roof	Uninsulated solid floor	Double glazing	141.0	55.7	0.0
19	Care home	Pre-1930	Uninsulated solid wall	Insulated pitched roof	Uninsulated suspended floor	Double glazing	113.3	64.6	30.0
20	Emergency services, local Gov services, law, military	After 1930	Insulated cavity wall	Insulated pitched roof	Uninsulated solid floor	Double glazing	177.8	94.5	0.0
21	Hospital	After 1930	Insulated cavity wall	Uninsulated flat roof	Uninsulated solid floor	Double glazing	162.6	86.4	45.0

Appendix B3
Buildings – non-domestic archetypes

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

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

Appendix B3

High demand retrofit options – domestic

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

Sponsors: Delivery partners:

Appendix B3

High demand retrofit options – non-domestic

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

22-27 not modelled, Industry modelled separately

Appendix B3
Low demand retrofit options – domestic

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

Appendix B3

Low demand retrofit options – non-domestic

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

Sponsors: Delivery partners:

Appendix B4
Transport - assumptions

No.	Assumption Description
1	[BASELINE] Typical 24-hour period for demand tables represented average day in a year.
2	[BASELINE] Rail supplied by transmission network so excluded.
3	[BASELINE] Trip distances = distance between zone centroids multiplied by route indirectness factor
4	[BASELINE] Total mileage of trips taken from zone A to zone B: $Mileage_{AB}$= $distance_{AB}$ * number of $trips_{AB}$
5	[BASELINE] Mileage summed and assigned to outbound zone (zone A)
6	[BASELINE] Multiply mileage by vehicle fuel consumption factors to estimate annual kWh.
7	[BASELINE] Fuel consumption factors for combustion vehicles: Car: 0.94 kWh/mile Van: 0.89 kWh/mile HGV: 6.21 kWh/mile Bus: 8.43 kWh/mile
8	[FUTURE] Car dependency factors (1: national average, <1: less car dependent, >1: more car dependent) based on average number of cars per household Flintshire: 1.09 Isle of Anglesey: 1.08 Gwynedd: 1.02 Wrexham: 1.01 Denbighshire: 1.00

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
[AREA]	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 buildin g 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 buildi ng 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	0.130 4	£/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./kWh th	Used in the NCA study – error in calliope input	Elec boiler O&M costs	0.0075	£ p.a./kWh th	Used in Arup HNDU feasibility studies; based on DECC report
ASHP peak capacity	50	% of EC peak heat	Assumption based on typical load duration curves	Elec boiler peak capacity	50	% of EC peak heat	Electric boilers are assumed to provide peaking role
ASHP annual supply	90	% of EC annual heat	Assumption based on typical load duration curves	Elec boiler annual supply	10	% of EC annual heat	Assumption based on typical load duration curves
Ambient air temperature	5	°C	Typical ambient temperature during heating hours – same as counterfactual	Elec boiler efficiency	100	%	Taken from calliope inputs
ASHP carnot cycle efficiency	60	%	Applied to ideal carnot cycle COP; typical technology assumption; higher than for smaller equipment	Electricity unit cost	0.1304	£/kWhe	HMT Green Book central commercial/public sector price
ASHP source ΔT	10	°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 tem perature	65	°C	Consistency in supply temperature

Appendix B6

Heat networks – assumptions

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

Assumptions log – 2/3

Item	Value	Units	Source/notes	Item	Value	Units	Source/notes
Waste-heat heat pump plant capex cost	420	£/kWth	Assumes large plant is 60% price of decentralised plant based on work on other Arup projects	Waste heat capture plant capex cost	*See note*	£/kWth	See waste heat assumptions; depends on source
Waste-heat heat pump lifetime	20	Years	Typical technology assumption	Waste-heat capture plant O&M costs	*See note*	£/kWhth	See waste heat assumptions; depends on source
Waste-heat heat pump O&M costs	0.01	£ p.a./kWhth	Used in the NCA study	Thermal storage capex cost	24	£/kWhth	Supplier quotes; used in Arup HNDU feasibility studies
Waste-heat heat pump peak capacity	50	% of EC peak heat	Assumption based on typical load duration curves	Thermal storage sizing	4	Hours of EC peak	High-level assumption
Waste-heat heat pump annual supply	90	% of EC annual heat	Assumption based on typical load duration curves	Network pipework cost	2000	£/m	DESNZ assumption
Waste-heat source temperature	*See note*	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

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

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

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: Industry – water-based capture

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

Appendix B6

Heat networks – assumptions

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

Assumptions log: Industry – flue gas-based heat capture

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

Appendix B7
Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Anaerobic digestion	Energy CAPEX	4,760.00	£ / kW	BEIS (2020) BEIS Electricity Generation Costs (2020). 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

Appendix B7
Technology parameters for future energy system scenario modelling

Technology	Setting	Value	Units	Reference	Notes
Hydrogen import	Lifetime	1	years	n/a	Selected to have no effect
Hydrogen import	Operational fuel consumption cost	0.0203	kgCO2e / kWh	BEIS Hydrogen Production Costs 2021 report and annex. Availabe at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	Carbon capture rate for SMR + CCUS of 93% (BEIS hydrogen production costs) multiplied by the carbon emissions per kWh of hydrogen produced.
Hydrogen import	Operational cost of production	0.051	£ / kWh	BEIS Hydrogen Production Costs 2021 Annex, average of all the methane reformation technologies for the wholesale price (central) in 2050. Availabe at: https://www.gov.uk/government/publications/hydrogen-production-costs-2021 (Accessed 2023).	Average of all the methane reformation technologies for the wholesale price (central) in 2050.
Biomass import	Energy efficiency	1	fraction	n/a	Default
Biomass import	Lifetime	1	years	n/a	Default
Biomass import	Operational cost of production	0.04	£ / kWh generated	Heat roadmap EU (2017) EU28 fuel prices for 2015, 2030 and 2050. Available at: https://heatroadmap.eu/wp-content/uploads/2020/01/HRE4_D6.1-Future-fuel-price-review.pdf (Accessed 2023).	Price for wood pellet - medium labour share + fuel handling charges medium scenario. Converted from Euros using 0.91 exchange rate.
Biomass import	Operational fuel consumption cost	0.01053	kgCO2e / kWh	BEIS (2022). Greenhouse gas reporting: conversion factors 2022. https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-20202	
Electrolyser	Annual investment fraction	0.02	(fraction) 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.

Appendix B7
Technology parameters for future energy system scenario modelling

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

Appendix B7
Technology parameters for future energy system scenario modelling

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

Appendix B7
Technology parameters for future energy system scenario modelling

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

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Technology	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.

Sponsors: Delivery partners:

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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.

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

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

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

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

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Technology 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 parameters for future energy system scenario modelling

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

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

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Technology 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.

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.

Sponsors: Delivery partners:

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

Primary Fuel Use

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

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

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

Year	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Electricity	0.15	0.14	0.13	0.12	0.11	0.10	0.09	0.07	0.06	0.05	0.04	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00

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

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

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

Transport Sector

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

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

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

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

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

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

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

References

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

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

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