Programme Area: Smart Systems and Heat

Project: WP2 Bridgend Area Energy Strategy

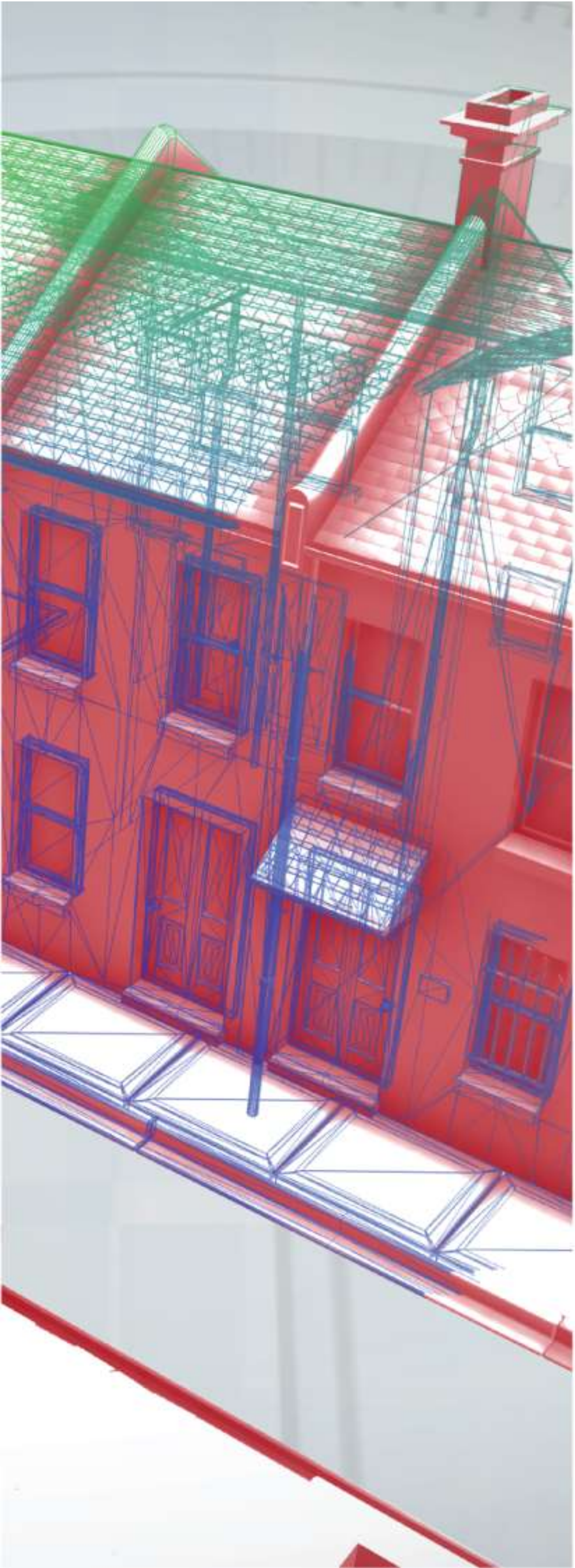
Title: Bridgend Local Area Energy Strategy – The Evidence Base

Abstract:

This Evidence Base provides the underlying technical detail to support the development of a local area energy strategy for Bridgend County Borough Council.

Context:

Bridgend County Borough Council has been working with a group of stakeholders consisting of Welsh Government, Western Power Distribution, Wales and West Utilities and the Energy Systems Catapult, to pilot an advanced whole system approach to local area energy planning. Bridgend is one of three areas including Newcastle and Bury in Greater Manchester participating in the pilot project as part of the Energy Technologies Institute (ETI) Smart Systems and Heat (SSH) Programme.



Local Area Energy Planning

Bridgend County Borough Council

Evidence Base

2018

Acknowledgements

The project was commissioned and funded by the Energy Technologies Institute (ETI) as part of the Smart Systems and Heat Programme and delivered by a public-private partnership between Energy Systems Catapult, Bridgend County Borough Council, Western Power Distribution, Wales and West Utilities and Welsh Government. The creation of the Strategy and its Evidence Base was motivated by the shared commitment to respond effectively to meet the requirements of International, European and national decarbonisation targets and the policy imperatives to address climate change and transition to a low carbon economy. EnergyPath is a registered trade mark of the Energy Technologies Institute LLP.

Glossary and Acronyms

Term	Definition
Analysis area	Spatial segmentation of study area for analysis in EnergyPath Networks. These are defined by the existing electricity grid assets.
Characteristic (weather) days	A set of daily weather profiles. Each profile represents different seasonal average conditions or the coldest day, which represents peak heating demand.
Clockwork	An ESME scenario that assumes a well-coordinated long-term investment plan, based on national-level planning to ensure a steady decarbonisation of power, deployment of large scale heat networks and the phasing out of the current gas grid.[1]
Green gas	Methane (CH4) that has been derived from biomass and waste feedstock, and injected into the gas network.
Patchwork	An ESME scenario that assumes less central government involvement, leading to a patchwork of distinct energy strategies at a local area level. Cities and regions compete for central support to meet energy needs tailored to local conditions. In some locations the local gas distribution grid is decommissioned entirely.[1]
Study area	The total land considered with the EnergyPath Networks analysis. In this report, the boundary contains the land that BCBC is responsible for. In this report this area is referred to as Bridgend, whereas “Bridgend Town” is used to reference Bridgend Town Centre.
Transition 1	The time period over which existing heating systems reach their end of life and require replacement.
Transition 2	The time period over which transition 1 heating systems reach their end of life and require replacement.

Acronym	Elaboration
ASHP	Air Source Heat Pump
ATES	Aquifer Thermal Energy Store
AQMA	Air Quality Management Area
BAU	Business as Usual
BCBC	Bridgend County Borough Council
BEIS	UK Government’s Department for Business, Energy and Industrial Strategy

[1] Options Choices Actions – UK scenarios for a low carbon energy system (http://www.eti.co.uk/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system/)

CO_2	Carbon Dioxide
UKCCC	UK Committee on Climate Change
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
CISBE	Chartered Institute of Building Services Engineers
DECC	(Former) Department of Energy and Climate Change (now part of BEIS)
DHN	District Heating Network
DNO	Distribution Network Operator
EHS	English Housing Survey
EPC	Energy Performance Certificate
ESC	Energy Systems Catapult
EfW	Energy from Waste
ESCo	Energy Service Company
ESME	Energy System Modelling Environment
ETI	Energy Technologies Institute
GHG	Green House Gases
GIS	Geographical Information System
GSHP	Ground Source Heat Pump
HOM	Housing Options Module
HV	High Voltage (for the purposes of this study defined as 11kV)
KSG	Key Stakeholder Group
LPG	Liquid Petroleum Gas
LV	Low Voltage (for the purposes of this study defined as 400V)
NAM	Network Analysis Module
OS	Ordnance Survey
POM	Pathway Optimisation Module
SAM	Spatial Analysis Module
SAP	Standard Assessment Procedure
SNG	Synthetic Natural Gas
(Solar) PV	(Solar) photovoltaics
SSH	Smart Systems and Heat (programme)
UCL	University College London
UPRN	Unique Property Reference Number
VOA	Valuation Office Agency
WHCS	Welsh Housing Conditions Survey
WPD	Western Power Distribution
WWU	Wales and West Utilities

Contents

1 Executive Summary

1.1 Context

This project was commissioned by The Energy Technologies Institute as part of the Smart Systems and Heat Programme and has been undertaken through a collaboration between Bridgend County Borough Council (BCBC), Western Power Distribution, Wales and West Utilities, Welsh Government and the Energy Systems Catapult, utilising the ETI's EnergyPath Networks modelling capability to pilot an evidence based whole system process of local area energy planning.

The UK has committed to a legally binding obligation to cut greenhouse gas emissions by 80% by 2050 (against 1990 levels). The Welsh Government approach for tackling the causes and effects of climate change is set out in their Climate Change Strategy for Wales. The Bridgend Strategy will need to consider and align with relevant and evolving Welsh Government guidance regarding climate change and energy such as:

- **The Environment (Wales) Act 2016 - Sets out the approach to help Wales reduce its carbon emissions and sets a minimum of 80% emission reduction by 2050.**
- **Planning Policy Wales –** Is currently under consultation and the conclusion of this process should be evaluated.
- **Renewable Energy Targets -** Welsh Government has set the following renewable energy targets:
    - Generating 70 per cent of Wales' electricity consumption from renewables by 2030
    - 1 GW of renewable electricity capacity in Wales to be locally owned by 2030
    - Renewable energy projects to have at least an element of local ownership by 2020

The Decarbonisation of Heat

Energy use in buildings is a significant contributor to carbon emissions. Heating accounts for over 40%[2] of the UK's total demand for energy. Decarbonising heat, particularly domestic heat, is critical to achieve a decentralised low carbon energy system. 96% of Bridgend's domestic heating in homes is by natural gas, with little incentive for consumers to change.

The Low Carbon Transition

Delivering a cost effective and socially accepted low carbon transition will require change to existing energy infrastructure and the types of energy that are used; as well as how, and when, they are used. The transition will involve evolving from natural gas fired boilers to other forms of energy and heating systems.

A Strategic Approach

This project focuses on considering the approach for decarbonising heat in Bridgend's buildings, with initial emphasis on decarbonising heat in homes. This recognises that it will be necessary to largely eliminate heat related emissions by 2050[3] and there has been little progress made to date in a static market with just

[2] October 2016, Next Steps for UK heat policy, Committee on Climate Change
[3] October 2016, Next Steps for UK heat policy, Committee on Climate Change

4% of homes in the UK having low carbon heating[4], whereas the decarbonisation of the electricity used in buildings is well underway[5]. In time, the Bridgend Strategy will need to evolve to consider the approach for decarbonising Bridgend's non-domestic buildings, along with emissions from other sectors.

1.2 Key Findings

- Across all model runs[6], the **average total costs were £7.23 billion**. However, **the Business as Usual scenario costs were £6.59 billion**, suggesting that **decarbonisation costs £0.66 billion.** Business as usual will see homes remain on gas boilers and continued significant investment in high carbon infrastructure.
- **A 95% local carbon reduction target is achievable**, providing some form of low carbon energy centres can be deployed, such as large-scale heat pumps.
- **Meeting a 95% carbon target will require at least 82% of domestic properties to transition away from their current heating system.** Across all model runs, on average, 97% of buildings changed heating systems.
- **Building fabric retrofit could be a quick win in areas of Bridgend where fuel poverty is high.**
- **There is no one solution.** Transition will require a mix of different technologies for different types of geography, buildings and people.
- **Building level changes result in significant network changes,** in terms of both electricity network upgrade and new build district heat.

All model runs culminated in two future local energy scenarios. Both scenarios:

- Consider local constraints on the siting of certain technologies and options resulting from EnergyPath Networks view of the least cost decarbonisation scenario.
- Were informed by a practical engineering review of barriers to low carbon technology deployment within specific local areas which examined the outputs of the analysis and project stakeholder group feedback.

The first scenario assumed that national gas does not decarbonise over time, whereas the second scenario considers the role of blending low carbon gas with natural gas in contributing to the cost-effective reduction of emissions.

1.2.1 Future Local Energy Scenarios

Scenario 1 – A World Without Green Gas

- **When green gas is not available there are more electric heating systems in domestic buildings.** Almost 80% of buildings having some form of heat pump.
- Around 15% of homes are connected to district heat, which are **fed by gas energy centres initially but switch to low carbon electric alternatives from the mid-2030s.**

[4] ETI 2015 Consumer Insight
[5] https://www.gov.uk/government/publications/decc-single-departmental-plan-2015-to-2020/single-departmental-plan-2015-to-2020
[6] See Section 6.3 for detailed analysis across model runs.

- **Electricity network upgrade is required to cope with the demand of the new electric heating systems.** For example, by 2050, almost 87MW of HV feeder upgrade is required (compared to Business as Usual).

Scenario 2 – A World with Green Gas

- **When green gas is available electric heating systems are still the dominant domestic heating solution for Bridgend in 2050.** There are around 5,100 less heat pumps (excluding hybrid heat pumps) but over 75% of homes have some form of electric solution (64% excluding hybrid heat pumps).
- Around 19% of homes are connected to district heat, which **are still using electrically driven energy centres by 2050. However, the low carbon gas acts as a seed for district heat in the early years by promoting increased gas CHP uptake.**
- **Green gas is also utilised in the non-domestic sector.** Around 1.6km^2 of extra non-domestic floor area remains on gas when green gas is available.
- The availability of green gas does not affect 76% of off-gas properties but there are around 200 more off-gas district heat connections when green gas is available. **This suggests that, for some off-gas buildings, it is the carbon content of standard gas and/or the cost of the low carbon alternative that prevents them from connecting to district heat, rather than high heat pipe costs due to the rurality of the buildings.**

Total transition costs are estimated to be £100 million cheaper when green gas is available.[7]

1.2.2 Costs

- The variations on the national (ESME) scenario had the most significant impact on the lowest cost solutions for Bridgend. This suggests that, **the national picture needs to be monitored carefully and both the Evidence Base and Strategy need to be revisited in the future.**
- In terms of technology costs, the biggest influencer on total costs of transition are the costs of district heating pipes. **If the cost of installing heat network pipes could be decreased, it could have a major impact on the viability and uptake of district heat**[8]**.**
- Applying constraints to save costs in one part of the system, can cause costs to rise in another part of the system by an amount that is more than that saved by applying the constraint, see for example Section 5.7.

1.2.3 National versus Local – Opportunities, Challenges and Trade-offs

- **If the national electricity gird does not decarbonise**[9]**, a 95% carbon reduction target would not be achievable**.
- Welsh Government view the Bridgend study area as a "mini-Wales", since its housing stock, heating systems (including off-grid) and social statistics broadly match Wales as a whole. **Both Welsh**

[7] Note that total transition costs are calculated for the entire transition time between 2015 and 2050.
[8] http://www.eti.co.uk/programmes/energy-storage-distribution/heat-infrastructure-development/
[9] ESME assumes a 2050 green house gas reduction target of 80% by 2050, relative to 1990 levels. This includes emissions from international shipping and aviation.

Government and BCBC could make the most of this opportunity moving forward and support each other to implement test projects in Bridgend that benefit both parties.

- The analysis has indicated that gas boilers will continue as the dominant form of heating technology in homes (remaining in around 85% to 90% of homes until circa 2025). **This highlights that there is a realistic timeframe to effectively plan for local decarbonisation.**

1.2.4 Consumers

It is important to consider constraints that are not assessed by EnergyPath Networks (such as consumer, policy, commercial, skills and supply chain aspects), since they can have a significant impact on the decarbonisation process. The analysis presented in this report has led to several consumer-related questions and opportunities that are note-worthy:

- **Most consumers are not currently familiar with the transitional technologies discussed in this report so organisations will need to develop corresponding products and services that individuals want to use.**
- **Most consumers avoid replacing their heating systems until they break down beyond repair, even if a new system would save them money overall.** The analysis in this report assumes there will only be two opportunities to replace heating systems, on average, until 2050. This could be influenced by new policies and business models.
- **Even familiar technologies cannot be assumed to be easy to implement.** For example, many building fabric retrofit measures are not high on consumers' wish lists.

2 Introduction

2.1 Context

Energy is the cornerstone of our society. The food we eat, the cars we drive, the goods we make, transport and buy as well as the heat, light and hot water that make our homes comfortable all rely on energy in one form or another. Energy use in buildings is a significant contributor to UK carbon emissions. Heating accounts for over 40% of the UK's total energy demand.

A new approach to planning and delivering our future local energy systems is needed if we are to meet the challenge of climate change and deliver a resilient and low carbon energy system that works for the people, communities and businesses of Bridgend. The UK has committed to a legally binding obligation to cut greenhouse gas emissions by 80% by 2050 (against 1990 levels), which is upheld in Wales by the Environment (Wales) Act 2016. Welsh Government are due to release regulations around their interim targets (2020 & 2030) by the end of 2018.

In addition, Welsh Government has set the following renewable energy targets:

- 70% of Wales' electricity consumption to be generated by renewables by 2030.
- 1GW of renewable electricity capacity to be locally owned by 2030.
- Renewable energy projects to have at least an element of local ownership by 2020.

The draft Planning Policy Wales (PPW)[10] is out for consultation until May 2018 and suggests that

1) **Planning authorities should develop an evidence base to inform the development of renewables and low carbon energy policies.**
2) **Planning authorities should consider the contribution that can be made by their local area towards emission reduction and renewable and low carbon energy production.**

This Evidence Base aims to support the planning and delivery of a low carbon future energy system for Bridgend. It takes a whole system approach to considering future pathways to decarbonise the local energy system with a focus on the options and choices for decarbonising heat. The Evidence Base presents:

- The results of the EnergyPath Networks modelling process.
- Conclusions and insights by analysing common themes across all analyses.

Insights have been shared with the Key Stakeholder Group (KSG) throughout the project and have been used to inform the development of the Strategy document. It is important to note that the analysis presented in the Evidence Base is a pure techno-economic perspective (see Chapter 4 for full details). The Strategy takes this analysis forwards and presents it in the wider context by considering consumers, policy & regulation and commercial factors.

[10] https://beta.gov.wales/planning-policy-wales-edition-10

2.2 Background

Bridgend local area is located on the South Coast of Wales and has the eighth largest population in Wales. The Strategy has considered a total of 67,600 existing buildings within Bridgend, made up of circa 62,000 domestic and 5,600 non-domestic buildings. Additional planned new development buildings are also included.

A Local Area Energy Strategy provides a long-term framework for reducing carbon emissions. It is based on whole systems analysis that has been developed specifically for the local area, produced using an extensive and robust evidence base.

This consists of two documents:

- An Evidence Base (this document). The Evidence Base provides the technical analysis and area specific evidence, summarising the whole systems optimisation analysis and supporting information that has been assessed to inform planning and future network choices of the local area.
- A Local Area Energy Strategy. The Strategy builds on the Evidence Base through considering the other essential interdependent aspects that are central to a local area's energy strategy including considering consumer, commercial and policy & regulatory issues in addition to the insights from the modelling.

2.3 Project Overview

The project was commissioned by The Energy Technologies Institute as part of the Smart Systems and Heat Programme and has been undertaken through a collaboration between Bridgend County Borough Council (BCBC), Western Power Distribution, Wales and West Utilities, Welsh Government and the Energy Systems Catapult, utilising the ETI's EnergyPath Networks modelling capability[11] to pilot an evidence based whole system process of local area energy planning.

This aims to provide a foundation for the Council and other key stakeholders, including existing network operators, local communities of interest, new energy service providers and academia, to work collaboratively and plan positively for long term energy system change and to design and demonstrate location-specific smart energy systems.

[11] See Froward for a description of EnergyPath Networks

2.4 Evidence Base Scope

As previously discussed, this Evidence Base provides the underlying technical detail to support the development of a local area energy strategy for Bridgend County Borough Council. To do this the Evidence Base needs to describe:

1. **What:** the resulting insights across all the analysis of the local energy system with a particular focus on items that can be investigated further in the near-term. These items are referred to as project themes.
2. **How:** the process used to obtain the insights, including the representation of Bridgend's existing local energy system in the modelling, the priorities and constraints agreed with the Key Stakeholder Group (KSG) and the analysis performed to identify near term "low-regret" options.
3. **Why:** Investigating the key drivers of the results and uncertainties.

It is important to note that "low-regret" options are low-regret from a modelling perspective, i.e. they are part of the least cost solution to decarbonise the local energy system, to society as a whole, under a wide range of inputs. However, there are many other unknowns that could cause modelled low-regret options to be very much high-regret in reality. For example, many of the technologies discussed in this report are not known to the average consumer. If a heat network is deployed in an area, consumers need to be engaged effectively, see real benefits/be incentivised to switch quickly enough to make the business viable and be comfortable with the level of disruption that will be caused as the heat network is deployed. This alone is a huge challenge and there are many others. Broadly, transition challenges will fall into one or more of the categories shown in Figure 2-1.

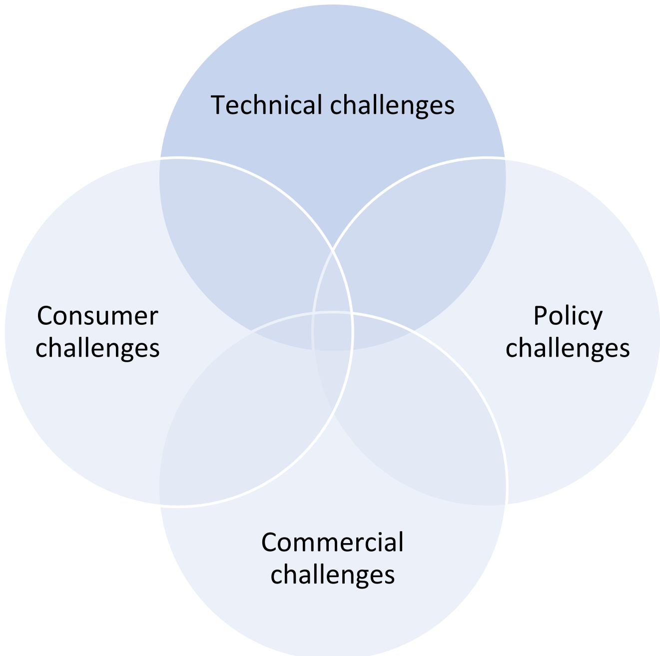


Figure 2-1 Challenge Categories for Transition.

Many technical restrictions are built into the modelling framework, e.g. no loft insulation in top floor flats. Other technical challenges will be much more unique to specific circumstances affecting local areas networks and buildings. For example, biomass technologies may not be appropriate in built up areas where such technologies could lead to air quality issues. These will have to be analysed through detailed specific feasibility studies and network designs. The Evidence Base identifies project themes to support decarbonisation of the local energy system but it does not assess their potential in terms of the other categories listed in Figure 2-1. These are discussed in the development of a Local Area Energy Strategy for Bridgend County Borough Council.

2.4.1 Key Scope Parameters

The Evidence Base and Local Area Energy Strategy is based upon the analysis of different low carbon heating options for Bridgend to reduce carbon emissions to an agreed 2050 carbon reduction target. The key parameters associated with its development include:

- The Evidence Base has evaluated heating technology options for domestic buildings and building fabric changes.
- The potential for non-domestic buildings to connect to heat networks are assessed – except where these buildings use gas for industrial purposes. Non-domestic buildings using electricity as a heating fuel were also assumed to continue using electricity, since a transition to district heat would require significant changes to internal heat distribution systems.
- Transport and associated emissions are not assessed; however, expected uptake of electric vehicles has been considered so that the impact of electric vehicles on the electricity network is assessed within the modelling approach.
- The modelling approach focuses on identifying the options with the lowest total cost (capital and operational) to reduce CO_2. As such it does not focus on options to reduce fuel poverty as this would involve a different set of priorities (and would likely result in a higher cost to decarbonise). However, it is recognised the Council will need to consider the impact of energy costs and fuel poverty when developing the Strategy further, accepting that there will be a cost to society and subsequently to consumers to decarbonise. Fuel poverty and other socio-economic indicators are discussed further in the policy document[12] and within the Strategy document in relation to project themes, where appropriate.
- The Evidence Base does not consider using hydrogen for heating and or the repurposing of the gas grid for hydrogen[13]. The introduction of green gas into the gas network was considered in two sensitivities (see Sections 5.8 and 6.1.2). A hydrogen pathway should be assessed once data is available, as part of an ongoing review process.

[12] Policy and Commercial Insights for Energy System Transformation- Bridgend County Borough Council
[13] These options are discussed in the Strategy document.

2.4.2 Evidence Base Project process

The Evidence Base has been developed using EnergyPath Networks, a software tool which has been designed in partnership with local authorities to develop cost-effective local energy system options for local areas in the UK. EnergyPath Networks:

- Is a multi-vector approach which allows trade-offs between energy vectors and networks to be understood.
- Has the ability to understand the spatial relationships between buildings and the networks that serve them so that costs and benefits correctly represent the area being analysed.
- Uses an optimisation process to compare a large number of combinations of options (over 17,000 building pathways in Newcastle)
- Optimisation for multiple analysis areas within the study area (10 for Bridgend) and for 4 separate time periods out to 2050. Analysis areas are defined as HV substations and everything down stream to ensure that analysis areas do not cut across the electricity network. It would be nonsensical to reinforce the 'downstream' end of an electricity feeder without considering the impact of the loads on those components further upstream in that network (see Section 4.8 for further details).

The process of using EnergyPath Networks and producing the strategy is shown below in Figure 2-2. It is important to note that engagement with the KSG is performed throughout this process.

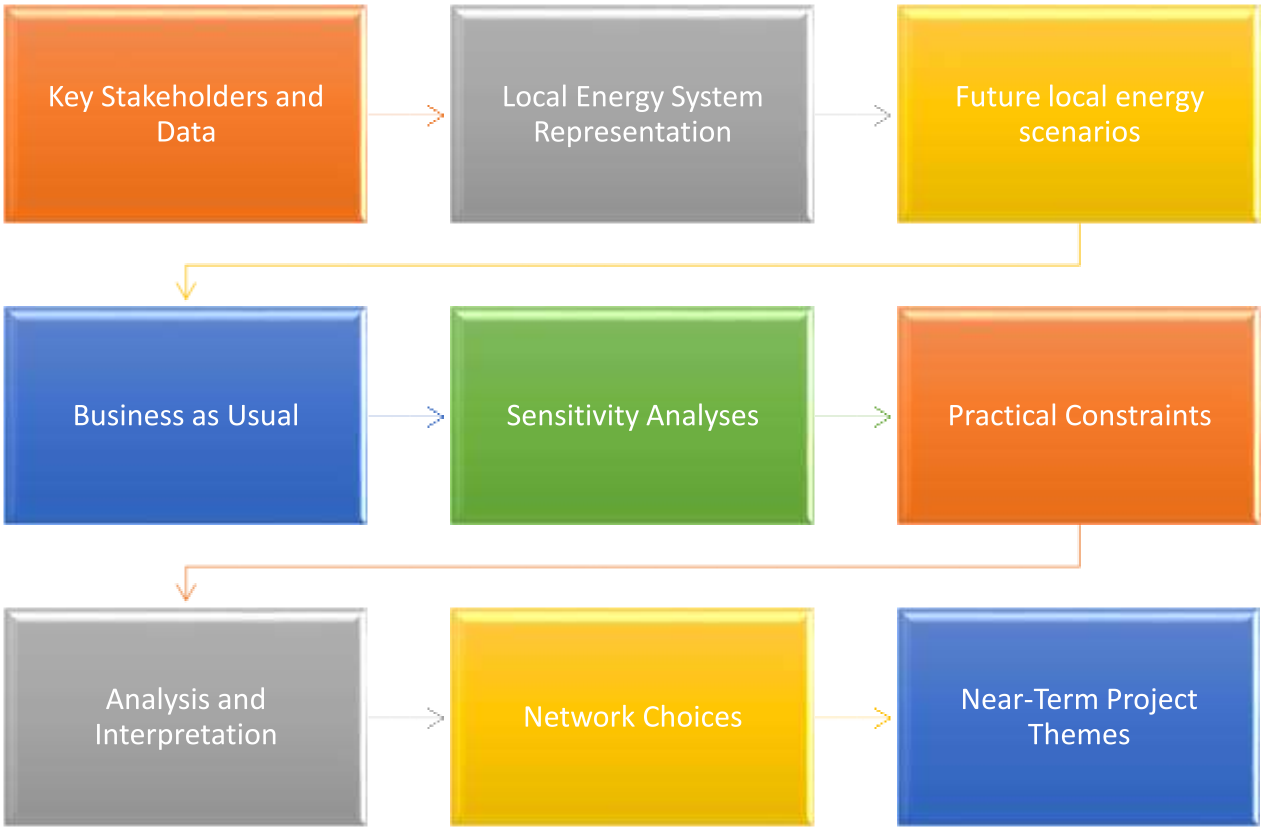


Figure 2-2 Modelling Process.

3 Local Energy System

This section summarises the existing Local Energy System in Bridgend that has been modelled within EnergyPath Networks. This modelling representation of the local energy system forms the basis for investigation of future decarbonisation pathways for the local area.

3.1.1 Local Electricity Distribution Network

Western Power Distribution's network provides power to some 7.8 million people throughout South Wales, the Midlands and South West England. Figure 3-1 shows the 10 Western Power Distribution high voltage substations that have been included in the analysis. Figure 3-2 shows the 759 Low Voltage (LV) secondary substations modelled within EnergyPath Networks[14]. The location of the High Voltage (HV) substations is important to the EnergyPath Networks analysis. This is explained later in Section 4.8.

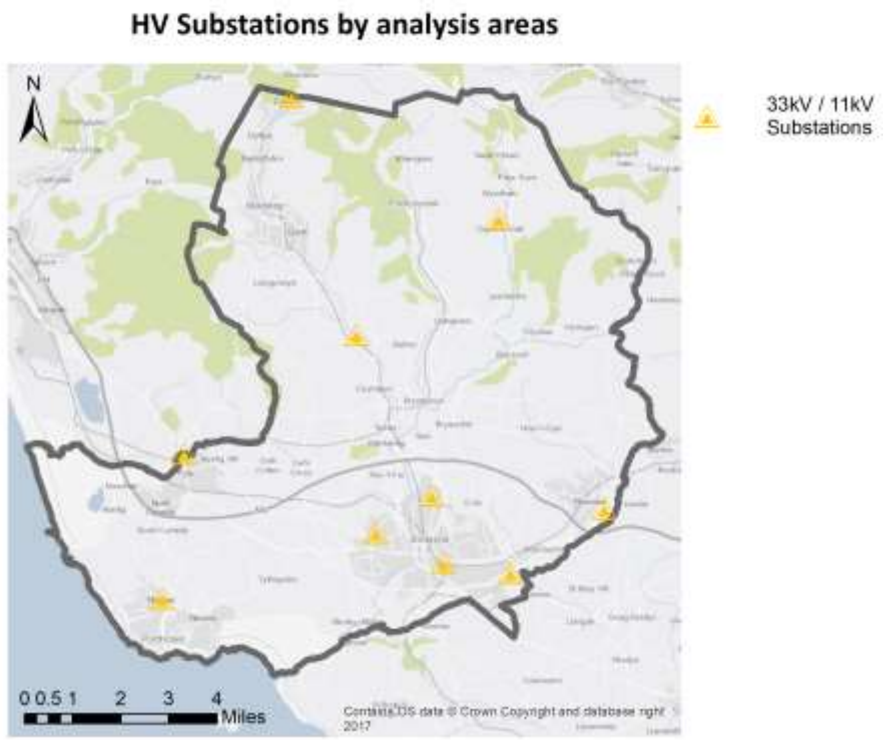


Figure 3-1 Western Power Distribution's HV Substations

[14] These are used as a basis for EnergyPath Networks modelling areas.

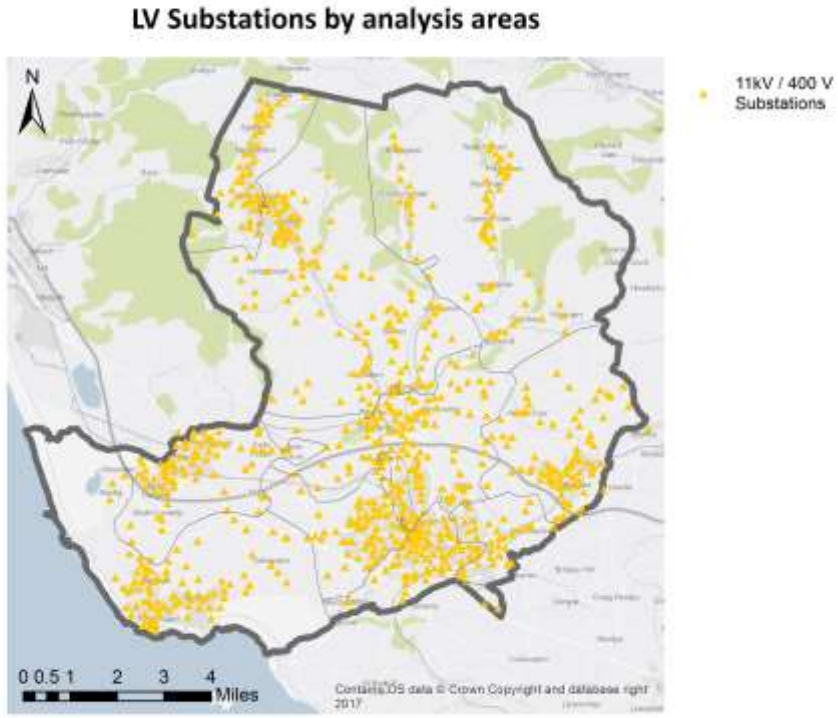


Figure 3-2 Western Power Distribution's LV Secondary Substations

The EnergyPath Networks representation of the network feeder routing between HV and LV substations, and HV/LV substations and customers is described in Section 4.6.

3.1.2 Local Gas Network

Wales and West Utilities currently distributes gas to 2.5 million households and businesses throughout Wales and the South-West of England. In the EnergyPath Networks analysis three gas entry points are represented. Their coordinates reflect the locations on the boundary of the study area lying closest to the points at which the national transmission system meets the local transmission system. The layout of high and medium pressure pipes within the study area are shown in Figure 3-3. Within the modelling, these are mimicked using connections between different areas.

The gas pipes are sized to meet the current demand levels simulated in EnergyPath Networks. Therefore, there is an underlying assumption that the present-day capacity of the network is large enough to meet all future demand. This is because the target of the modelling process is to reduce carbon emissions which is expected to result in a reduction in gas demand. Even if enough green gas were available local gas demand is not expected to increase.

In the Bridgend EnergyPath Networks analysis, gas network components can be decommissioned or extended to cover off-gas areas (see Figure 3-4 for domestic off-gas properties). Around half a square mile of non-domestic floor area are prevented from disconnecting from the gas network since they the buildings require gas for industrial purposes.

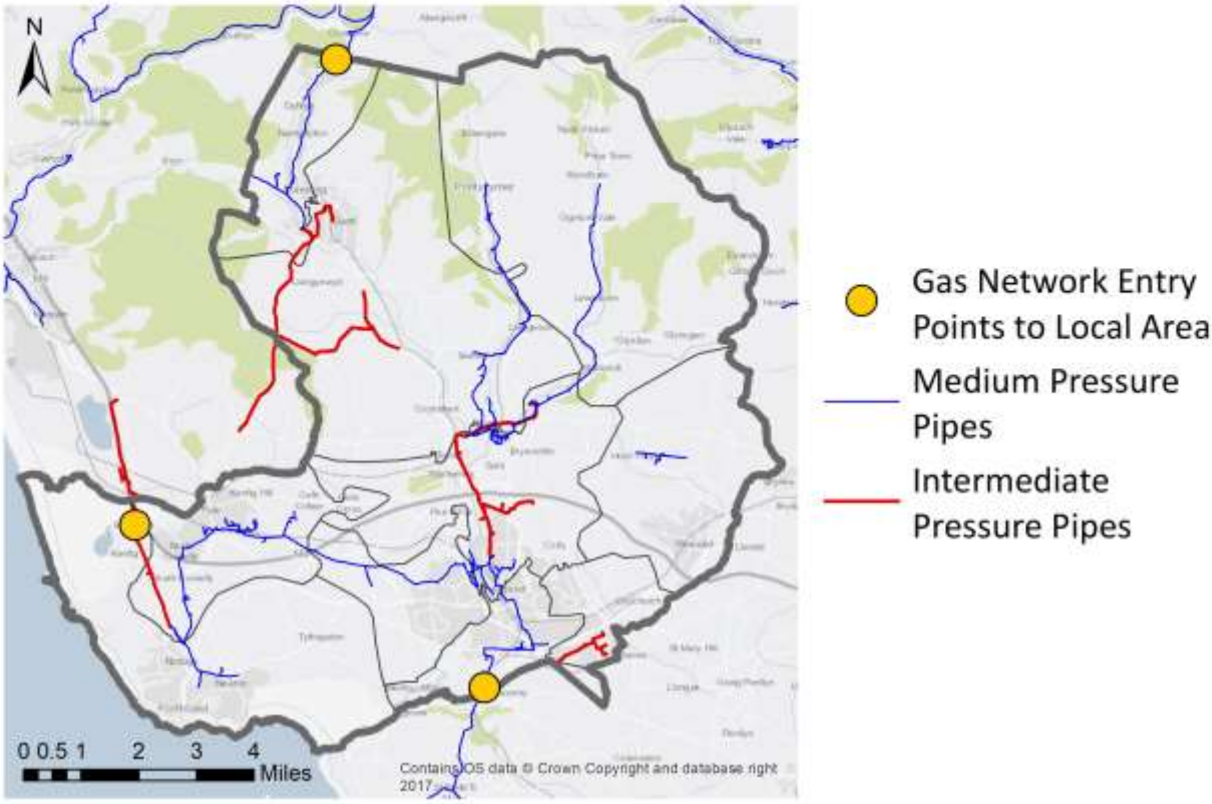


Figure 3-3 High and Medium Pressure Gas Pipes in Bridgend

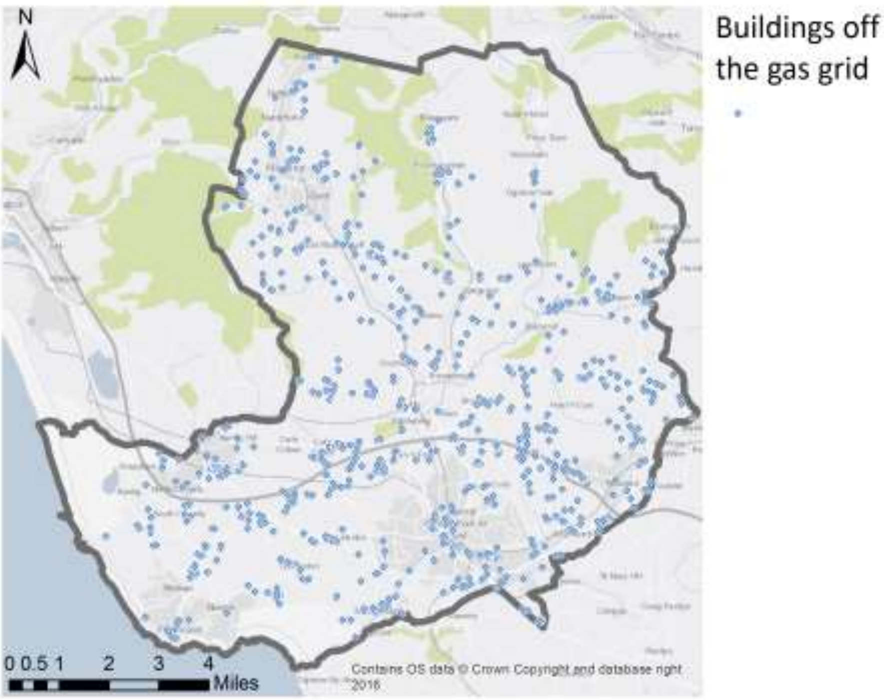


Figure 3-4 Properties Off the Gas Network Based on Xoserve Data

Figure 3-4 shows buildings that are assumed to be off-gas based on Xoserve[15] data. This makes up around 3% of the Bridgend domestic housing stock (10% of postcodes).

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[15] Xoserve provide services to the gas industry, including management of gas supplier switching and transportation transactional services, www.xoserve.com

3.1.3 Existing Building Stock

Figure 3-5 shows the percentage of each building type in Bridgend as modelled in EnergyPath Networks. These percentages are based on a collation of multiple data sources, as described in Table 4-1.

There is no Welsh housing survey data for comparison[16]. However, compared to the English Housing Survey (EHS) data, Bridgend has a higher proportion of terrace buildings compared to the English national average. Over half of these terraces were built before 1914 (see Figure 3-6), suggesting that Bridgend has a high proportion of solid wall properties. This could pose challenges from both a decarbonisation and fuel poverty perspective if these solid walls are uninsulated.

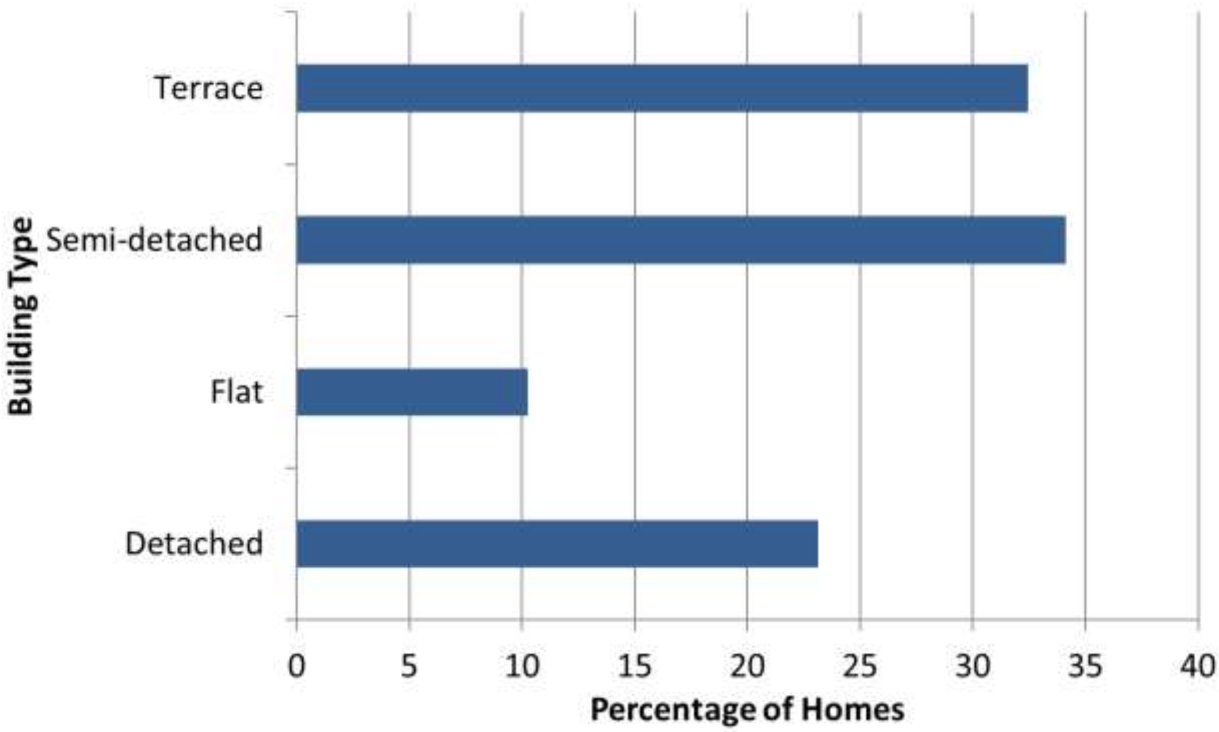


Figure 3-5 Percentage of Homes by Building Type in Bridgend

[16] Welsh Housing Conditions Survey (WHCS) is due for release Autumn 2018 (http://gov.wales/statistics-and-research/welsh-housing-conditions-survey/?lang=en)

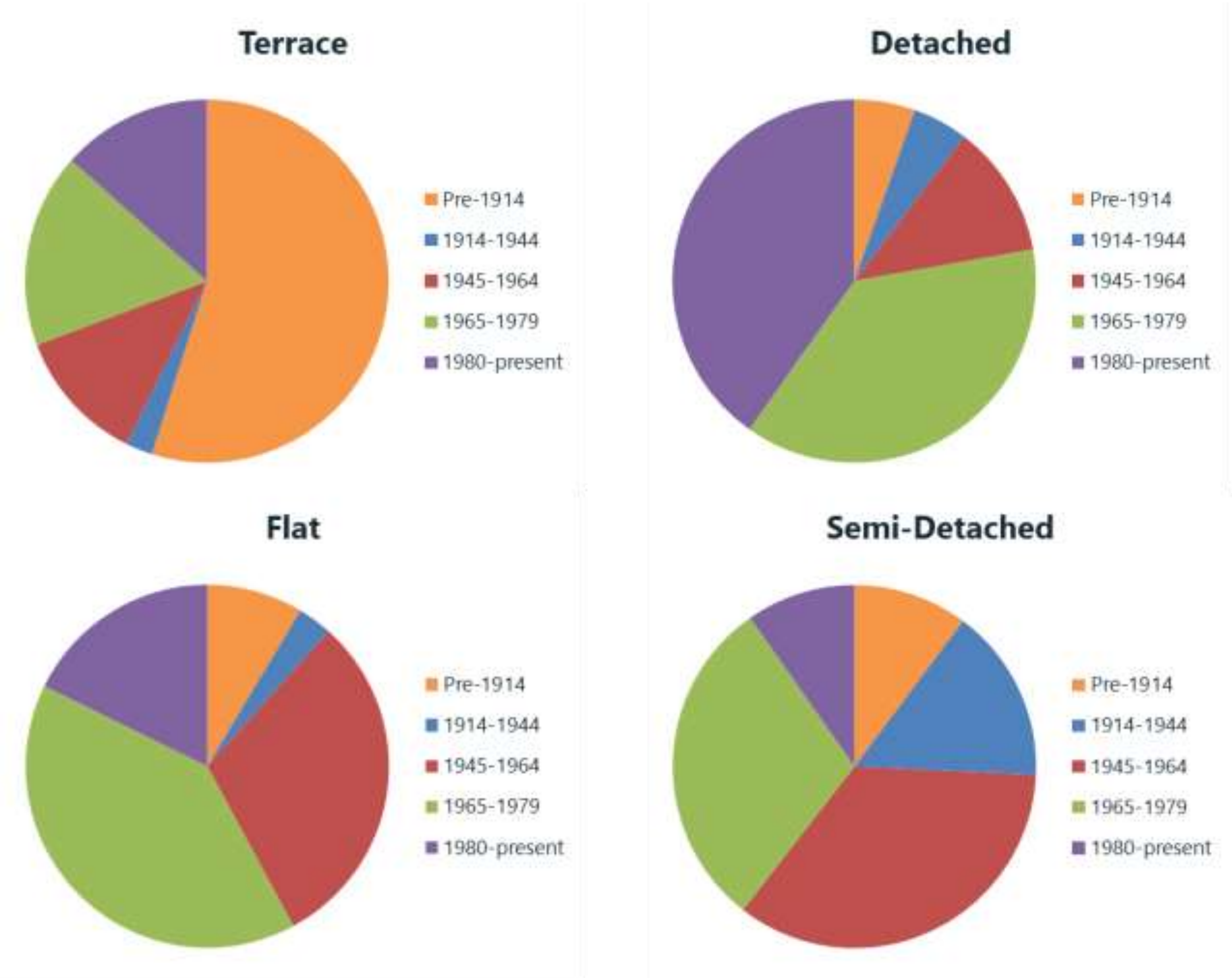


Figure 3-6 Percentage Age of Building for Each Property Type

3.1.4 Current Demand

Figure 3-7 and Figure 3-8 show the peak and annual building demands in Bridgend for all buildings (domestic and non-domestic). These demands have been simulated based on the current building stock described in Section 3.1.3 (compare Section 4.4 for a description of the demand simulation process).

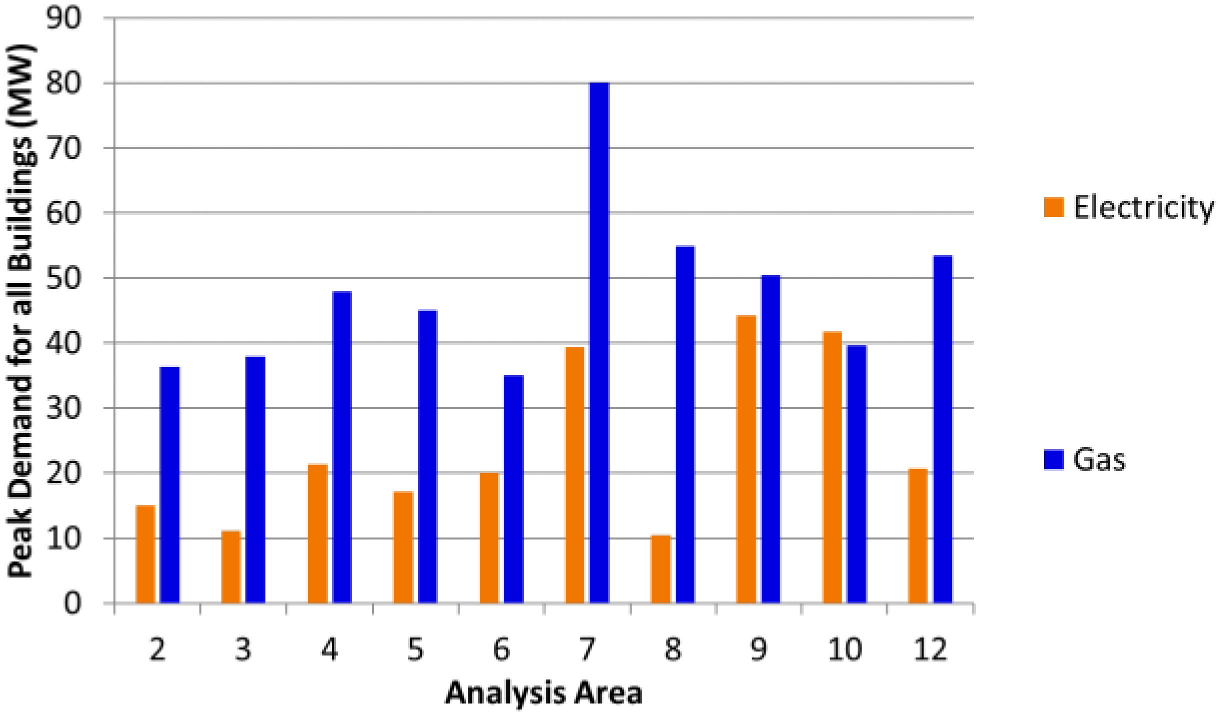


Figure 3-7 Current Building Peak Demand (Domestic and Non-Domestic)

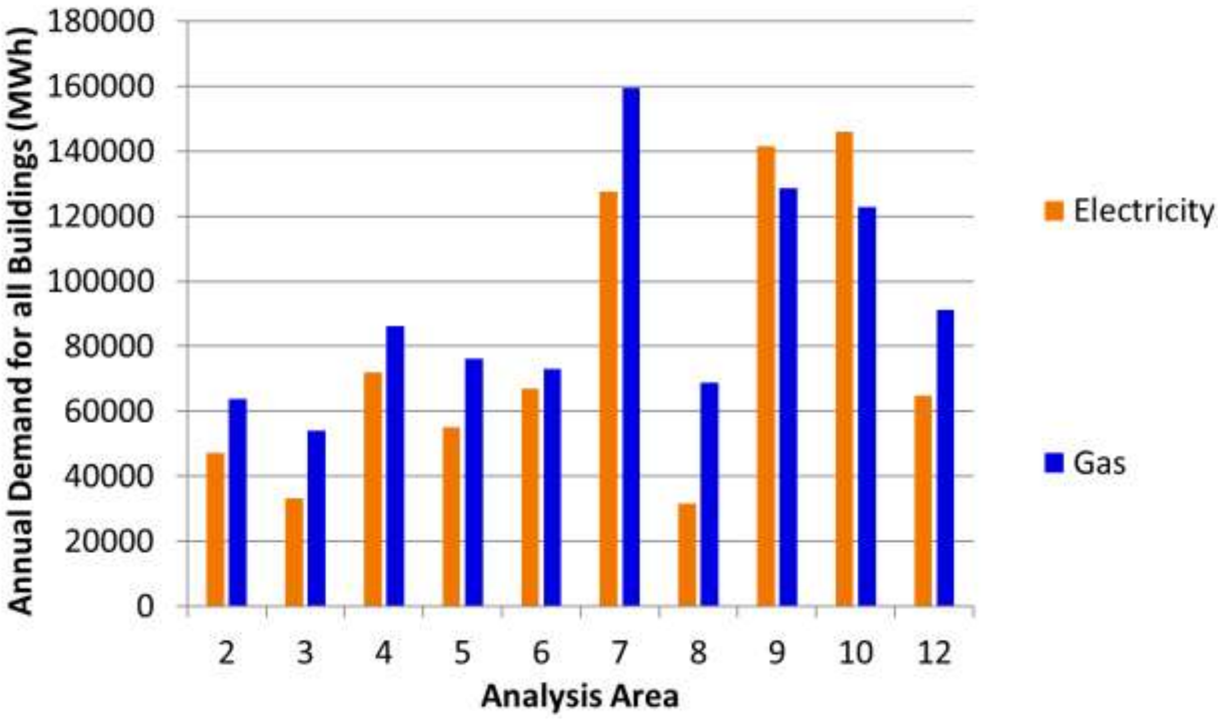


Figure 3-8 Current Building Annual Demand (Domestic and Non-Domestic)

3.1.5 Planned Growth

Understanding future growth in Bridgend is important as it will lead to increasing energy demand arising from heating and electricity use in new homes and buildings. Figure 3-9 and Figure 3-10 show the new build domestic and non-domestic locations respectively[17], as represented in the EnergyPath Networks modelling. The breakdown of the domestic and non-domestic buildings, as modelled, by ward are illustrated in Chapter 8[18]. Based on these assumptions, domestic and non-domestic buildings demand lead to an additional 14% gas demand and 13.5% electricity demand above current Bridgend demand. Figure 3-11 shows the resulting peak for new builds as a percentage of the total peak demand for all buildings (current and new build). This shows a significant variation in the change in peak demand by analysis area, which is largely driven by the volume of non-domestic new builds. Therefore, Bridgend's new homes, commercial and industrial floor space will result in an increasing demand on the local energy system and pose additional challenges to meeting decarbonisation targets.

Of note, whilst new domestic developments will use less energy than an existing similar building, their inclusion within the EnergyPath Networks is important to achieve decarbonisation targets. As such the analysis considered if new buildings' heating systems should be changed throughout the strategy's lifetime (as some new buildings will still be provided with carbon intensive heating systems), however building fabric improvement would not be a focus for these buildings.

Due to low data availability for both the current state of non-domestic building fabric, and for the cost and efficiency improvements associated with their fabric retrofit, improvements in non-domestic building fabric were not considered. However, heat network connections were considered for suitable non-domestic buildings. It was not deemed appropriate to allow transition where:

1. Buildings use gas for industrial purposes, since a heat network would not be able to deliver the high temperatures required.
2. Buildings use electricity as a heating fuel, as the changes to the internal radiator system were deemed to be prohibitive and these emissions of these buildings will reduce with decarbonisation of electricity generation.

[17] Based on adopted local development plan geospatial data for new build areas where provided by BCBC. Otherwise locations identified using the planning portal http://planning.bridgend.gov.uk/
[18] Building types allocated based on https://democratic.bridgend.gov.uk/documents/s10059/290916%20-%20JHLAS%202016%20INCLUDING%20APPENDIX.pdf?LLL=0 where details available. Otherwise, breakdown suggested by BCBC planning department was used.

Domestic New Build Areas

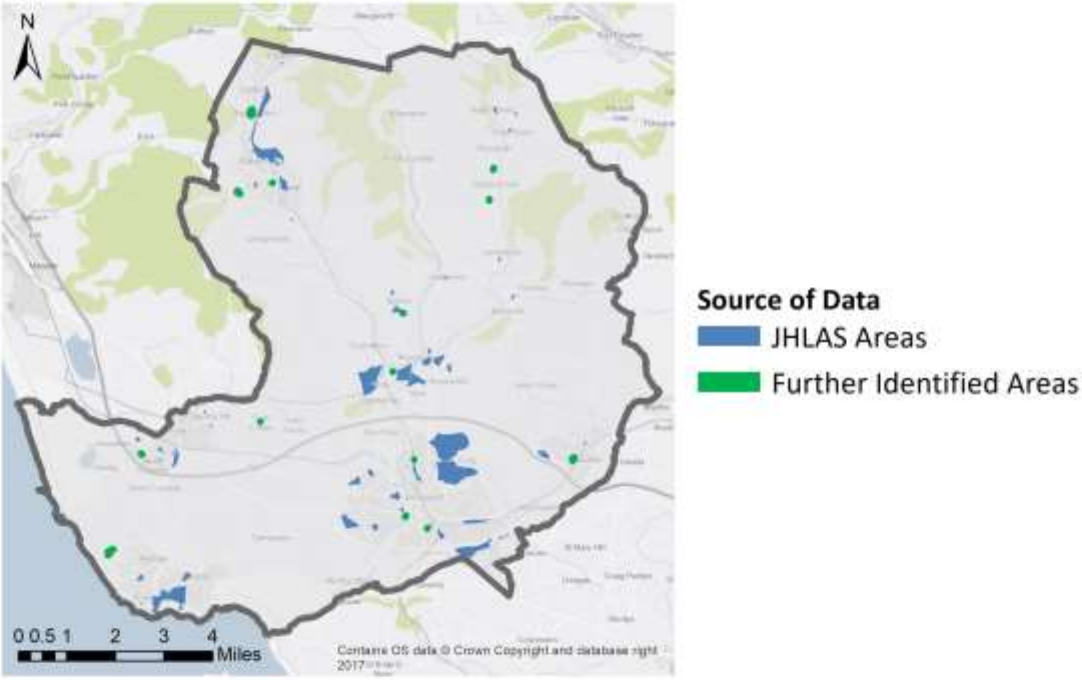


Figure 3-9 Bridgend's Proposed Domestic New Build Locations

Non-Domestic New Build Areas

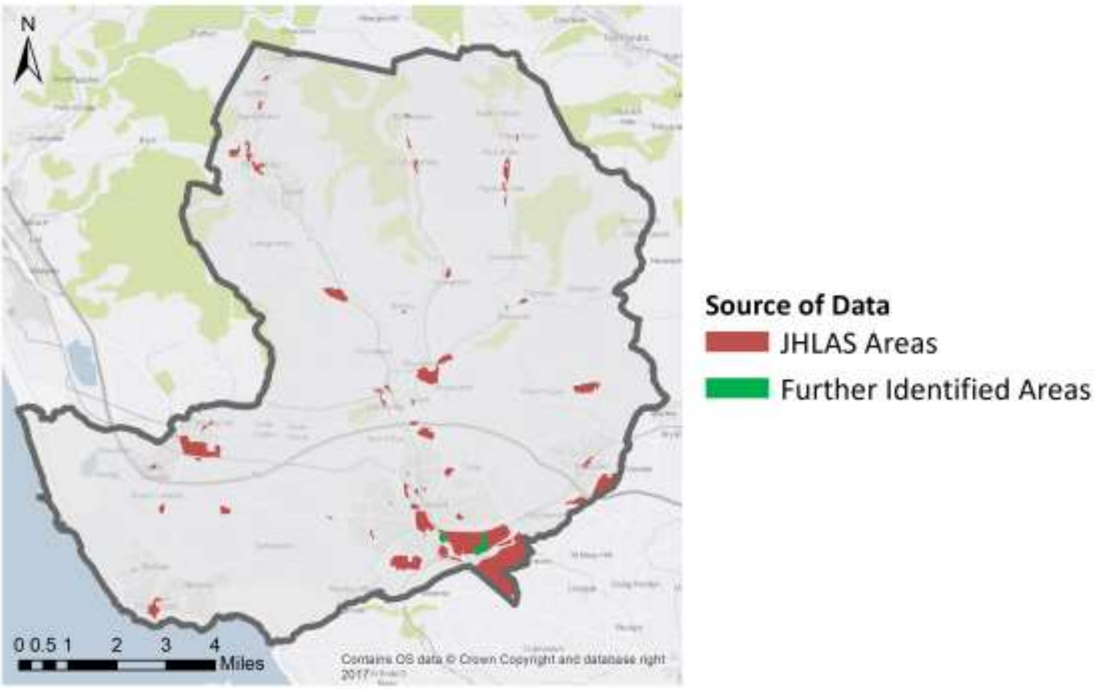


Figure 3-10 Bridgend's Proposed Non-Domestic New Build Locations

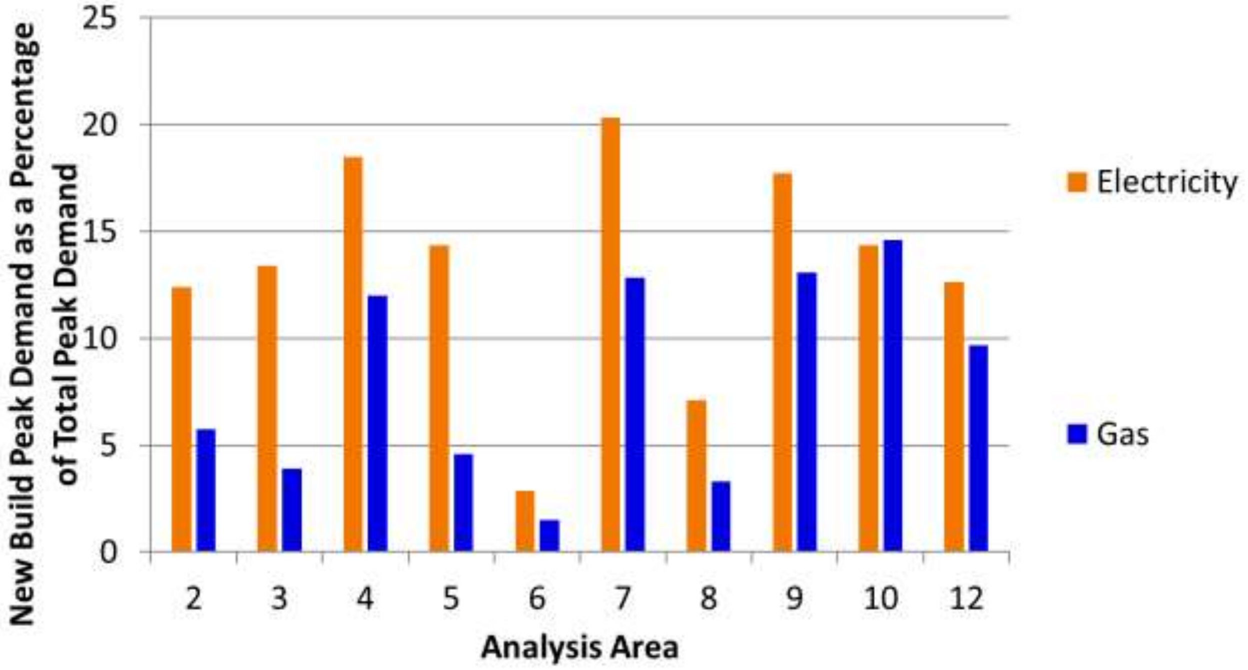


Figure 3-11 New Build Peak Demand as a Percentage of Total Peak Demand

3.1.6 Summary

In summary, the Local Area Representation considers:

- Existing and planned energy centres – locations and technologies.
- Buildings connected to future and planned heat networks.
- Possible sites for future energy centres.
- HV and LV substation locations and capacities.
- Energy network connections between analysis areas for gas and heat (analysis areas are defined as HV substations and everything down stream).
- Points where the gas network enters the study area.
- Planned new build areas[19]. Within each area:
    - Number and type of domestic buildings
    - Number and planned use of non-domestic buildings.
    - Build schedule.
- Any significant planned demolitions.
- Properties off the gas grid.
- Domestic building archetype – age and type for every building. Uno data has also been used (where possible) to define further characteristics.
- Non-domestic building use for every building.
- Electricity network reinforcement costs.
- Carbon target.
- Electric vehicle take-up.
- Biomass availability.

[19] Building types allocated based on https://democratic.bridgend.gov.uk/documents/s10059/290916%20-%20JHLAS%202016%20INCLUDING%20APPENDIX.pdf?LLL=0 where details available. Otherwise, breakdown suggested by BCBC planning department was used.

4 EnergyPath Networks Modelling Approach

This Chapter describes the EnergyPath Networks modelling approach that has been used to pilot a whole systems process of local area energy planning in Bridgend and inform the development of a local area energy strategy. It explains the data and inputs that are created on a building by building level of granularity, along with the process EnergyPath Networks uses to assess the options through its Decision Module. The Decision Module compares decarbonisation option combinations and selects the set that meets the set CO_2 emissions target at minimum total cost to society.

A variety of local energy system pathways are possible to meet 2050 emissions targets. As EnergyPath Networks runs multiple scenarios and involves detailed sensitivity analysis, this generates repeated decarbonisation themes that are prevalent across all scenarios, where the same solutions are highlighted as the lowest cost decarbonisation measure, and can be confidently progressed to deployment within current policy and market arrangements or require innovation to overcome current technological, commercial or regulatory barriers.

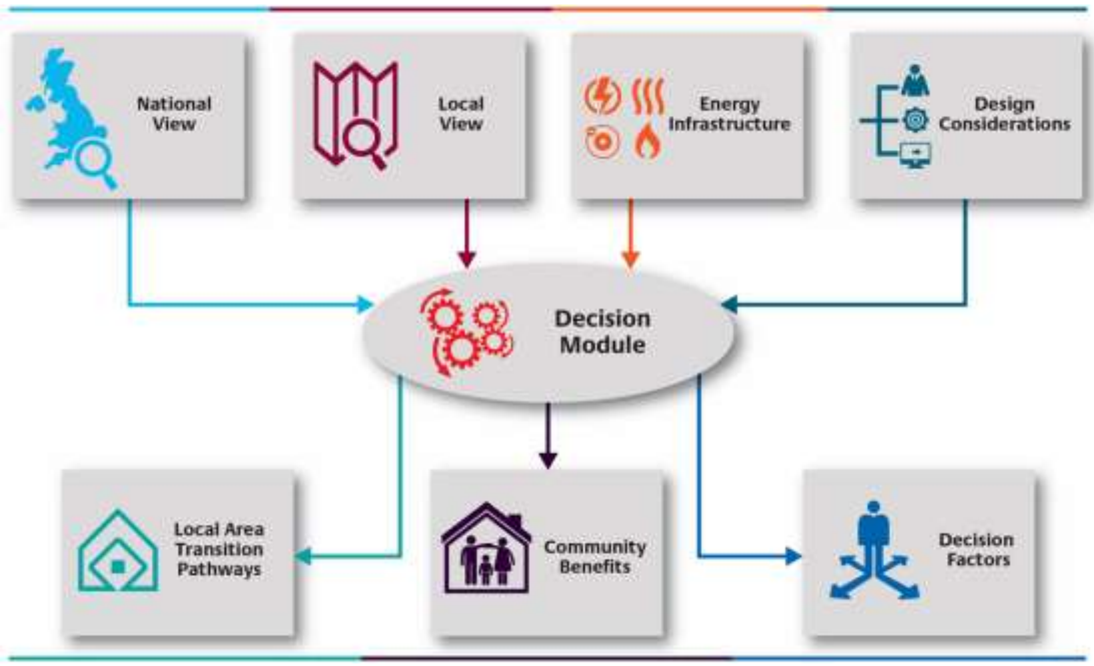


Figure 4-1 Overview of EnergyPath Networks

4.1 Overview

EnergyPath Networks is a whole system optimisation analysis framework. It uses optimisation techniques in a decision module to compare a large number of combinations of options (10s of thousands) rather than relying on comparisons between a limited set of user defined scenarios. The focus is decarbonisation of heat and energy used by buildings at a local level, enabling informed evidence-based decision making by key stakeholders.

The analyses are set in a national energy strategy context, using scenarios created with input from industry and government stakeholders. The analyses include:

- Integration and trade-off between gas, heat and power as methods of meeting heat demand.
- Integration through the energy supply chain from building, upgrading or decommissioning assets (production, conversion, distribution and storage) to upgrading building fabric and converting building heating systems.
- Integration of existing and new build domestic and commercial buildings.
- The ability to understand the spatial relationships between buildings and the networks that serve them so that costs and benefits are correctly represented for the area being analysed.
- Spatial granularity up to a few thousand dwellings level (potentially finer where required).
- A modelled time frame of 2015 to 2050.

Taken together, the analyses provide a view out to 2050 to ensure long-term resilience in near-term decisions, mitigating the risks of stranded assets.

Figure 4-2, Figure 4-3, Figure 4-4 & Figure 4-5 below illustrate some of the components assessed during the EnergyPath Networks analysis.

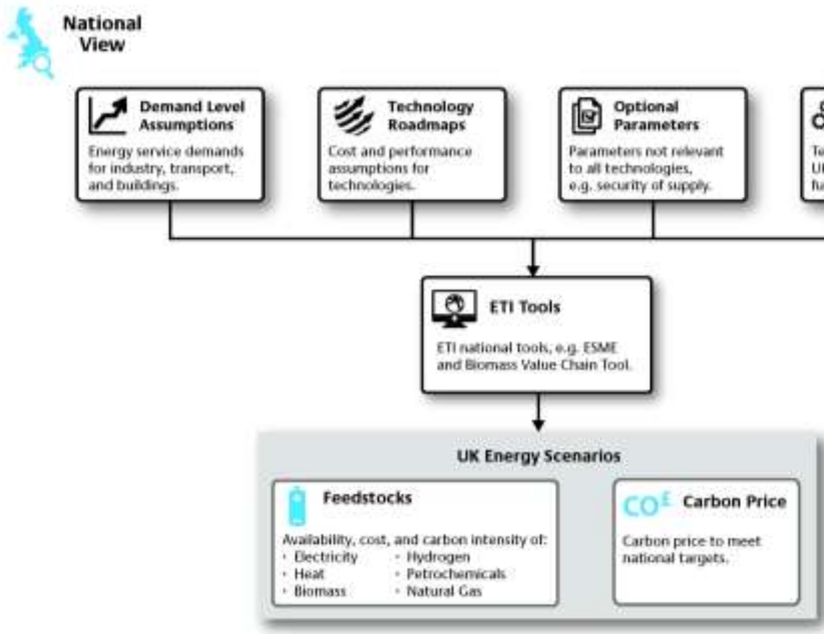


Figure 4-2 National Considerations

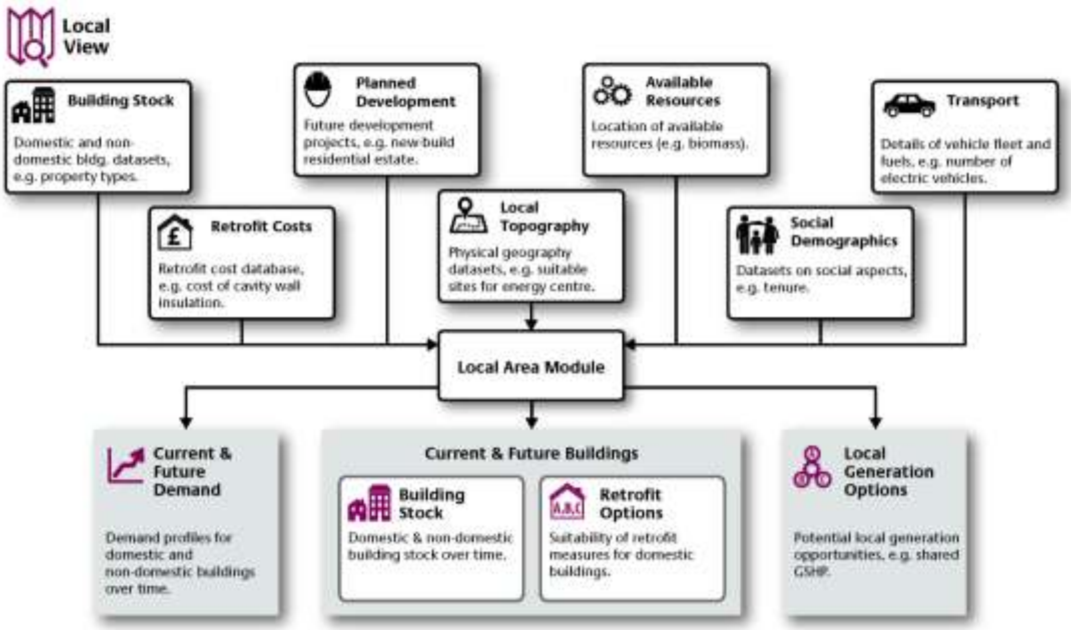


Figure 4-3 Local Considerations

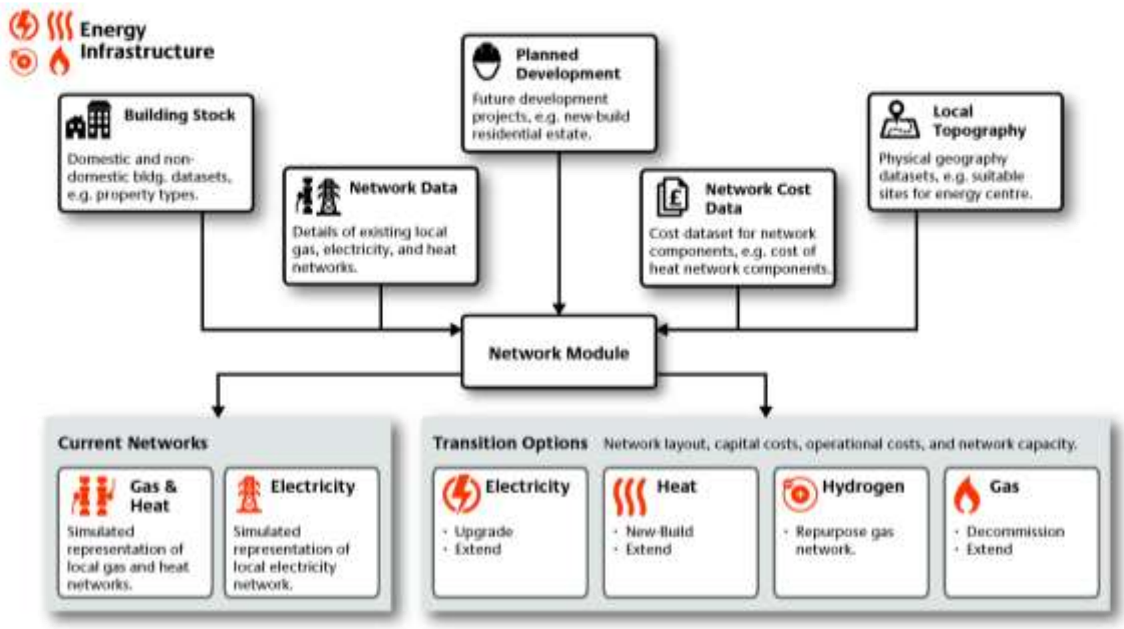


Figure 4-4 Energy Infrastructure Considerations

Figure 4-5 Design Considerations

4.2 Data

EnergyPath Networks requires data for the local buildings and energy networks within the study area. Primary sources of data on building types, condition and thermal properties are shown in Table 4-1. Primary sources of gas and electricity network data, such as network configuration, topography and heat networks, are shown in Table 4-2.

Table 4-1 Primary Data Sources used in EnergyPath Networks Study of Bridgend - Buildings

Building Data	
Item	**Primary Data Sets**
Domestic building archetype	GeoInformation building classification, Ordnance Survey (OS) AddressBase, UNO data (based on collated Energy Performance Certificates (EPCs) and BCBC owned data)
Domestic building thermal properties	Buildings Research Establishment: Standard Assessment Procedure calculator
Domestic building current condition	UNO data (based on collated Energy Performance Certificates (EPCs) and BCBC owned data)
Domestic appliance use profiles	DECC[20] household electricity survey
Domestic retrofit costs	Energy Technologies Institute data
Domestic heating system prices	DECC inputs into domestic RHI
EV charging profiles	National Travel Survey analysis
Non-domestic building use class	Valuation Office Agency (VOA) Ordnance Survey GeoInformation building classification
Non-domestic building energy profile	UCL CARB2 data CIBSE energy benchmarks

Table 4-2 Primary Data Sources used in EnergyPath Networks Study of Bridgend – Networks

Network Data	
Item	**Primary Data Sets**
Electricity network: current configuration	Distribution Network Operator (Western Power Distribution)
Gas network current configuration	Gas Network Operator (Wales and West Utilities) Xoserve
Topography – building locations, building heights and existing road network	Ordnance Survey
Electricity network costs	Distribution Network Operator (Western Power Distribution)
Electricity network technical parameters	Distribution Network Operator (Western Power Distribution)

[20] The Department of Energy and Climate Change (DECC) is now part of the Department of Business, Energy and Industrial Strategy (BEIS).

Gas network costs	Energy Technologies Institute Infrastructure Cost Calculator[21]
Heat network costs	Energy Technologies Institute infrastructure database ARUP
Heat Network technical parameters	ARUP
Energy Centre costs	Energy Technologies Institute data[22], AECOM reports on mine water project prepared for BCBC
Energy Centre technical parameters	Energy Technologies Institute data.

4.3 Practical Constraints

Bridgend is seen, by many, as representative of Wales as a whole, due to its broad mix of rurality, tenures, levels of affluence, building types and geographies. This provides a wealth of opportunities and challenges that, if addressed, could provide learning for Local Authorities throughout Wales.

EnergyPath Networks relies on good data on the built environment and existing energy systems and infrastructure to help produce a model which reflects existing energy systems, energy use and physical constraints for technology deployment. Arup and partners were commissioned to consider specific areas/decarbonisation options and assess their suitability as potential transition options, focusing on:

- Assessment of the potential constraints associated with:
    1. District heat connections for semi-detached buildings built between 1945 and 1964 near Bridgend Town.
    2. District heat connections for terrace buildings built after 1980 near Bridgend Town.
    3. Hybrid heat pumps, standard ASHPs and biomass boilers in pre-1914 terrace buildings in the rural North of Bridgend.
    4. Hybrid heat pumps pre-1914 semi-detached buildings in the rural North of Bridgend.

  This high-level assessment included review of feasibility of building fabric retrofit where identified by EnergyPath Networks. Constraints examined included costs of transition, flood risks, ground conditions, noise (construction and operational), air quality, floor area required for transition, civils/highways, heritage/planning/permitting/visual impact and fuel supply chain and delivery constraints.

- Analysis of area wide development of district heating networks and energy centres, including technology suitability/feasibility and costs. Arup assessed any potential constraints in terms of highways, air quality and visual impact, as well as any value/risks associated with significant heat transmission between energy centres. In particular, Arup were asked to consider suitability and constraints to the use of large scale heat pump technologies in energy centres between 2030 and 2050.

[21] http://www.eti.co.uk/library/energy-storage-and-distribution-brochure-2/
[22] http://www.eti.co.uk/programmes/distributed-energy/macro-de/

- Evaluation of some selected outputs delivered consistently by EnergyPath Networks, namely:
    1. Replacement of existing gas boilers in semi-detached, predominantly privately-owned buildings.
    2. Replacement of existing gas boilers in detached, predominantly privately-owned buildings.
    3. District heat into specific non-domestic buildings including their potential to act as anchor loads.

  These investigations included assessments of the heat demand, energy centres, district heat pipe routing, costs, commercial aspects and risks, as well as the identification of any network installation considerations and real-world case studies.

The assessments have been used to inform the development of the decarbonisation themes discussed in the strategy document.

4.4 Domestic Buildings

Domestic and non-domestic buildings are modelled differently within EnergyPath Networks. The thermal efficiency of domestic buildings is related to the construction methods used and the level of any additional insulation that has been fitted since construction. The oldest buildings in the UK generally have poor thermal performance compared with modern buildings. In addition to building age, the type and size of a building also have a direct influence on thermal performance. For example, large, detached buildings have a higher heat loss rate than purpose-built flats due to their larger external area.

Buildings are categorised into five age bands from pre-1914 to the present in EnergyPath Networks, shown in Table 4.3. The thermal efficiency of new builds is intended to represent the minimum efficiency level required by current building regulations. There are ten modelled property types, shown in Table 4-4. This allows more than 60 different age and property type combinations which are used to define the thermal characteristics of existing and planned domestic buildings.

Table 4-3 Domestic Building Age Bands

Property Age Band
Pre - 1914
1914 - 1944
1945 - 1964
1965 - 1979
1980 - Present
New Build

Table 4-4 Domestic Building Types

Property Type
Converted Flat: - Mid Floor / End Terrace
Converted flat: - Mid Floor / Mid Terrace
Converted Flat: - Top Floor / End Terrace
Converted Flat: - Top Floor / Mid Terrace
Detached
End Terrace
Mid Terrace

Purpose-Built Flat: - Mid Floor
Purpose-Built Flat: - Top Floor
Semi-detached

4.4.1 Current Housing Stock

Once the current characteristics of a building have been defined based on its age and type, the basic construction method can then be categorised. For example, the oldest buildings in the region can be expected to be constructed with solid walls. Buildings constructed between 1914 and 1979 are more likely to have been built with unfilled cavity walls. Buildings constructed from 1980 onwards will have filled cavity walls.

Where available, address level data is utilised in the EnergyPath Networks modelling to provide accurate building attributes. For example, Energy Performance Certificates (EPCs) and Local Authority owned data (collected by UNO) are used to define current heating systems and level of fabric retrofit. However, EPCs are generally only performed when a property is to be sold or rented and Local Authorities will only have building fabric data in relation to LA run retrofit schemes. However, in Bridgend, this collated data covers around 50% of domestic properties.

Generally, missing building attributes are filled using logic rules based on housing survey data but no Welsh Housing Survey exists at present[23]. Therefore, the UNO data was used to define logic rules to fill in any gaps. For example, if within the buildings for which data is available, 80% of semi-detached buildings built between 1965 and 1979 are known to have had their cavity walls insulated, then this proportion of that building type across the whole stock will be categorised as having this measure applied.

The Retrofit measures considered in the study are shown in Table 4-5.

Table 4-5 Domestic Retrofit Measures

Domestic Retrofit Measures
Cavity wall insulation
Double glazing
Energy-efficient doors
External wall insulation
Floor insulation
Internal wall insulation
Loft insulation
Mechanical ventilation
More than triple glazing[24]
New build upgrade to High Thermal Efficiency
Reduced infiltration 1 (Draught proofing)
Reduced infiltration 2 (Whole dwelling)

[23] Welsh Housing Conditions Survey (WHCS) is due for release Autumn 2018 (http://gov.wales/statistics-and-research/welsh-housing-conditions-survey/?lang=en)

[24] Consideration of improving the thermal performance of glazing above that of the assumed level of triple glazing, for example improving the U value from 1.8 W/m²K to 1 W/m²K

Triple glazing

4.4.2 Current and Future Heating Systems

The definition of current heating systems is handled in a similar way to the definition of the building fabric. Xoserve data is first used to identify which buildings are not connected to the gas grid. Then, as discussed above, UNO data is used to identify the heating system by:

1) Direct input where actual heating system in individual buildings is known.
2) Defining logic rules based on the most likely heating system combinations within each archetype group. For example, 97% of terrace buildings built since 1980 have gas boilers.

Once the current thermal efficiency of a building has been defined, the Ordnance Survey MasterMap data is used to establish its floor area and height. With this knowledge of a building's characteristics there is sufficient information to allow a Standard Assessment Procedure (SAP) calculation[25]. SAP calculations have been used to calculate the overall heat loss rate and thermal mass of every domestic building in the study area. EnergyPath Networks utilises these SAP results, as well as detailed retrofit and heating system cost data, to group buildings into similar archetypes, thereby making the problem easier to solve. EnergyPlus[26] is used to calculate dynamic energy profiles for heat and power demand for each archetype, for the current and all potential future pathways. These pathways include potential to install varying levels of retrofit and different future heating systems. Restrictions are applied so that inappropriate combinations are not considered. As an example, neither loft insulation nor a ground source heat pump could be fitted to a mid-floor flat. EnergyPath Networks also filters out heating systems that cannot be sized large enough to meet a predefined target comfort temperature based on the EnergyPlus analysis.

Possible current and future heating system combinations are shown in Table 4-6. Three primary elements are defined in each heating system combinations:

1. The main heating system.
2. A secondary heating system which can provide additional heat or hot water.
3. Thermal storage – either not present or a hot water tank[27].

Table 4-6 Heating System Combinations

Primary Heating System	Secondary Heating System	Heat Storage Technology
Gas Boiler	None	None
Gas Boiler	Electric Resistive not storage heating	None
Oil / LPG Boiler	None	None
Oil / LPG Boiler	Electric Resistive not storage heating	200 litre water tank
Biomass Boiler	None	None

[25] The Standard Assessment Procedure (SAP) is the methodology used by the UK Government to assess and compare the energy and environmental performance of dwellings. (https://www.gov.uk/guidance/standard-assessment-procedure)
[26] EnergyPlus is a widely used dynamic building energy modelling tool developed by the US Department of Energy
[27] The heating tank sizes were chosen so that the heating system combinations had sufficient capacity to meet demand in a range of buildings.

High Temperature Air Source Heat Pump	None	500 litre water tank
Low Temperature Air Source Heat Pump	None	500 litre water tank
Low Temperature Air Source Heat Pump	Gas Boiler	None
Low Temperature Air Source Heat Pump	Solar Hot Water	500 litre water tank
Electric Resistive storage heating	Electric Resistive not storage heating	300 litre water tank
Electric Resistive not storage heating	Solar Hot Water	None
Ground Source Heat Pump	None	200 litre water tank
Ground Source Heat Pump	None	400 litre water tank
District Heating	None	None
Gas Source Heat Pump	None	200 litre water tank
Low Temperature Air Source Heat Pump with electric resistive top up	None	500 litre water tank
Low Temperature Air Source Heat Pump with electric resistive top up	Solar Hot Water	500 litre water tank

4.5 Non-Domestic Buildings

Non-domestic (commercial) building stock is more diverse than domestic stock. There is a wide variety of construction methods and few data sets are available defining the method used for any particular building, its heating system or thermal performance. Due to these limitations, an energy benchmarking approach is used to establish the energy demand of the non-domestic stock. Different building uses are given an appropriate energy use profile per unit of floor area. Benchmarks are defined for electricity, gas and heat demand in 30-minute time periods for different characteristic days. The characteristic heat days for which energy demand profiles are defined are shown in Table 4-7. Benchmarks are defined for current and future use to represent changing energy use over time.

Table 4-7 Characteristic Heat Days

Characteristic Heat Day
Autumn Weekday
Autumn Weekend

Peak Winter
Spring Weekday
Spring Weekend
Summer Weekday
Summer Weekend
Winter Weekday
Winter Weekend

The footprint floor area and height for each building is derived from the OS MasterMap data. The building height is then used to establish the number of storeys, from which the total building floor area is estimated. Using an energy benchmark appropriate to the particular use class, the half hour building energy demand for gas, electricity and heat is calculated for each of the characteristic days.

As discussed in Section 3.1.5, non-domestic heat network connections are considered where buildings currently use gas as a heating fuel but do not use gas for industrial purposes. EnergyPath Networks provides non-domestic pathway options for these buildings, with transition costs based on data provided by Arup.

For both domestic and non-domestic pathway options, EnergyPath Networks includes costs of replacing all technologies at their end of life. At these points technologies can be replaced with a lower carbon system or like-for-like. For example, even in a business as usual scenario, costs will be incurred when gas boilers and windows are replaced with analogous technologies.

4.6 Energy Network Infrastructure

In order to assess potential options for future changes to energy systems, knowledge of current electricity, gas and heat network routes and capacities is required. From this the costs to increase network capacities in different parts of the local area, as well as extending existing networks to serve new areas, can be calculated. The road network is used in EnergyPath Networks as a proxy to calculate network lengths and current and future capacities are established using steady-state load flow modelling of networks. For example, EnergyPath Networks will find the load at which a Low Voltage (LV) feeder will require reinforcement and the costs associated with doing so. The cost of operating and maintaining the networks vary with network capacity and is modelled using a cost per unit length broken down by network asset and capacity. In Bridgend, there are no existing heat networks so only future heat network options are modelled.

The EnergyPath Networks method does not replicate the detailed network planning and analyses performed by network operators. Rather, the energy networks are simplified to a level of complexity sufficient for numerical optimisation and decision-making. The method is used to model the impact of proposed changes to building heat and energy demand on the energy networks that serve them, for example increased or reduced capacity. The costs of these impacts can then be estimated and the effects of different options on different networks can be compared.

Western Power Distribution provided the following data for the current electricity network:

1) Locations and nameplate capacities of the HV (33kV to 11kV) and LV (11kV to 400V) substations.

2) HV to LV substation connections.

3) Average costs of replacing network assets.

EnergyPath Networks synthesises the routes of the HV to LV substation connections based on 2), assuming that feeders follow the road layout. Customer connections are then found based on nearest substation and peak load constraints for each feeder. Non-domestic buildings with demand above 161kW are assumed to connect directly to the HV network. Network feeder capacities are then calculated based on the current load on each feeder and a headroom allowance. EnergyPath Networks performs steady state load flow modelling for electricity and heat networks using the Siemens tool PSS®SINCAL[28].

To establish which buildings in the study area are currently connected to the gas grid data from Xoserve[29] is used. Buildings for which the user explicitly specifies non-gas heating systems are also assumed not to have an existing gas connection.

Xoserve data is further supplemented by data from Wales and West Utilities, providing the points at which the gas network enters the study area and the routes of the local transmission system through the local area. EnergyPath Networks does not carry out detailed modelling of gas networks. It is assumed that the current network has sufficient capacity to meet current demand and that, in general, gas demand will decline over time due to efficiency improvements and the wider need to decarbonise energy systems. This assumption can fail when gas Combined Heat and Power (CHP) energy centres are deployed in the modelling in areas where the gas network does not have sufficient capacity to meet their demand. For this reason, Wales and West provided cost data for gas CHP connections in areas of interest for the post-sensitivity runs. These costs were included in the cost of the energy centre to reflect the costs of building and connecting gas CHP energy centres more accurately.

4.7 Spatial Analysis

Using different building classification data sets it is possible to identify whether an individual building is domestic or non-domestic and to classify either the age and type for domestic buildings or the use category for non-domestic buildings.

Using the OS MasterMap it is then possible to locate all the buildings spatially in the study area. Once this has been done the following can then be identified:

- The nearest road, to identify where the building is most likely to be connected to energy networks.
- The building height, to give the number of storeys.
- The building plan area, to allow calculation of the building energy demand.

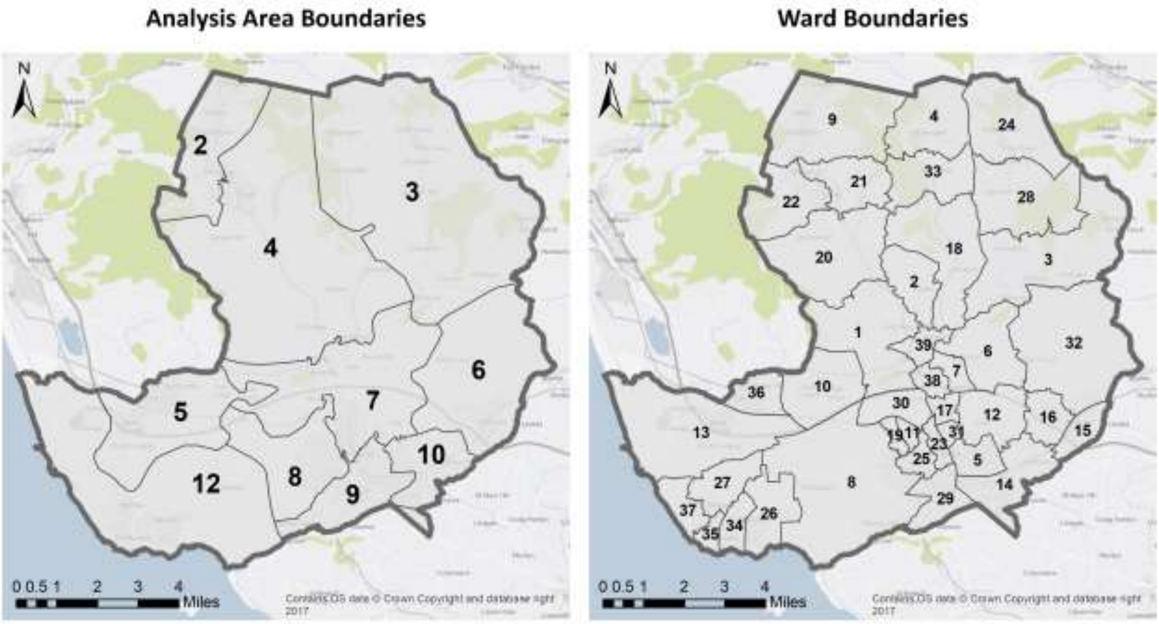
As described in Section 4.6, it is assumed within EnergyPath Networks that energy networks follow the road network. Identification of the road nearest to each building allows the energy demand (for gas, heat and electricity) of that building to be applied to the appropriate energy networks at the appropriate point on those networks. In this way the total load and the load profile for each energy network can be calculated at different scales from individual building level, through local networks up to aggregate values for the whole study area as required. This allows an understanding of different energy load scenarios in different parts of the local area and the energy flows between those locations. In addition, an understanding of network lengths and required capacities can be established.

[28] http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/software-solutions/planning-data-management-software/planning-simulation/pss-sincal/pages/pss-sincal.aspx
[29] Xoserve provide services to the gas industry, including management of gas supplier switching and transportation transactional services, www.xoserve.com

4.8 Analysis areas

Due to the sheer complexity of the options presented to EnergyPath Networks (for buildings, networks and generation technologies) the problem cannot be solved at individual building or network asset level. The study area (Bridgend) is divided into a number of spatial analysis areas. Decisions are made at this level based on aggregating similar buildings and network assets within each area. These analysis areas were defined by the area served by the High Voltage substations illustrated in Section 3.4.1.

The analysis areas are necessary conceptually within the EnergyPath Networks model but do not correspond directly to local districts, wards or neighbourhoods recognised by the local community. Figure 4-6 shows the relationship between ward boundaries and analysis areas in Bridgend.



ID	Ward	ID	Ward	ID	Ward	ID	Ward
1	Aberkenfig	10	Cefn Cribwr	20	Llangynwyd	30	Pen-y-fai
2	Bettws	11	Cefn Glas	21	Maesteg East	31	Pendre
3	Blackmill	12	Coity	22	Maesteg West	32	Penprysg
4	Blaengarw	13	Cornelly	23	Morfa	33	Pontycymmer
5	Brackla	14	Coychurch Lower	24	Nant-y-moel	34	Porthcawl East Central
6	Bryncethin	15	Felindre	25	Newcastle	35	Porthcawl West Central
7	Bryncoch	16	Hendre	26	Newton	36	Pyle
8	Bryntirion, Laleston and Merthyr Mawr	17	Litchard	27	Nottage	37	Rest Bay
9	Caerau	18	Llangeinor	28	Ogmore Vale	38	Sarn
		19	Llangewydd and Brynhyfryd	29	Oldcastle	39	Ynysawdre

Figure 4-6 EnergyPath Networks Analysis Areas Relative to Bridgend County Borough Council Ward Boundaries

Within each analysis area, different components of the system are aggregated as described in Section 4.4.2. As discussed, the aggregation of buildings is performed based on energy demand and cost of retrofit. This way, similar buildings within an individual analysis area will then all follow the same pathway. Similarly, decisions on network build and reinforcement are made at an aggregated level. If the electricity loads in one analysis area increase such that the aggregated capacity of the low voltage feeders is exceeded, then reinforcement of all low voltage feeders within that area will be assumed to be required. The same applies for all other aspects of the energy networks such as low voltage substations, high voltage feeders and substations and heat network capacity.

Since scenario options are aggregated it is important that the boundaries between analysis areas do not cut across the electricity network. It would be nonsensical to reinforce the 'downstream' end of an electricity feeder without considering the impact of the loads on those components further upstream in that network. To ensure consistency in the analysis of electricity network options, the study area was divided by considering each high voltage substation within the local area and all of the electricity network downstream of each substation to give the analysis areas discussed above. Once these analysis areas had been defined energy network links between them were defined. This allows transmission of heat and gas across the analysis area boundaries.

4.9 Local Energy System Design Considerations

Within EnergyPath Networks only feasible technical solutions are considered e.g. those listed in Section 4.4.2, including Heat Networks, Ground Source or Air Source heat pumps, electric resistive, hybrid boilers and domestic thermal storage. Options which are not feasible are excluded, for example, fitting a ground source heat pump or loft insulation into a mid-floor flat or cavity wall insulation to a building which has solid walls.

There are other options which, whilst they might be logically possible, are not generally practical in a real-world environment. For example, the selection of ground source heat pumps into areas of dense terraced housing is excluded from the analysis. A lack of space means that cheaper ground loop systems cannot be fitted whilst there is insufficient access for the equipment required to create vertical boreholes. In addition, the heat demand for a row of terraced houses may cause excessive ground cooling in winter leading to inefficient heat pump operation and a need for additional top-up heat from an alternative source. A shared GSHP scheme could be technically feasible for a row of terraces, providing accessible land is available. Again, this land would need to be of sufficient size to avoid excessive ground cooling.

In addition to technical and commercial reasons, consumer preferences also influence why certain options may not be appropriate. The installation of domestic hot water tanks for heat storage is a good example. Many households have removed old hot water tanks and fitted combi-boilers to provide hot water on demand. This allowed the space previously occupied by the hot water tank to be repurposed for other uses which householders find more valuable, maybe as additional storage, or to increase the size of a room. Others still value a hot water tank, for example, as a means of drying wet washing indoors. Many new, low carbon, heat technologies such as air source heat pumps, work at a lower output power than conventional gas boilers. This can require the use of heat storage in order to be able to meet peak demand for heat on cold days.

Whilst re-installation of the hot water tank might be technically feasible, and the cheapest low-carbon choice for heat provision to a particular building, it is unlikely to be an acceptable solution to many households who value the space gained by removal of the hot water tank. These considerations restrict the scale of domestic heat storage which is viable and the types of buildings into which it might be deployed. Table 4-6 illustrates the storage tank sizes considered in EnergyPath Networks for each primary and secondary heat combination. Particular primary and secondary combinations may be able to provide necessary output if paired with larger storage options, e.g. an ASHP in a pre-1914 large detached building may not be able to meet necessary heat demand with a 500 litre storage tank but combining with a larger storage tank is not considered a credible option. Of course, consumers may not be willing to accept any size of hot water tank for the reasons discussed above. This binary choice is not reflected in EnergyPath Networks since we cannot credibly predict consumer behaviour at this level. Instead, questions like this are considered as part of the strategy document and any resulting feasibility studies. From a technical perspective, investigations into the development of storage technologies that better meet consumer needs could be worthwhile. The technical and cost requirements necessary to make these technologies part of the least cost solution from a whole system perspective.

Even if building level storage is developed, further work may be necessary to understand whether future heating systems with building storage are really an option consumers will choose. This will lead to questions such as “what policy would be required to make these options attractive?”, “if consumers will not accept these technologies, how much more would it cost to install similar options that do not require storage (e.g. high temperature ASHPs or hybrid heat pumps)?”. These aspects are discussed further in the Strategy.

In some cases, it is appropriate to force or constrain different technology options in EnergyPath Networks for particular building types and geographic areas to reflect technical, commercial, social and consumer choices. For example, a Local Council, or Housing Association (a Registered Provider of Social Housing), might be planning a wide scale home improvement programme in a part of a local area with the objective of tackling fuel poverty. This retrofit programme should be included in the EnergyPath Networks analysis. Alternatively, technologies may be restricted, e.g. if the Local Authority contains conservation areas.

4.10 Limitations and Uncertainties

Within any technical modelling exercise decisions must be made as to the level of complexity and detail that is appropriate to the purposes of the study being undertaken. There are several areas where limitations have been applied to limit the complexity of the EnergyPath Networks analysis to keep the scale of the analysis being performed at a level that allows for practical analysis.

4.10.1 Exogenous Input Parameters

Some parameters are considered as exogenous inputs within EnergyPath Networks. That is, they are derived externally and presented as inputs to the tool. Any options to vary these parameters are excluded from the decision module. The following energy demands are modelled as inputs:

1. Domestic lighting and appliance demands are based on data from DECC’s (Department of Energy and Climate Change)[30] household electricity survey which gives these demands for different house types.
2. Electric vehicle charging profiles are based upon assumed take-up rates for electric vehicles and are based on car journeys extracted from the Department for Transport’s National Travel Survey. This means that distances travelled (level of charge required) and times of arrival (time of charging) reflect the diversity of real world use.
3. Non-domestic building demands for current systems and future transition options are calculated based on building use and a set of energy benchmarks.

Note that electricity use for “non-heating” practices is not considered within EnergyPath Networks, which precludes 1. and 2. from the decision module. Non-domestic heating demands are calculated based on energy benchmarks by building use, as described in Section 4.5. In theory, non-domestic could be simulated in a similar way to domestic building demands. However, at the time of the Bridgend study, the data necessary is not available.

[30] Now part of BEIS (the department of Business, Energy and Industrial Strategy)

4.10.2 Building Modelling

Within the domestic building simulation, a standard target temperature profile is used for all domestic buildings. This is intended to reflect typical building use patterns. The profile used is that used within SAP. It is recognised that real-world building use will not match this profile in many cases. In order to reflect this diversity factors are applied within EnergyPath Networks when individual building energy demands are aggregated to calculate total network demands. These diversity factors modify both the magnitudes of the demands and the times at which they occur.

Construction standards are assumed for buildings of different ages. For example, all pre-1914 buildings are assumed to have solid walls. Similarly, for some building ages the thermal conductivity of the walls is assumed to be the same for each level of insulation. For example, all buildings constructed between 1945 and 1964 with filled cavity walls are assumed to have the same thermal performance. Note that these performance assumptions are based on 'traditional' brick construction. Buildings constructed in other ways may not be correctly represented in terms of their thermal performance.

4.10.3 Network Modelling

The network modelling approach assumes that development of future energy systems should be driven by consumer needs rather than network operators attempting to change energy demands through imposition of solutions upon consumers. On this basis, the EnergyPath Networks modelling framework works on a traditional network reinforcement model. If load on a network is calculated to exceed capacity, then the network will be reinforced to meet that load.

There is no capability within the model to consider 'Smart' network control or all aspects of demand side response. However, it is possible to restrict the times at which domestic energy storage can be charged. This allows simulation of reduction of network loads during times of peak demand through heating system choice.

High voltage and low voltage substation connections and heat networks are synthesised where connection and capacity data are not available. Building level electricity connections are always synthesised. This means that decisions concerning network reinforcement may be inaccurate where network operators do not provide HV to LV substation connection data. This is not the case for Bridgend, since WPD provided all requested data.

Load-flow modelling is based on steady state loads and is not dynamic. The intention is to establish peak loads and the capacity required to meet them to understand the influence of different options on network costs. It is not intended to replace full network modelling conducted by network operators.

4.10.4 Technology Cost and Performance

EnergyPath Networks attempts to establish the future energy system which will have the lowest cost to society. It is expected that, once a preferred strategy has been defined, the mechanisms which enable and encourage its implementation will then be developed. As well as technical parameters, the selected option is determined by the costs associated with different technology options. It is important that cost is used as an input rather than price as this will be influenced by supply and demand and market conditions for any particular technology.

Where available, cost data from public sources were used, although cost and price data can be difficult to distinguish in publicly available data. It can also be difficult to establish the true costs of a technology when deployed at scale. As an example, cost data sets associated with the domestic renewable heat incentive were used to produce the cost data for domestic heat pumps. However, heat pump suppliers may have inflated their submitted costs in an effort to increase the amount of subsidy or sold units at reduced prices for trials in an effort to build a market for future sales. For some technologies, cost data might be commercially sensitive, for example CHP plants and heat networks, in these cases a variety of data sources are used to ensure that estimated costs are within reasonable bounds.

There may be reductions in future costs due to improved design and manufacturing methods which are difficult to estimate, therefore a range of likely future costs has been defined for each technology to account for this uncertainty. A series of sensitivity runs of the Decision Module have been performed where different values were selected randomly from the range to generate a set of possible outcomes. The results of this sensitivity are discussed in Section 5.6.

4.10.5 Validation of Modelling Approach

The EnergyPath Networks Bridgend study has been developed in partnership with a Key Stakeholder Group including Bridgend County Borough Council, Western Power Distribution, Wales and West Utilities and Welsh Government. This group has been involved throughout the process and has been given the opportunity to review:

- The underlying cost data and input assumptions.
- The modelling process used.
- Setting of the carbon target.
- Outputs from all model runs.
- Decisions based on those outputs that have been used to define inputs for subsequent runs.
- The final local area energy strategy.

The group also chose the items to be assessed via sensitivity analyses.

In addition, engineering consultants Ove Arup and Partners[31] were engaged to assess the engineering feasibility for specific technical options and provide additional insights for the EnergyPath Networks model. Specific areas of involvement included:

- Cost data for non-domestic district heat connection by building use.
- Analysis of outputs across wide areas of the local area to ensure consistency and technical appropriateness and to identify areas where outputs may not be feasible due to real world constraints.
- Review of district heat networks included in EnergyPath Networks outputs including consideration of capacity, cost and heat provision technologies.

[31] An independent firm of designers, planners, engineers, consultants and technical specialists. (http://www.arup.com/)

4.11 Technologies

A variety of technologies have been considered within the EnergyPath Networks analysis. These are described below.

4.11.1 Primary Heating Systems

Different heating systems have been considered within the analysis including current systems and possible future options. Table 4-6 shows details of how the main and secondary heating systems have been considered in combination with building level heat storage. Some of these, such as gas and oil boilers emit significant quantities of carbon dioxide. Electrically powered heating systems have the potential for much lower emissions, particularly if the electricity is sourced from low carbon generation. The heating systems assessed are as follows:

- Gas boilers are the main source of heat for domestic premises in the UK at present.
- Oil / LPG boilers are a popular heat source for those buildings which are not connected to the gas network.
- Biomass boilers can provide a low carbon heat source by burning fuel derived from sustainably sourced wood products.
- Heat pumps use electrical energy to transfer heat energy from one source to another and to change its temperature in the transfer process. They are similar to a domestic refrigerator which transfers heat from a cold space to the surrounding room. This is reversed in a heat pump system so that the internal space is warmed by transferring heat from outside. Heat pumps have an advantage compared to other electrically powered heat sources as they produce more heat energy than the electrical energy required to power them. Different types of heat pump are considered:
    - Low Temperature Air Source Heat Pumps (ASHPs) use the outside air as the source of heat and provide hot water to the heating system at temperatures around 45°C. This temperature is lower than that normally used for domestic heating with a gas boiler and so may require changes to heating distribution system, such as the provision of larger radiators to allow the building to be heated effectively.
    - Low Temperature Air Source Heat Pump – Gas Boiler Hybrids use a combination of a low temperature ASHP to provide a large proportion of the heat demand but can top up this heat using a conventional gas boiler at times when it is not efficient to operate the heat pumps, or the heat pump cannot meet the required demand.
    - Low Temperature Air Source Heat Pumps can also have supplementary heat provided by direct electric heating at times when it is not efficient to operate the heat pump.
    - High Temperature Air Source Heat Pumps are similar to a low temperature Air Source Heat Pump but provide hot water at a higher temperature (typically 55°C) which can remove the need for other modifications to the heating system.
    - Ground Source Heat Pumps use heat energy stored in the ground to provide hot water to the heating system. Since ground temperatures are higher than air temperatures in winter they can operate more efficiently and provide higher water temperatures than air source

heat pumps. Space is required, however, to install pipework to extract heat from the ground and this adds considerably to the cost of installing these systems.

  - Gas Source Heat Pumps burn gas to provide the heat source for a heat pump. They are more efficient than a conventional gas boiler but burning gas means that they will never be a low carbon heat solution.

- Electric Resistive storage heating is the most commonly used system for buildings which have electric heating. Room heaters are typically heated overnight (where there can be an option to charge the system at a lower (night rate) electricity tariff) and then release this heat over the course of the following day.
- Electric Resistive heating without storage provides instant heat through panel, fan or bar heaters.
- District heating provides heat to buildings through pipes that carry the heat from a central heat source. In current systems, this is typically a large gas boiler or gas fired Combined Heat and Power (CHP) plant which provides heat to the network and generates electricity which is either consumed locally or exported to the electricity network. Once installed these systems can be converted from using gas to lower carbon alternatives such as a large-scale Ground Source Heat Pump or a biomass boiler.

4.11.2 Building Retrofit Options

Domestic buildings in the UK have been constructed to a wide variety of building regulations depending on their age. Many older buildings have low levels of insulation and require much more energy to keep them warm in winter than those built to more recent regulations. There are many options available to reduce heat loss from older buildings some of which could also be applied to more modern buildings. Loft insulation, wall insulation (cavity or solid depending on existing building fabric) and triple glazing retrofit options are modelled within the EnergyPath Networks model. In addition, some minor improvements are considered as secondary measures. That is, “quick wins”, such as draught proofing, that could be installed at the same time as more substantial building fabric upgrades.

4.11.3 Solar Power

EnergyPath Networks considers the deployment of solar panels to generate electricity and hot water. Both systems can produce significant amounts of energy in summer months but may produce close to zero energy on winter days when the sun is low in the sky and days are much shorter. This means that their benefits are limited as energy demand for heat is at a maximum at precisely the times when these systems are least effective.

In the case of electricity generation, the power might be used by the home owner or might be exported to the electricity network if the amount being generated exceeds the demand of the generating building.

Solar Hot Water systems typically heat water in a hot water tank by circulating a fluid between a heating coil within the tank and the roof mounted panel which is heated by the sun.

4.11.4 Energy Centre Technologies

District heating provides heat to buildings through pipes that carry the heat from a central heat source. A wide variety of technologies are available that can provide this heat:

- Heat from power stations can be used directly to provide energy to heat networks.
- Heat pumps can be used at a large scale in a similar way to that discussed above for individual building heating systems. They can use a variety of heat sources:
    - Ground Source Heat Pumps typically use deep boreholes to take advantage of the higher temperatures underground.
    - Water Source Heat Pumps take advantage of the fact that most rivers and seas have reasonably stable temperatures throughout the year. This makes them a good source of heat in the winter.
    - Waste Heat Pumps typically use warm air that is emitted from industrial or commercial purposes. Examples have included warm air vents from the London Underground and heat emitted from the computers within data centres.
- Biomass can provide a low carbon source of heat in two main ways:
    - Boilers burn the biomass to provide heat directly to a network.
    - Combined Heat and Power (CHP) systems work like small-scale power stations where the heat that would normally be discarded to the atmosphere is used to provide heat to a network and the electricity generated is either consumed locally or exported for use in the local electricity network.
- Domestic and industrial waste can be incinerated to provide heat for networks. This can be done in conjunction with a generation system that produces electricity as well as heat.
- Gas can be burnt in three different technologies to provide heat for networks:
    - Gas Boilers are large-scale versions of domestic systems.
    - Gas Engine CHP runs a large engine, similar to that in a heavy goods vehicle. This drives a generator to produce electricity and the heat that would be wasted in the truck radiator and exhaust gas is captured and delivered to the heat network.
    - In Gas Turbine CHP, an engine similar to that on a jet airliner is used to power a generator to produce electricity. The exhaust heat is captured and delivered to the heat network. These types of systems are only likely to be used where there is considerable demand for both heat and electricity.

4.11.5 Heat Storage

Heat storage can be considered at two scales:

- Individual domestic storage in hot water tanks.
- Large-scale storage in association with heat networks.

In both cases, it is assumed that more heat could be produced at certain times than is required to meet demand. This provides an option to store that heat and then release it back into the heating system at times when the peak demand is very high. It can often be the case that this will be a cost-effective solution as it allows a less powerful heat source to be installed that can be topped up using stored heat at times of peak demand. It is appreciated that many households have removed hot water tanks and fitted gas combi-boilers which provide hot water on demand, as discussed in Section 4.9.

4.12 Carbon Emissions

Calculation of carbon emissions and setting of future targets is a complex subject. This section does not attempt to provide full details on the subject but to give a high-level view of the approach used for this study.

Not all of the total emissions from the study area are included in the EnergyPath Networks model. Domestic, industrial and commercial emissions (i.e. those related to buildings) are included, whereas transport emissions and those resulting from land use change are excluded from the analysis. Some non-domestic buildings do show emissions reductions over the time period to 2050, even if their heat demand is met using gas or electricity. Emissions from these buildings are represented by the input parameters and are related to:

- Conversion of the national grid to low carbon electricity which decarbonises the emissions associated with local electricity consumption.
- Reduced gas use in buildings where there is historical evidence to support this trajectory – mainly associated with professionally managed buildings whose managers have a commercial incentive to improve energy efficiency.

4.13 Decision Module

EnergyPath Networks has been used to provide evidence to support the development of a local area energy strategy that helps to meet carbon reduction targets. The importance of other factors such as fuel poverty and health benefits are recognised in the Strategy but they are not core parameters in EnergyPath Networks.

Once a set of potential scenario options for the buildings and energy networks in the local area have been identified, the Decision Module compares all valid option combinations and selects the set that meets the CO_2 emissions target at minimum cost. Costs are considered to be the total cost to society for the whole energy system including capital costs, fuel costs and operation and maintenance costs, discounted (see box) to 2015. Taxes and subsidies are excluded, these being transfer payments with zero net cost to society. Their inclusion in the analysis may result in the selection of sub-optimal solutions. The intention is that, once an appropriate strategy has been defined, the mechanisms that will allow and encourage development and deployment of that strategy can then be developed.

> Discounting is a financial process which aims to determine the "present value of future cash flows", or in other words: calculating what monies spent or earned in the future would be worth today. Discounting reflects the "time value of money" – one pound is worth more today than a pound in, say, one year's time as money is subject to inflation and has the ability to earn interest. A Discount Rate is applied to financial inflows or outflows – this generally reflects what it costs a company to borrow money or is a defined rate such as the 3.5% discount rate suggested in the UK Treasury's "Green Book" (this is used in the financial evaluation of UK Government projects).

For each domestic building, the model assumes that the heating system will be replaced twice between now and 2050, (referred to as transitions one and two). This assumes that heating systems are replaced at their end of life (generally around 15-20 years). On each of these occasions there is an opportunity to change to an alternative heating system and perform some level of building fabric retrofit. Three different levels of retrofit (thermal performance enhancement) are considered, ranging from do-nothing to a full retrofit[32]. In addition, each heating system option (see Table 4-6) can be combined with advanced heating controls and each level of retrofit. Options will be excluded if a new heating system technology is unable to provide sufficient power to meet heat demand in a building with a given level of retrofit. These combinations mean that for each building there can be as many as 126 different future pathways which must be considered.

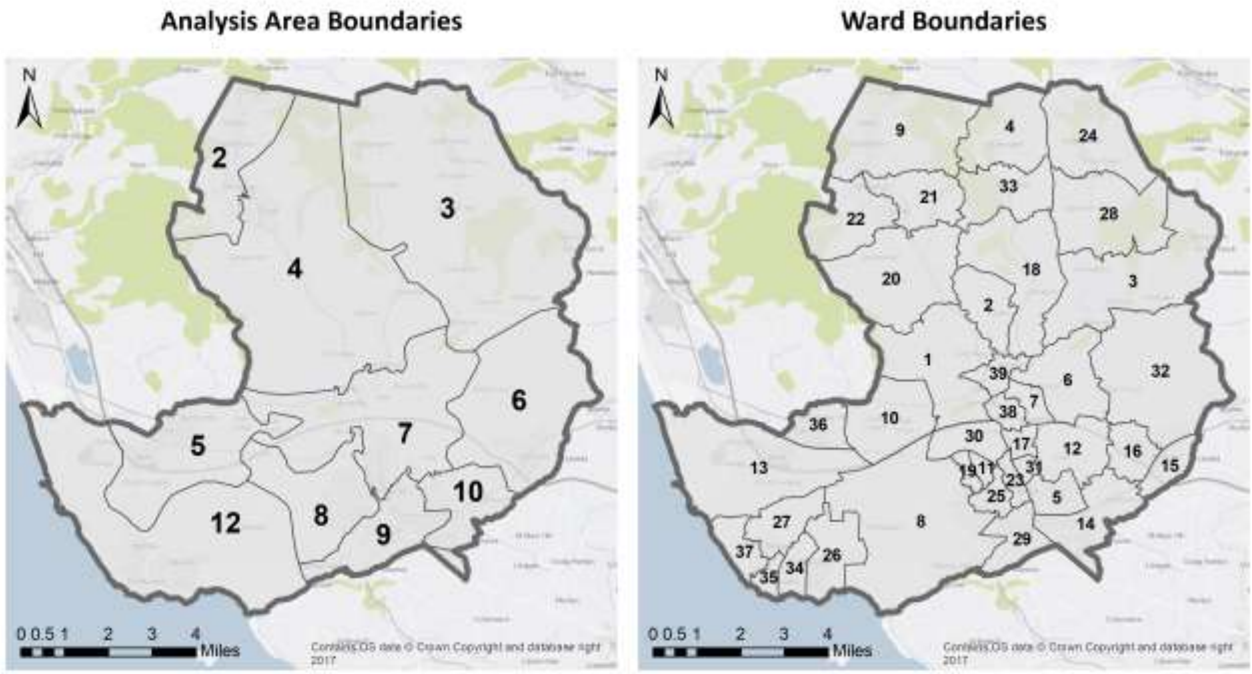
Buildings are aggregated into base archetypes as described in Section 4.4.2 and the study area is divided into analysis areas as defined by the HV network as per Figure 4-6. This generates over 120,000 building pathways for analysis in Bridgend. Additional options for new-build, non-domestic buildings, reinforcement and decommissioning of energy networks, and for heat network technologies further increase the number of options in EnergyPath Networks.

[32] A basic retrofit package consists of cavity wall and loft insulation only whereas a full retrofit would also include external wall insulation and improved glazing (up to triple glazing).

5 Options and Choices for a Low Carbon Local Energy System

This chapter provides a summary of the local area representation that has been developed for Bridgend, followed by introducing the base run created by EnergyPath Networks. The sensitivity analyses that are applied to the base run to inform the development of Bridgend's potential decarbonisation scenarios, is then discussed. The purpose of the various modelling approaches is to understand the prevalent decarbonisation themes identified through the analysis, based on the assumptions used and limitations of the model. These can then be considered alongside one another to assess the resultant conclusions. This chapter also details the Business as Usual (BAU) scenario that has been developed to represent a do-nothing situation.

Figure 4-6 is repeated here to aid the interpretation of analysis area level results in this chapter.



ID	Ward						
		10	Cefn Cribwr	20	Llangynwyd	30	Pen-y-fai
1	Aberkenfig	11	Cefn Glas	21	Maesteg East	31	Pendre
2	Bettws	12	Coity	22	Maesteg West	32	Penprysg
3	Blackmill	13	Cornelly	23	Morfa	33	Pontycymmer
4	Blaengarw	14	Coychurch Lower	24	Nant-y-moel	34	Porthcawl East Central
5	Brackla	15	Felindre	25	Newcastle	35	Porthcawl West Central
6	Bryncethin	16	Hendre	26	Newton	36	Pyle
7	Bryncoch	17	Litchard	27	Nottage	37	Rest Bay
8	Bryntirion, Laleston and Merthyr Mawr	18	Llangeinor	28	Ogmore Vale	38	Sarn
9	Caerau	19	Llangewydd and Brynhyfryd	29	Oldcastle	39	Ynysawdre

Figure 5-1 EnergyPath Networks Analysis Areas Relative to Bridgend County Borough Council Ward Boundaries

The previous chapters have set the scene for the creation of the Evidence Base. Through applying the process described in Chapter 4, a representation of Bridgend's local area has been developed and imported into EnergyPath Networks. This provides the starting point on which to conduct the analysis and develop the strategy.

5.1 Base Run

The Base Run is the first model run generated using EnergyPath Networks. It is used to set the baseline position to make all future decisions regarding subsequent modelling decisions/analysis. In effect, the model generates an initial lowest cost transition model but without applying any considered learning, such as outcomes from sensitivity testing. Each subsequent model run provides a new layer of understanding and insight that is considered and then applied to the model to improve its robustness as required. Results from the Base Run are also discussed with the project stakeholders to ensure local consideration is reflected in the outputs and transition options suggested by the model, providing a necessary level of real world and local applicability.

The decarbonisation trajectory for Bridgend was agreed with the stakeholder working group and is represented by the red line in Figure 5-2. This trajectory was used for all Bridgend model runs apart the BAU scenarios, created for comparison with the base run and post-sensitivity runs.

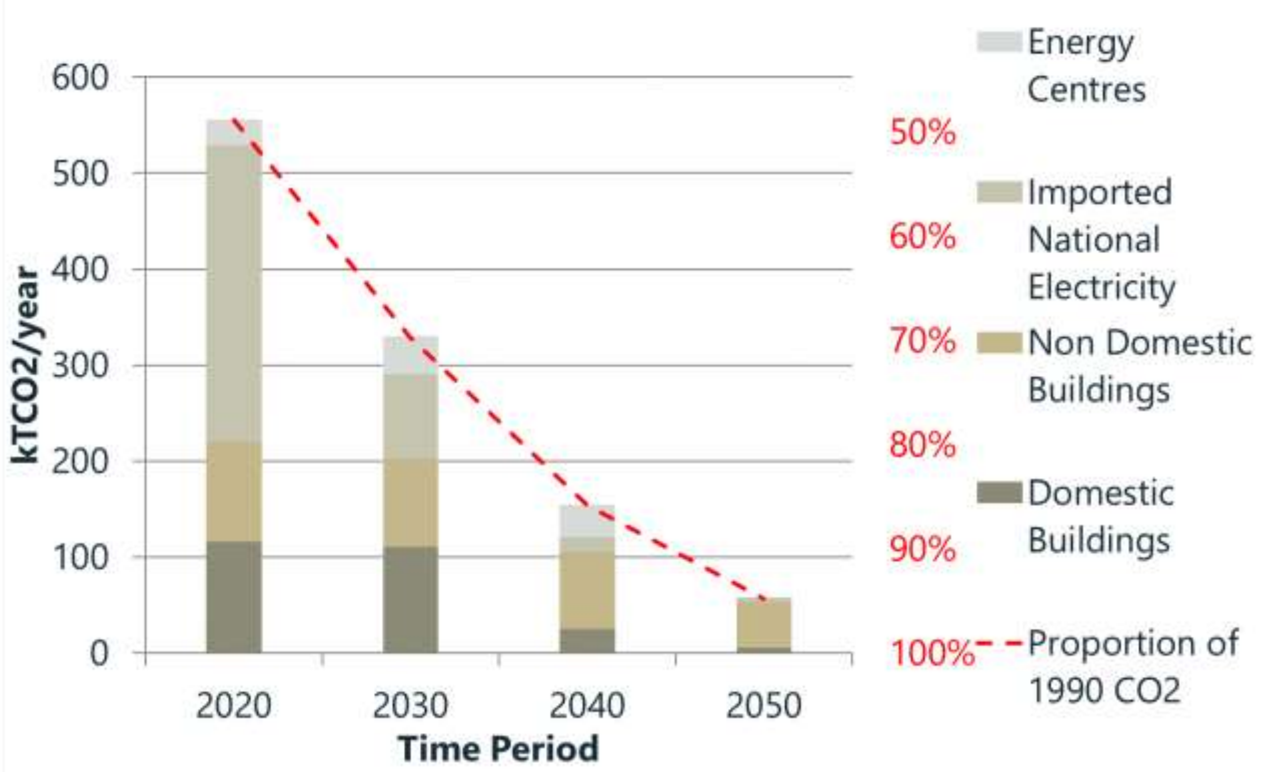


Figure 5-2 Carbon Reduction Trajectory and Emissions by Sector for Base Run

The bars in Figure 5-2 illustrate where carbon dioxide was "spent" in the base run for Bridgend. This shows decarbonisation occurs in all sectors with around 5% of carbon (relative to 1990 levels) remaining in non-domestic buildings. Non-domestic buildings that utilise gas for industrial purposes are prevented from transitioning to district heat. However, this does not completely account for the ~5% of remaining carbon, suggesting that (at least some) of the Bridgend non-domestic buildings are more expensive to decarbonise than any other option.

The other key results of the Bridgend base run are compared with the BAU analysis in Section 5.2.

5.2 Business as Usual

5.2.1 Context

To assess the impact of any proposed decarbonisation scenarios/measures, they should be compared with the modelled baseline do-nothing or business-as-usual option under which no decarbonisation measures are implemented. This comparison provides an indication of the benefits of the proposed changes and their associated costs.

This analysis is very useful as it provides an insight into the costs that would be incurred regardless of decarbonisation targets. It also identifies any transitions that are also chosen despite the absence of a carbon target, thereby helping to identify low regret projects.

In the BAU scenario the Town Heat network is forced to allow direct comparison with the base run. The non-domestic connections forced are in analysis areas 7, 8 and 9.

Under a BAU scenario a local area carbon target for the period to 2050 was set to be unchanged from the emissions in 2014. However, the EPN analysis assumes that decarbonisation of electricity generation will occur in parallel being subject to national greenhouse gas emissions reduction targets. Projections for the BAU carbon emissions are show in Figure 5-3.

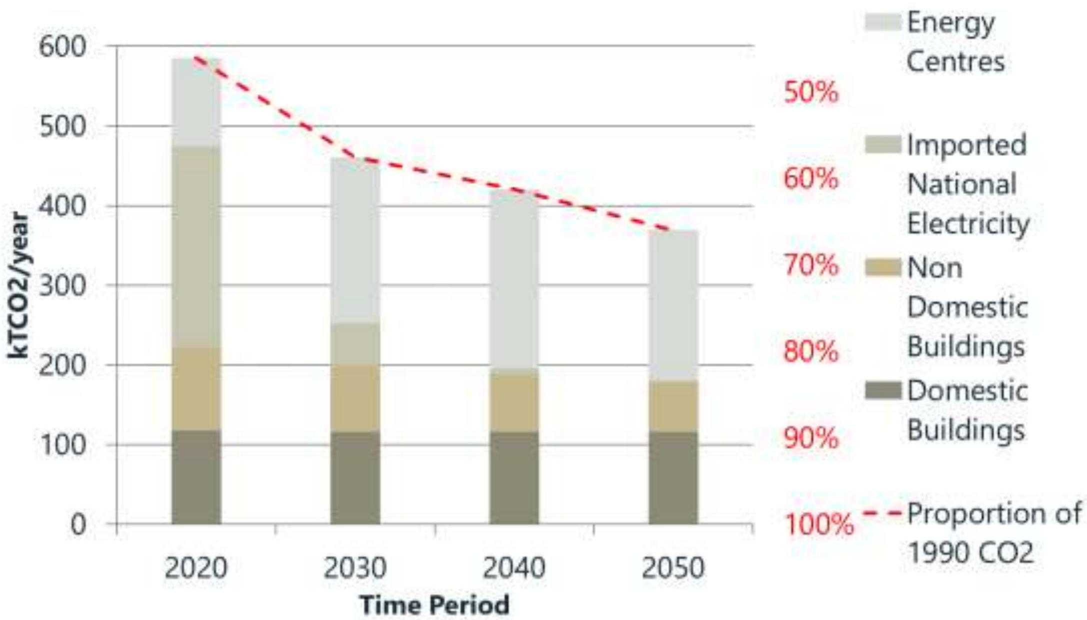


Figure 5-3 Carbon Emissions Projection for the Business as Usual Case

5.2.2 Results

In the BAU scenario there is no incentive for households to transition to a low carbon heating system. As a result, in most cases, when the existing heating system approaches its end of life it is replaced with a gas boiler, since this is usually most cost-effective solution. Household heating system transition differences between the two scenarios are shown in Figure 5-4.

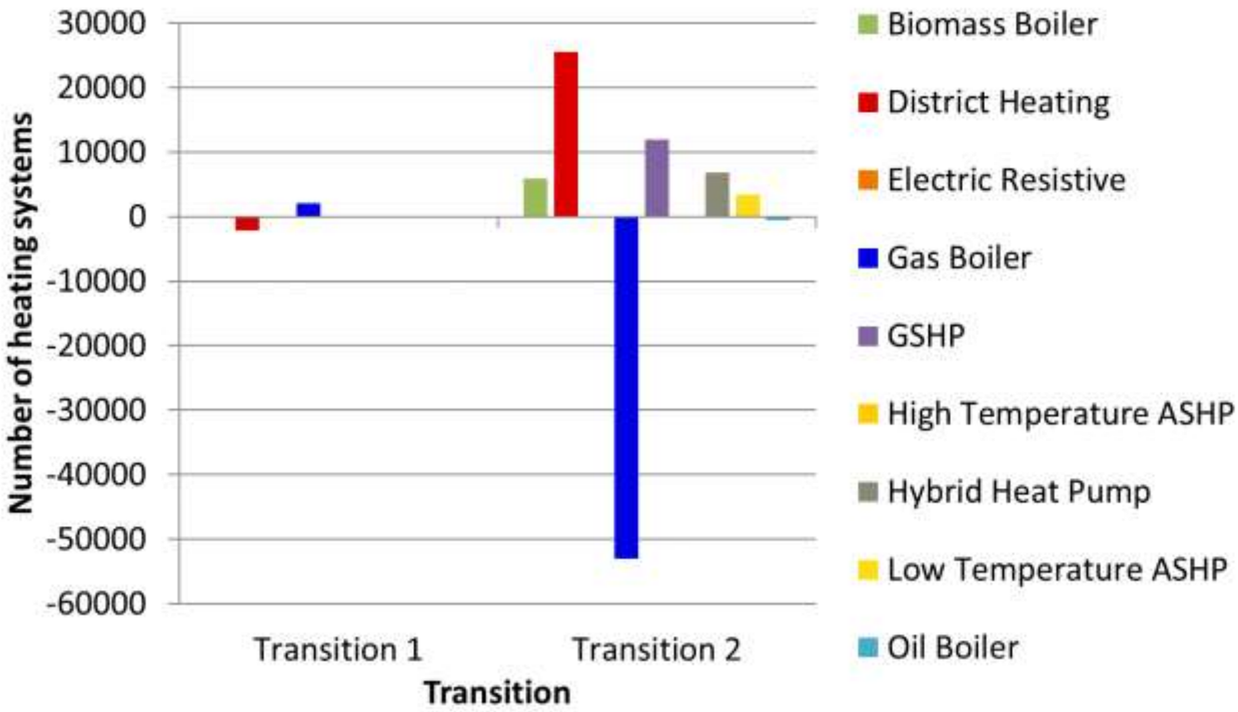


Figure 5-4 Differences in Household Heating systems Installed under Base Run and Business as Usual (Positive Numbers show Increased Heating Systems under Base Run)

In the base run there was a total of circa 66,300 household heating system transitions, whereas in the BAU run there was only around 12,700 (98% compared to 12%). Out of a total 67,650 domestic buildings in Bridgend there were 53,650 homes with gas boilers in the BAU run compared to just 700 in the base run. The vast majority of the properties have remained on gas boilers as there is no carbon target to meet in the BAU scenario. There are 12,450 (18%) properties on district heat networks by 2050 in BAU, this is mainly due to the forcing of the Town Heat network, which provided a network that could be grown to allow additional buildings to connect. This can be seen in Figure 5-5, which shows the domestic heat connections are in analysis areas 7, 8 and 9 which is in the vicinity of the Town Heat network scheme (analysis areas 7, 8 and 9). Recall that only fur non-domestic connections are forced to connect to the Town Heat network but this acts as a seed for other domestic and non-domestic connections.

In the post-sensitivity modelling the Town Heat network was not forced and another business-as-usual analysis was completed for comparison (see Section 6.1.1). This shows that, even when the Town Heat network is not forced, there is some district heat present under business-as-usual, suggesting that district heat is the most cost-effective solution in some instances – even in the absence of a carbon target.

Figure 5-6 shows the non-domestic floor area heat connections in the base and BAU runs. 19% of the non-domestic floor area (that has the option) is connected to the heat network in the BAU scenario, the majority of these connections are concentrated in areas around the Town Heat network.

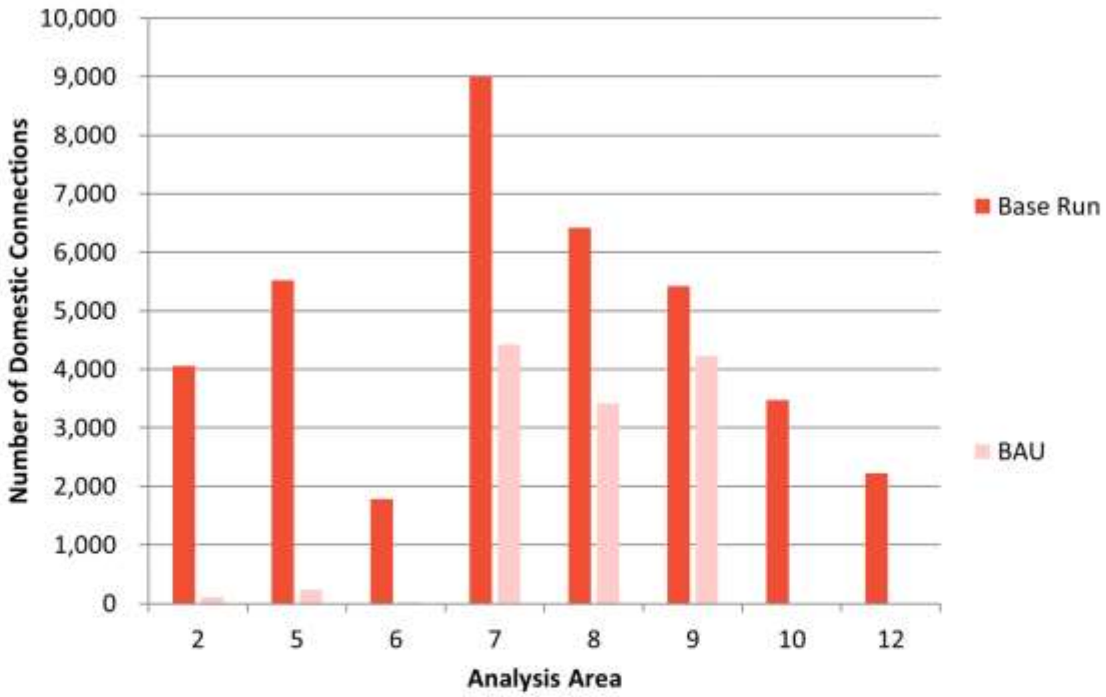


Figure 5-5 Domestic Building Connections by Analysis Area

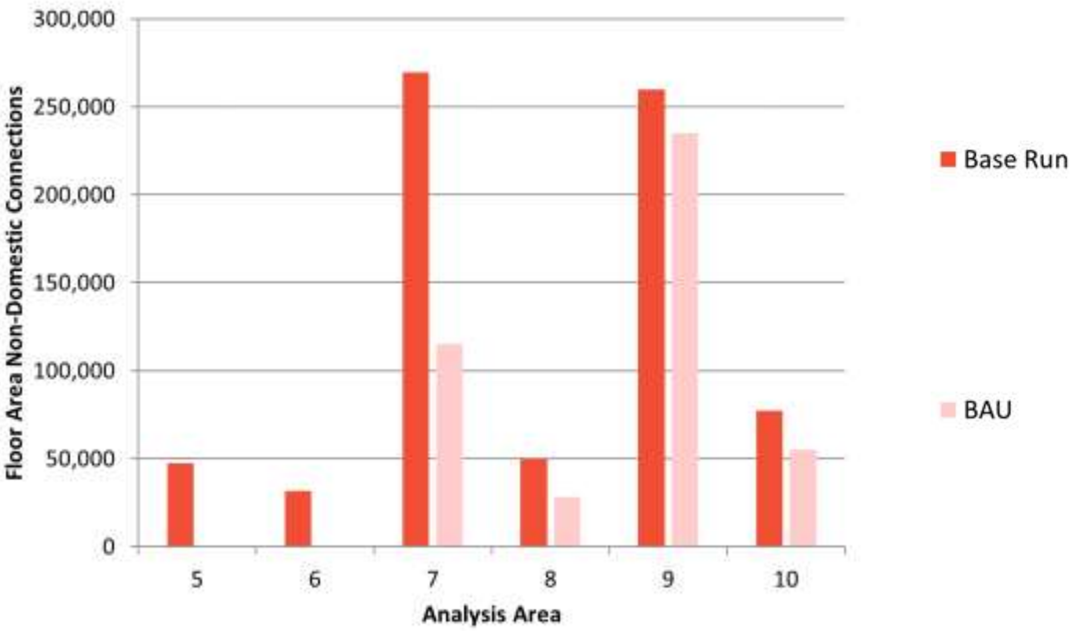


Figure 5-6 Floor Area of Non-Domestic Heat Connections

Some building fabric retrofit still takes place in the Business as Usual scenario. This is discussed later in the identification of potential project themes in Section 6.3.4.

Figure 5-7 and Figure 5-8 show the production of electricity, used heat and unused heat under the base run and BAU scenarios respectively. The large amount of unused heat in the BAU scenario is a result of the excess heat generated from the use of gas CHPs to produce electricity. This is cost effective as imported electricity costs rise due to decarbonisation of national generation, since this scenario still assumes national but not local decarbonisation occurs. Without a local carbon target the cost of installing and running gas CHP is less than the cost of importing electricity. However, there is less incentive to use the heat produced due to the absence of a carbon target.

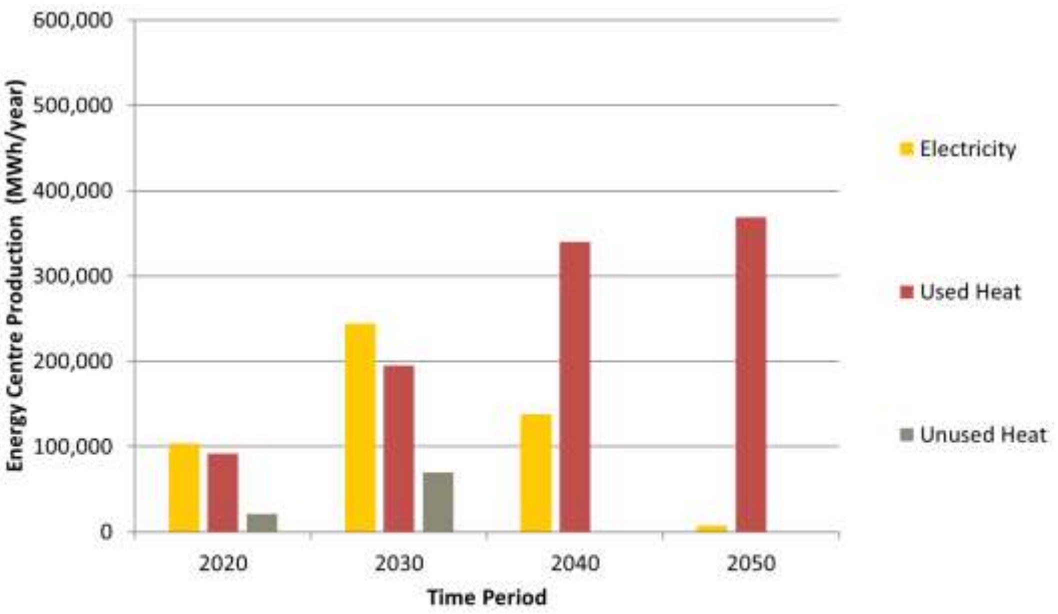


Figure 5-7 Energy Centre Generation in the Base Run

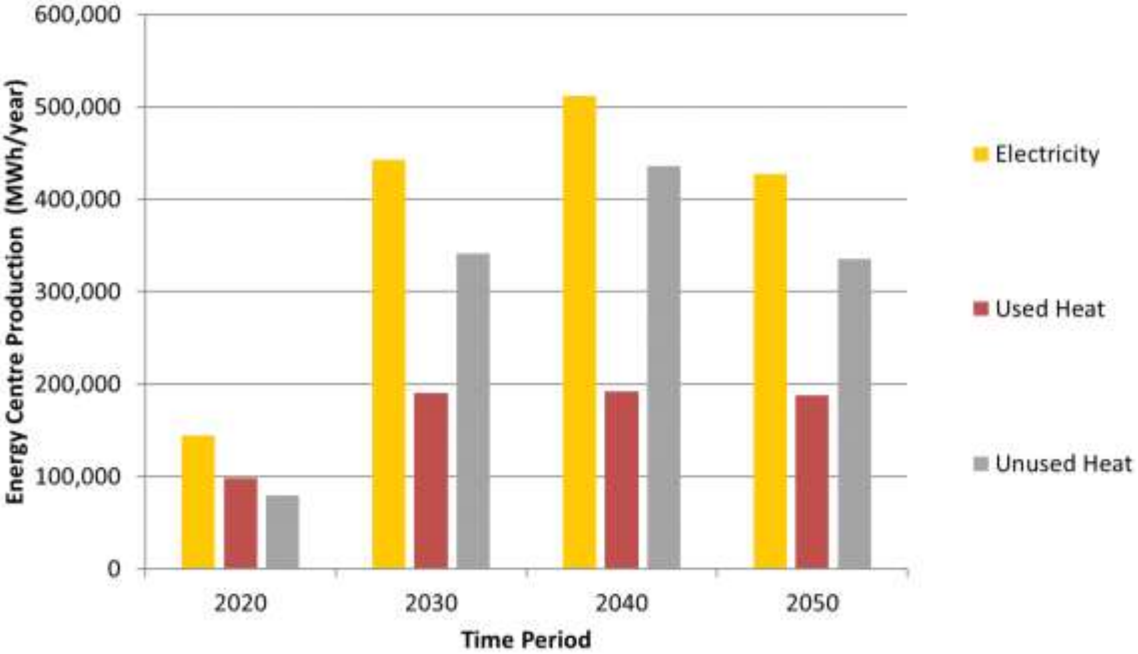


Figure 5-8 Energy Centre Generation in the BAU Scenario

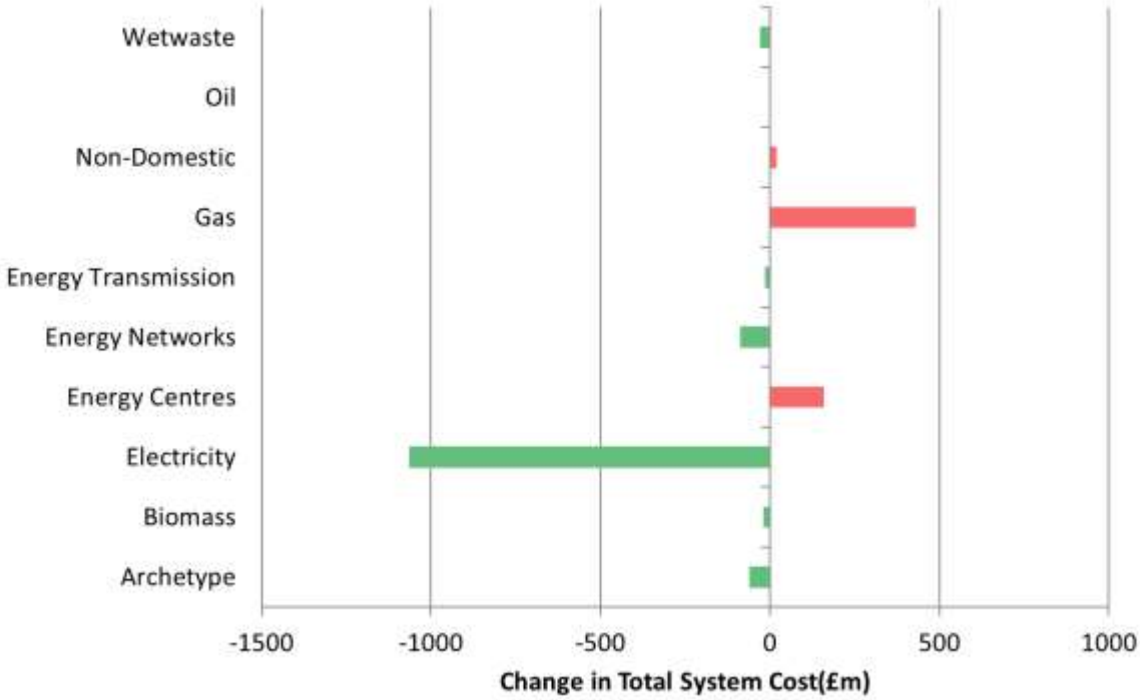


Figure 5-9 Total system cost difference from 2015 - 2050 in 2015£ (Positive Green Bars Indicate More Money Spent under BAU)

The difference between the total system costs in the base and BAU runs is shown in Figure 5-9. The biggest saving under BAU is on imported electricity, due to local electricity generation from gas technologies hence the subsequent increase in the cost of using more gas. Therefore, the true cost difference will depend on imported electricity costs and relative benefits of local gas CHP. As there is no building level transition to electric heating technologies there is less spend on energy network reinforcements. Under BAU there is around 16% less electricity network reinforcement (as a percentage of the total capacity under BAU). The capacity saving is greater for substations than feeders. Note that, as with all costs in this report unless otherwise stated, the reported costs represent the total cost of transition between now and 2050.

In the base run the total system cost is circa £7.25 billion, compared with BAU scenario costs of £6.59 billion, this underlines the significant cost required on the whole energy system regardless of the carbon target.

5.2.3 Key Points

Under the business-as-usual scenario there is no incentive to decarbonise at a local level, resulting in:

- A 67% decrease in domestic district heating connections.
- Gas energy centres built primarily for electricity generation, thereby avoiding some of the costs associated with imported low carbon electricity from the national grid.
- Overall total system costs for the BAU scenario that are £660m lower than the base run (£6.59 billion, compared with £7.25 billion in the base run).

5.3 Sensitivity Testing

The EnergyPath Networks base run identified the most cost effective low carbon transition scenario for a given set of fixed input data, representing Bridgend and the national scenario. However, there is significant uncertainty out to 2050 so it is critical to understand how potential changes in this input data influence the outputs of the EnergyPath Networks decision module. To assess this, a series of sensitivity tests were performed, where input parameter values were changed and the impacts on the transition scenarios were assessed. This helps to understand the robustness of the results and assess the relative sensitivity of key criteria, such as technology options, to changes in model inputs and model constraints. These are discussed in the following sections.

The sensitivity testing assesses the effects of variations in the following areas:

- National decarbonisation pathways.
- Energy costs.
- Technology costs.
- Restricted storage charging.
- Green gas availability.
- Forced mine water scheme.
- Impacts of a Town Heat scheme.
- Removal of large scale heat pumps.

The sensitivity testing process is important as it can identify risks and opportunities associated with potential transition scenarios, where the process and learning may help set new assumptions or a new baseline position on which to base further analysis.

An important element of the sensitivity testing also involves discussing the outcomes with the stakeholder group, where insight into specific areas can lead to discussion and then consensus on what parameters should be applied moving forward. Any key decisions resulting from this process are highlighted in the following sub-sections.

In addition, the learning derived throughout the sensitivity testing process is used to inform the parameters and assumptions used to generate the post-sensitivity models.

5.4 Impacts of National Decarbonisation Pathway

5.4.1 Context

The lowest cost option to decarbonise the UK's energy system is expected to be through a centralised planning approach where a 'system architect' can make decisions and ensure coordination. Many consider that a more piece-meal approach to energy system planning is evident and is likely to be the path followed. These two national approaches are likely to influence which options are most appropriate in Bridgend.

The cost and carbon content of energy imported into the study area is defined within EnergyPath Networks using results from the ETI's ESME (Energy System Modelling Environment) model[33]. Using this model, the ETI have looked at a number of different future scenarios for the UK energy system, of which two (Clockwork and Patchwork[34]) have been used as national pathway scenarios for assessment in EnergyPath Networks in the Bridgend study. In all other scenarios Patchwork is used to represent the national energy system. Therefore the "Patchwork" scenario defined here is actually the base run.

Clockwork: This assumes a well-coordinated long-term investment plan, based on national-level planning to ensure a steady decarbonisation of power, deployment of large scale heat networks and the phasing out of the current gas grid.

Patchwork: This assumes less central government involvement, leading to a patchwork of distinct energy strategies at a local area level. Cities and regions compete for central support to meet energy needs tailored to local conditions. In some locations the local gas distribution grid is decommissioned entirely.

The primary differences in inputs between these two scenarios are:

1. National electricity prices are lower in 2020 and higher in 2040 and 2050 under the Patchwork scenario. Figure 5-10 shows the average price difference across the year for each time period.
2. Nationally generated electricity has a higher carbon content under Patchwork, especially in 2020.
3. Biomass prices are lower in 2050 in Patchwork. Other product prices also vary but the differences are small in comparison.

These differences are driven by the variation in technologies chosen under the two scenarios

Note that the costs shown in Figure 5-10 are the average cost for electricity. The model input costs are broken down so that EnergyPath Networks understands that electricity will be, for example, more expensive to generate on the coldest days of the year. The carbon content of electricity, however, is generally aggregated. That is, EnergyPath Networks assumes that imported electricity has the same carbon content throughout the year. In reality, the carbon content of electricity will vary since the mix of generation technologies that are used at any given time will be determined by the current demand. However, in the general model testing, both approaches to modelling the carbon content were investigated showing little impact on overall results.

[33] See http://www.eti.co.uk/modelling-low-carbon-energy-system-designs-with-the-eti-esme-model/

[34] Options Choices Actions – UK scenarios for a low carbon energy system (http://www.eti.co.uk/options-choices-actions-uk-scenarios-for-a-low-carbon-energy-system/)

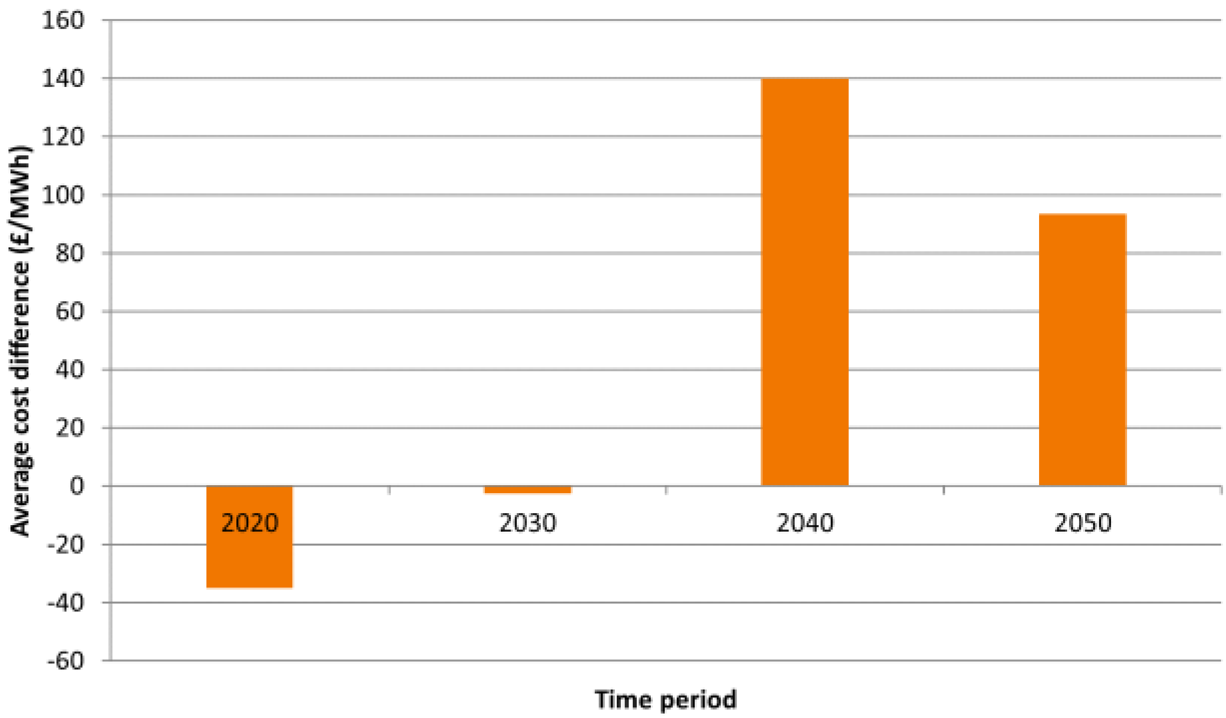


Figure 5-10 Average Electricity Cost Difference (Positive Numbers show Increased Cost under Patchwork).

For all other scenarios in this study, Patchwork was used to represent the national energy system, since the Key Stakeholder Group agreed that it is a more likely representation of the future national energy system.

5.4.2 Results

Figure 5-11 shows the differences in heating systems between the two scenarios in transition one and two (Patchwork minus Clockwork). The lower electricity price under Clockwork in the later time periods leads to higher proportions of heat pumps in transition 2, in preference to district heat. The higher biomass price under Clockwork also leads to increased numbers of gas boilers and heat pumps in houses that have biomass boilers under Patchwork. In contrast, in transition 1, around 6000 buildings with gas boilers under Patchwork have district heat connections under Clockwork. Therefore, the movement towards district heat happens more quickly under Clockwork but there are less buildings with district heat by 2050. It is worth noting that the cost and carbon content of gas does not vary between the two scenarios so the differences in district heat levels are not cause by a push away from natural gas. In fact, the additional energy centres are fed by gas as shown in Figure 5-12. The reason for increased heat network deployment is explained by Figure 5-13 where increased levels of gas CHP lead to increased production of local electricity. Therefore, the motivation for building increased energy centres under Clockwork is avoiding the higher costs of national electricity. In some cases the heat produced is used in district heat networks. In other cases the heat is unused suggesting that it is does not make economic sense to build a heat network in these cases - at least not in the 2020 time period.

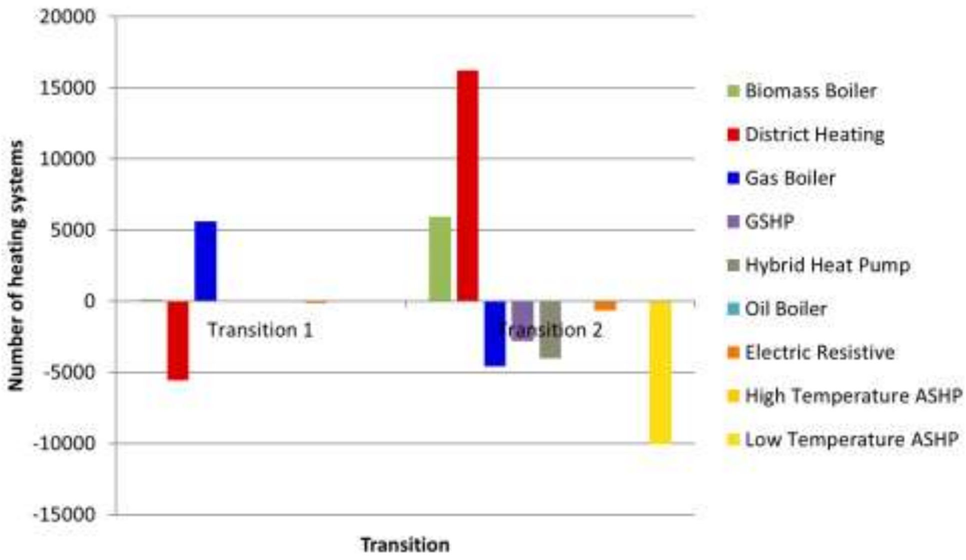


Figure 5-11 Difference in the Numbers of Heating Systems Installed Between the Clockwork & Patchwork Scenarios (Positive Numbers show Increased Deployment under Patchwork)

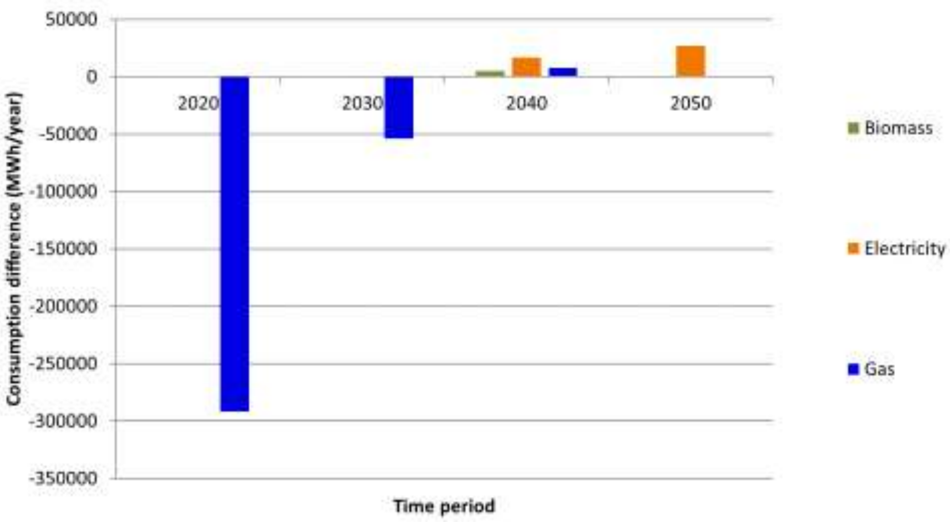


Figure 5-12 Difference in Energy Centre Annual Consumption by Product under the Clockwork & Patchwork Scenarios (Positive Numbers show Increased Consumption under Patchwork)

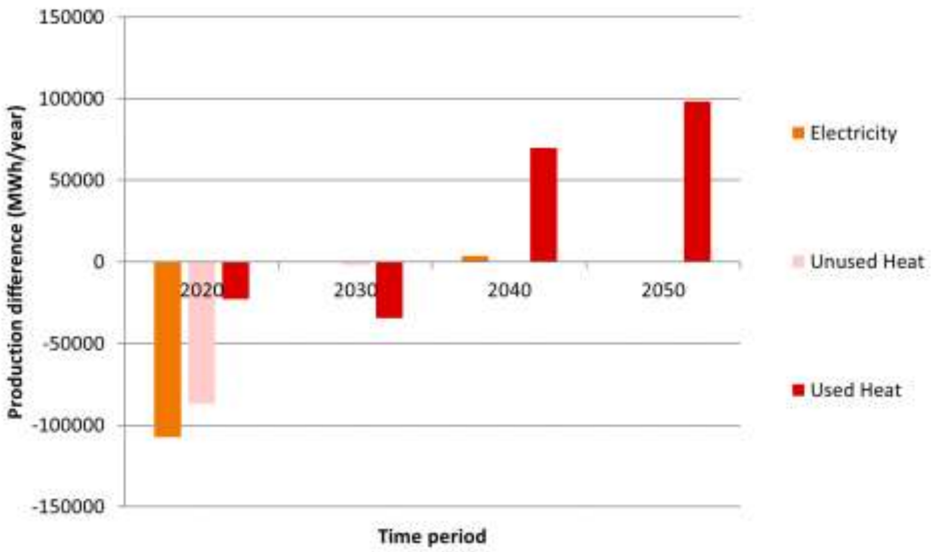


Figure 5-13 Difference in Energy Centre Annual Production by Product under the Clockwork & Patchwork Scenarios (Positive Numbers show Increased Production under Patchwork)

Figure 5-14 shows the differences in costs by sector under the two national scenarios and Figure 5-15Figure 5-15 shows the change in carbon emissions by sector. Note that overall carbon emissions are the same in both scenarios, since EnergyPath Networks is using the same reduction target in both cases. The costs of transition under Patchwork is around £7.23 billion whereas Clockwork transition costs are of the order of £6.65 billion. The main reason for the increased cost under Patchwork is the increased cost of national electricity in the 2040 and 2050 time periods. The model balances these higher electricity costs against costs associated with district heat, considering the increased efficiency of central ASHPs over decentralised domestic units even after heat network losses (depending on the network pipe length). Therefore, under Patchwork, there is increased district heat deployment since the cost of electricity saved outweighs the extra upfront investment required to build the network.

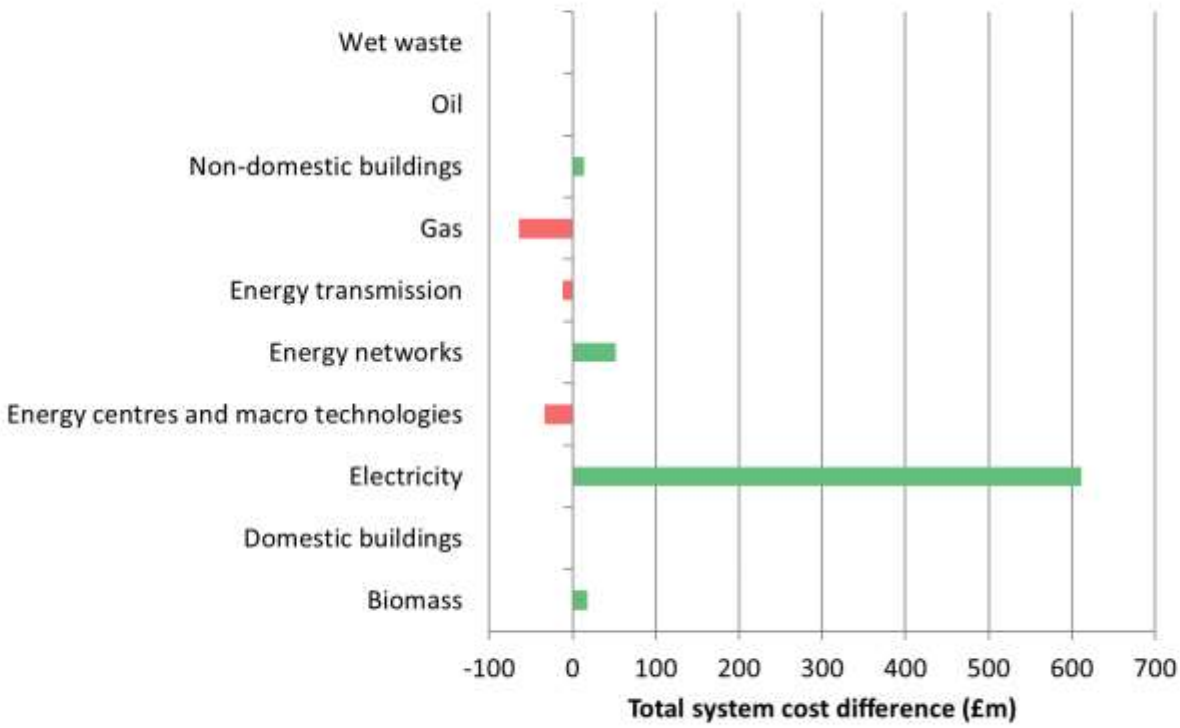


Figure 5-14 Total system cost difference from 2015 - 2050 in 2015£ (Positive Green Bars Indicate More Money Spent under Patchwork)

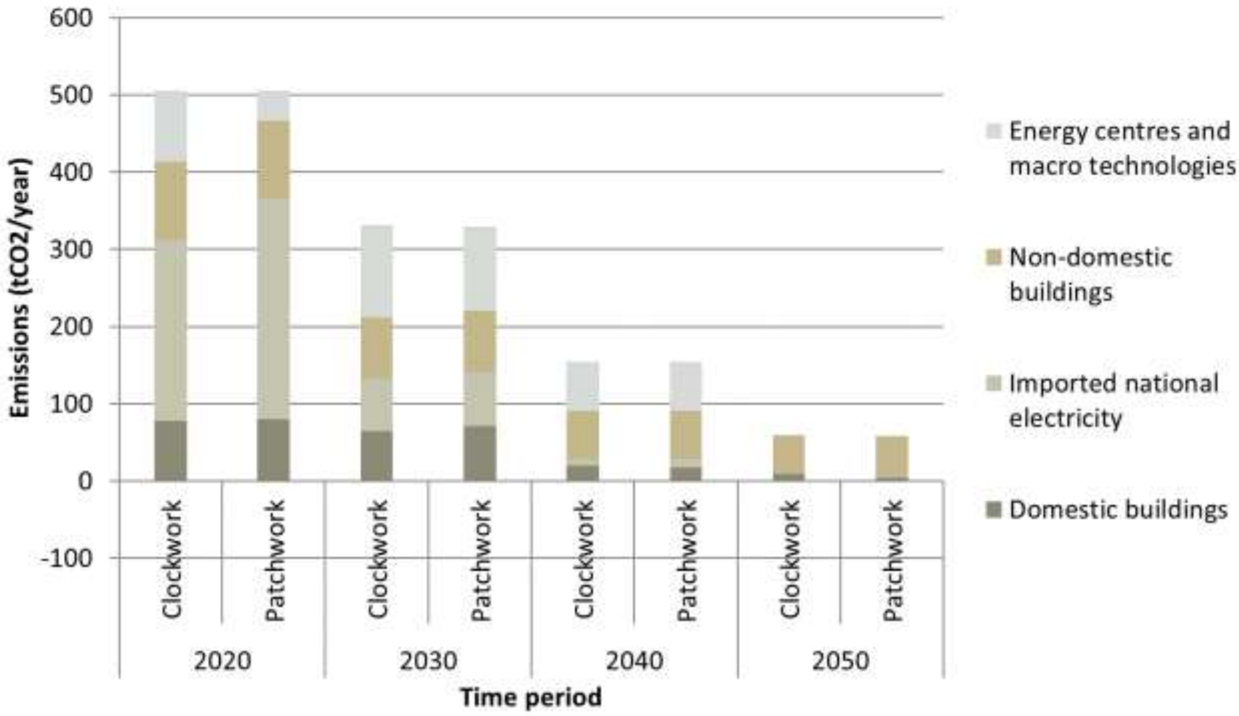


Figure 5-15 Carbon Emissions under Clockwork & Patchwork by Sector

5.4.3 Key Points

Changes in national electricity price govern most of the behaviour changes between the two scenarios, namely:

- Around 11,000 more electrical heating systems under Clockwork in later time periods, leading to level lowers of district heat.
- Circa 6,000 more buildings on district heat under Clockwork in early time periods due to increased CHP energy centres – built primarily for electricity production.
- An overall cost difference of £0.58 billion (£7.23 billion under Patchwork versus £6.65 billion under Clockwork).

The variation between the two scenarios is significant and suggests that central government actions can directly influence the options available locally and which of those options are most suitable.

5.5 Impacts of Changing Energy Costs

5.5.1 Context

A wide variety of global, national and local factors could influence the cost of different energy sources between now and 2050. Changes in the absolute and relative costs of different energy sources could have a significant impact on the decarbonisation scenarios assessed. A series of model runs of EnergyPath Networks were performed with the costs of different energy sources set to different values compared to the base case. These scenarios are shown in Table 5-1.

Table 5-1 The Energy Cost Scenarios Modelled in EnergyPath Networks

Scenario	Vector	Unit Costs
Baseline	All	Modelled future energy costs from ESME Patchwork scenario (see Section 5.4)
Electricity Low Price	Electricity	-25% reduction in all electricity costs from baseline
Electricity High Price	Electricity	25% increase in all electricity costs from baseline
Biomass Low Price	Biomass	-25% reduction in all gas costs from baseline
Biomass High Price	Biomass	25% increase in all gas costs from baseline
Gas Low Price	Gas	-25% reduction in all gas costs from baseline
Gas High Price	Gas	25% increase in all gas costs from baseline

It is important to note that EnergyPath Networks has different levers it can pull to avoid increased costs of energy products or to make the most of lower costs, namely:

1) Variations in domestic heating systems.
2) Variations in building fabric retrofit deployment.
3) Variations in energy products consumed by energy centres.

4) Variations in non-domestic district heat connections.

However, there are some potential limiting factors:

1) The carbon content of natural gas.

2) The availability of biomass.

5.5.2 Impacts of Changing Electricity Costs

Figure 5-16 illustrates the influence of electricity price on heating systems deployed. As the electricity cost increases, the number of electric heating systems generally fall as district heat and biomass boilers are installed instead. GSHP numbers remain relatively constant (less than 1% of total Bridgend buildings choose to install an alternative heating system). However, the properties with GSHPs do have other heating system options, suggesting that in most cases GSHPs are still the most cost-effective solution overall, even if running costs increase.

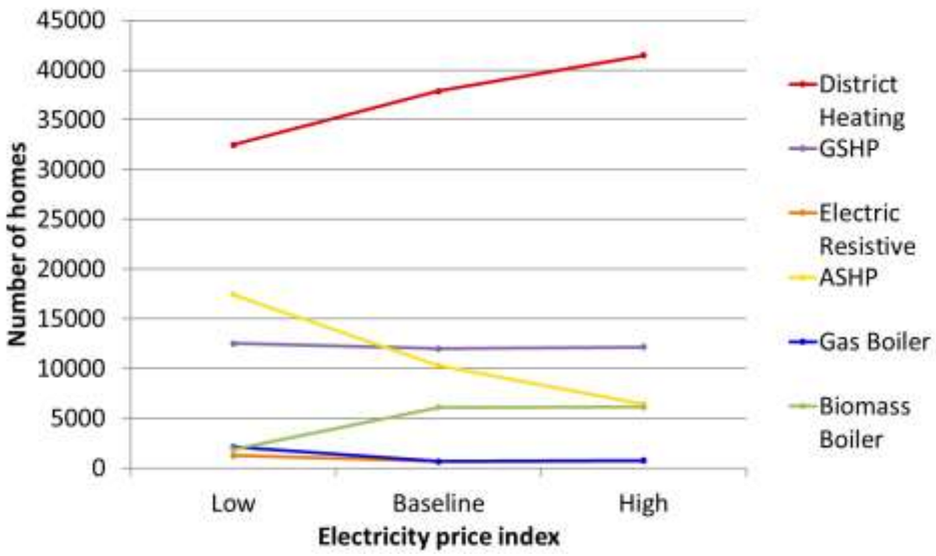


Figure 5-16 Influence of Electricity Price on the Numbers of Different Heating Systems Deployed

Note that the amount of biomass available to Bridgend is limited to reflect the local area's fair share of nationally available biomass. Therefore, there is a limit to the number of biomass boilers that can be installed in domestic buildings. This will be traded off against any potential biomass energy centres of which there is around 3.6MW total capacity by 2050 in the high electricity price scenario. Under the high electricity cost scenario, there is less than 0.3MWh/year of available biomass remaining.

Furthermore, increased district heat connections do not completely avoid any increases in the price of electricity, since the modelled low carbon alternative to gas energy centres is large scale heat pumps. Therefore electricity is still used but centrally, rather than in homes. This is illustrated in Figure 5-17, which shows that more electricity is used in energy centres as the electricity price increases. However, these large-scale systems can be a more efficient way of using electricity than individual electric solutions. Alternative energy products are also utilised. In particular, almost 76,000MWh/year more wet waste is consumed in the 2030 time period under the high electricity price scenario.

With a lower national electricity cost, there is less of a need for local electricity generation. This leads to more domestic gas boilers and low temperature ASHP.

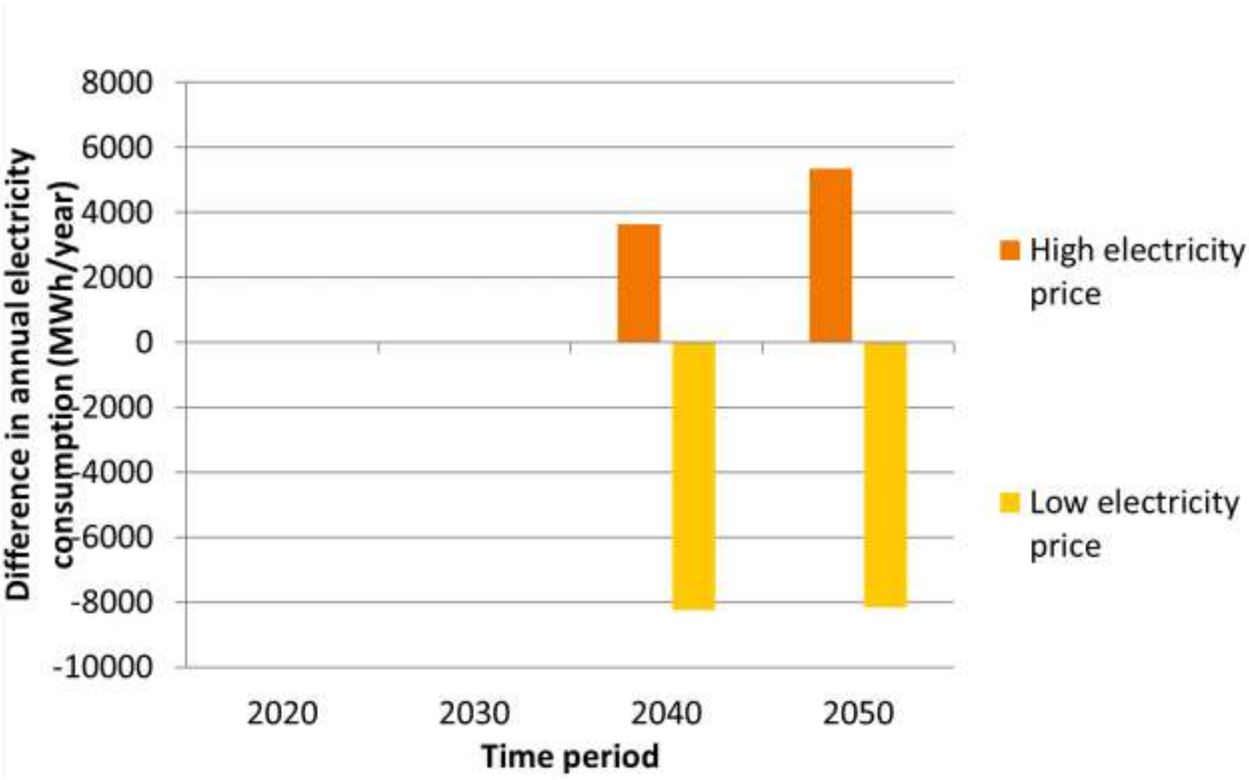


Figure 5-17 Difference in Annual Electricity Consumption in Energy Centres (Positive Numbers show Increased Consumption when Electricity Price is High)

5.5.3 Gas cost sensitivity results

Figure 5-18 shows the variation in heating systems across the gas cost scenarios. Counterintuitively, the number of gas boilers in homes increases as the gas price increases. This is because, as the gas cost increases, more non-domestic floor area transitions to district heat (around 1% more floor area relative to base run). This in turn allows more domestic properties to keep their gas boilers whilst still meeting the carbon target.

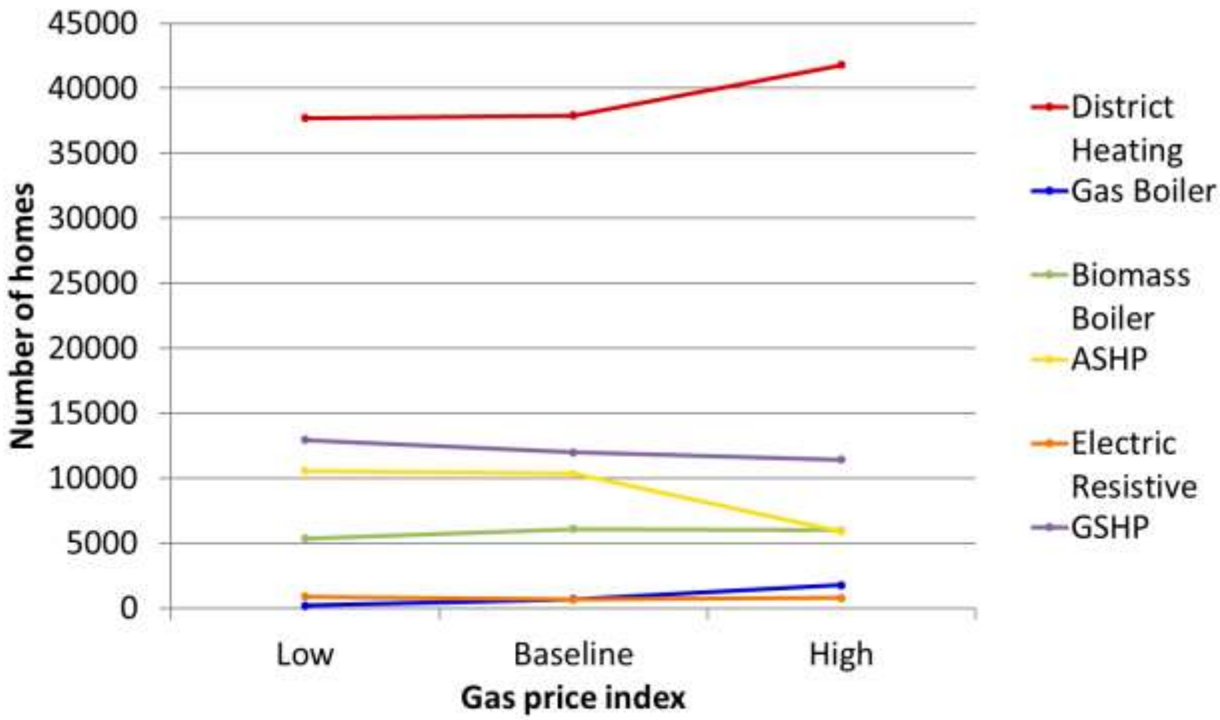


Figure 5-18 Influence of Gas Price on the Numbers of Different Heating Systems Deployed

5.5.4 Biomass cost sensitivity results

Figure 5-19 shows the influence of biomass cost on the number of different heating systems deployed by the model. Clearly, the number of biomass boilers decrease as the cost of biomass increases. However, the change is quite modest at less than 2% of the total buildings in Bridgend. As discussed previously, the amount of biomass available in Bridgend is limited. This limit means that, even if biomass were free to the local area, there would be a cap on how many biomass boilers could be installed. In the low biomass cost scenario, there is no further biomass available to the local area.

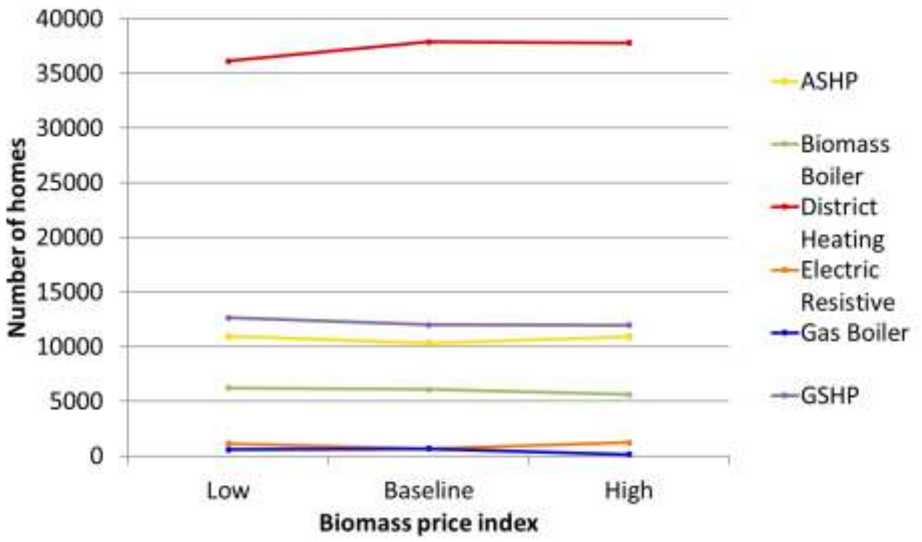


Figure 5-19 Influence of Biomass Price on the Number of Different Heating Systems Deployed

5.5.5 The influence of different energy costs to those planned for

The impact of planning for one set of energy costs but getting a different set of costs is shown in Table 5-2. The table shows the extra cost if a low carbon transition scenario is assumed based on the prices in the left-hand side of the table but the actual prices experienced are those along the top. For example, if the baseline costs are planned for but the electricity cost is actually 75% of that expected, then £22.3m extra will be spent to achieve the transition between 2015 and 2050. Generally, basing assumptions on a lower cost gives a higher risk than assuming a higher cost, i.e. if you assume for a low cost but costs are high you overpay by more than if you had assumed for a high cost and costs were low. The exception to this is the high gas cost run where the overall cost of transition is much higher if a high gas cost is assumed but not experienced. This is due to the increase in heat pipe installation of around 80MW pipe capacity under this scenario.

Table 5-2 Influence on system cost of outcomes that are different to planned

	Price Scenario Experienced							
	Difference to Optimal Cost (£m)	Baseline	Low Electricity Price	High Electricity Price	Low Gas Price	High Gas Price	Low Biomass Price	High Biomass Price
Plan Adopted	Baseline	0.0	22.3	9.2	-2.0	-314.5	4.7	-9.3
	Low Electricity Cost	23.4	0.0	78.2	30.6	-300.3	31.4	10.8
	High Electricity Cost	-2.2	27.1	0.0	-4.7	-316.1	2.4	-11.3
	Low Gas Cost	2.1	24.7	11.0	0.0	-312.2	7.3	-7.5
	High Gas Cost	316.0	342.0	321.5	315.5	0.0	320.7	306.7
	Low Biomass Cost	-4.7	16.1	5.9	-6.4	-319.5	0.0	-14.0
	High Biomass Cost	9.5	32.0	18.4	8.1	-305.5	14.5	0.0

5.5.6 Key Points

Varying the cost of energy products clearly has an impact on the transition route and costs. However, there are some limiting factors:

- The amount of available biomass to Bridgend is restricted to be Bridgend's fair share of UK biomass. Therefore, lowering the biomass cost will impact amount of biomass techs installed to a point, below which decreasing price will not change solution.
- The amount of gas technologies deployed will be limited because of carbon content of gas. This is particularly true as time progresses and carbon target becomes more stringent.

5.6 Impacts of Changing Technology Costs

5.6.1 Context

The future cost of any technology is uncertain and will depend upon a wide variety of global, national and local factors. Changes in the absolute and relative costs of different technologies could have a significant impact on the most appropriate solutions to decarbonise the buildings in Bridgend.

For each of the technologies considered within EnergyPath Networks a range of cost values were defined. The average range across all the simulated parameters was 45% with some parameters varying by over 240%. One hundred runs of the model were performed where the cost of every technology was selected randomly from within its range of defined values. The purpose of this sensitivity assessment is to test what impact changes in technology cost have on modelling outputs, accepting that we cannot predict with certainty what future costs could be.

These selections were performed so that similar technology costs always increased or decreased together. For example, the cost of Ground Source Heat Pumps was correlated with the cost of Air Source Heat Pumps so that if one of these had a higher cost for a run the other also had a higher cost.

These correlations could be weak or strong depending on the technology pairs. As an example, the cost of a gas boiler was very closely correlated to the cost of an oil boiler but the cost of a biomass boiler was less closely correlated to that of a gas boiler as these technologies have larger technical differences.

Technology types that were included in this analysis were:

- Domestic heating system capital cost.
- Domestic building storage capital cost.
- Domestic heat control capital cost.
- Domestic building fabric retrofit capital cost.
- Domestic solar PV.
- Energy network capital cost for gas, heat and electricity.
- Energy centre technology capital cost.
- Other macro technology capital costs (e.g. ground mounted solar PV).

5.6.2 Heating System Results

The overall costs of transition over all simulations vary from £7.17 billion to £7.54 billion, with an average cost of £7.23 billion. These costs are discounted to 2015 costs[35] [36] . Transition costs are most sensitive to changes in the capital costs of district heating pipes.

Across the simulations there is significant variation in domestic heating system deployment as shown in Figure 5-20. The blue bars represent the average number of heating systems across all runs and the whiskers represent the range. The capital costs of connecting domestic buildings to a heat network, installing heat exchangers and building energy centres do not have a significant impact on the results. The decision of whether to build district heat is mainly driven by the cost of the pipes. Other heating system choices are then affected. For example, under a high cost district heat, low heat pump cost scenario, heat pumps systems are installed in preference to district heat where possible.

Deployment of some heating systems are still limited in 2050, even when their costs are low relative to district heat. For example, gas boiler costs have a significant influence on the solution in the early time periods when current gas boilers are assumed to reach their end of life ("transition one") since the carbon target does not drive high levels of decarbonisation (for reference see Figure 5-2). At this point, low gas boiler costs would cause more buildings to replace gas boilers with like-with-like, whereas high gas boiler costs can cause more buildings to switch to some alternative. However, when the heating system is due for replacement again ("transition two"), the carbon target is much more stringent and low gas boiler costs can only have a limited influence on the number of domestic gas boilers. Furthermore, deployment of other heating systems can be limited by fuel availability. This is the case for biomass boilers in Bridgend since the analysis assumes that Bridgend has access to its' "fair share" of nationally available biomass. Therefore low biomass boiler costs have a limited impact on biomass boiler deployment.

[35] Discounting is a financial process which aims to determine the "present value of future cash flows", or in other words: calculating what monies spent or earned in the future would be worth today. Discounting reflects the "time value of money" – one pound is worth more today than a pound in say one year's time as money is subject to inflation and has the ability to earn interest. A Discount Rate is applied to financial inflows or outflows – this generally reflects what it costs a company to borrow money or is a defined rate such as the 3.5% discount rate suggested in the UK Treasury's "Green Book" (this is used in the financial evaluation of UK Government projects).

[36] Total Net Discounted Cost – this is the additional cost of the Carbon Target run versus the business as usual (BAU) approach, discounted using a 3.5% discount rate (as stipulated in the HM Treasury Green Book).

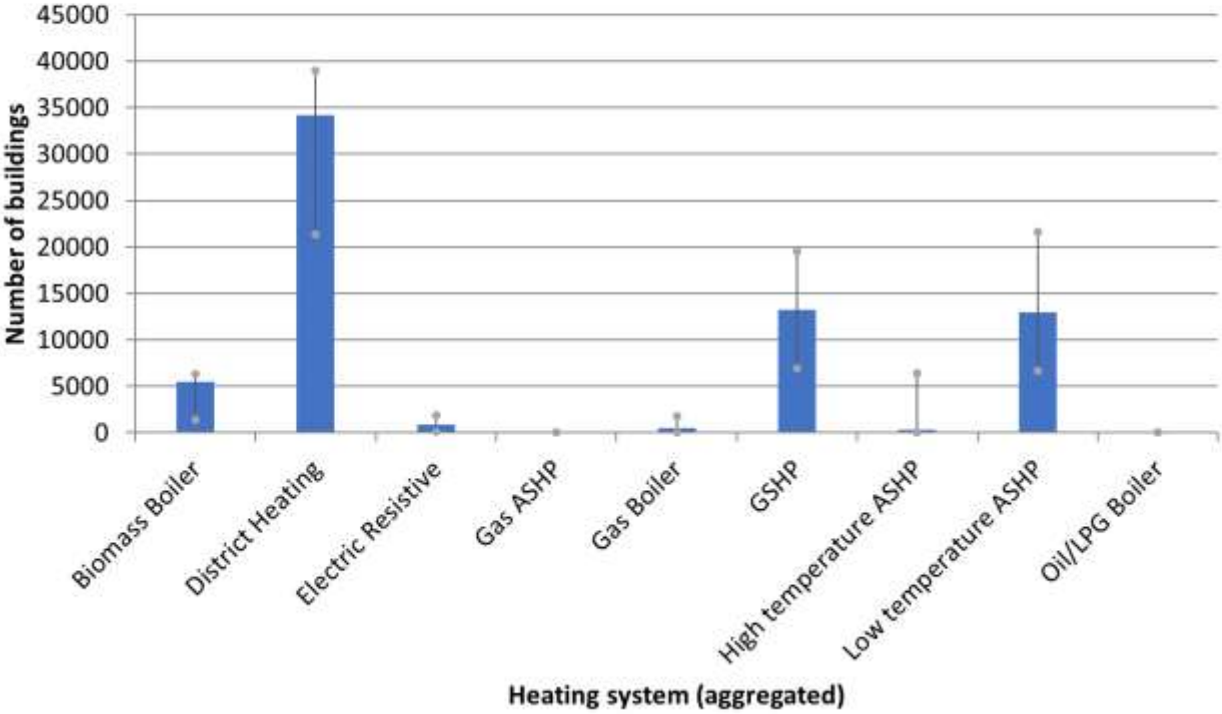


Figure 5-20 Variation by 2050 Heating System over all Simulations

5.6.3 Heating System Number Trends

Results across the full range of simulations were analysed to establish which costs influence the deployment levels of building level technologies. Figure 5-21 shows the technology costs which have the greatest influence on the numbers of different heating systems deployed. Increasing numbers of houses (separated by trees) represent an increase in the number of heating systems in question and the size of the text represents the magnitude of the influence. For example, the red box illustrates that the biggest influencers on the number of district heat connections are the costs of heat pipes and ASHPs, followed by the costs of domestic heat connections and GSHPs. As the costs of ASHPs and/or GSHPs rise, EnergyPath Networks chooses to install more district heat in preference to heat pumps. However, if the costs of heat pipes and/or heat connections rise, the tool chooses to install less district heat. Note that the relationship between GSHP and district heat deployment is only relevant for detached properties.

The biggest influencers on the cost of transition are the costs of district heat pipes, followed by the costs of gas boilers. This is because district heat pipes most heavily influence the uptake decisions for district heat and various types of ASHPs. These two choices represent the most common heating system choices in the Bridgend modelling because alternatives either:

1. Cannot meet energy demand in the building in question.
2. Are restricted from being installed in the building (e.g. GSHPs cannot be installed in terrace properties due to access restrictions).

If heat network pipe costs were reduced, it could have major implications for the viability of heat networks in a local area. The Energy Technologies Institute have considered this as part of their Energy Storage and

Distribution Programme and found that total heat network costs cost be reduced by as much as 45% if a series of eight recommendations were followed[37].

The relationships between technology deployment and their own costs is obvious, for example heat pump numbers decrease as heat pump costs increase. However, the magnitude of the influence is interesting in these cases. For example, the costs of heat pipes are as big an influencer on ASHP deployment as ASHP costs.

[37] https://d2umxnkyjne36n.cloudfront.net/teaserImages/Reducing-the-capital-cost-of-district-heat-network-infrastructure.pdf?mtime=20171103092304

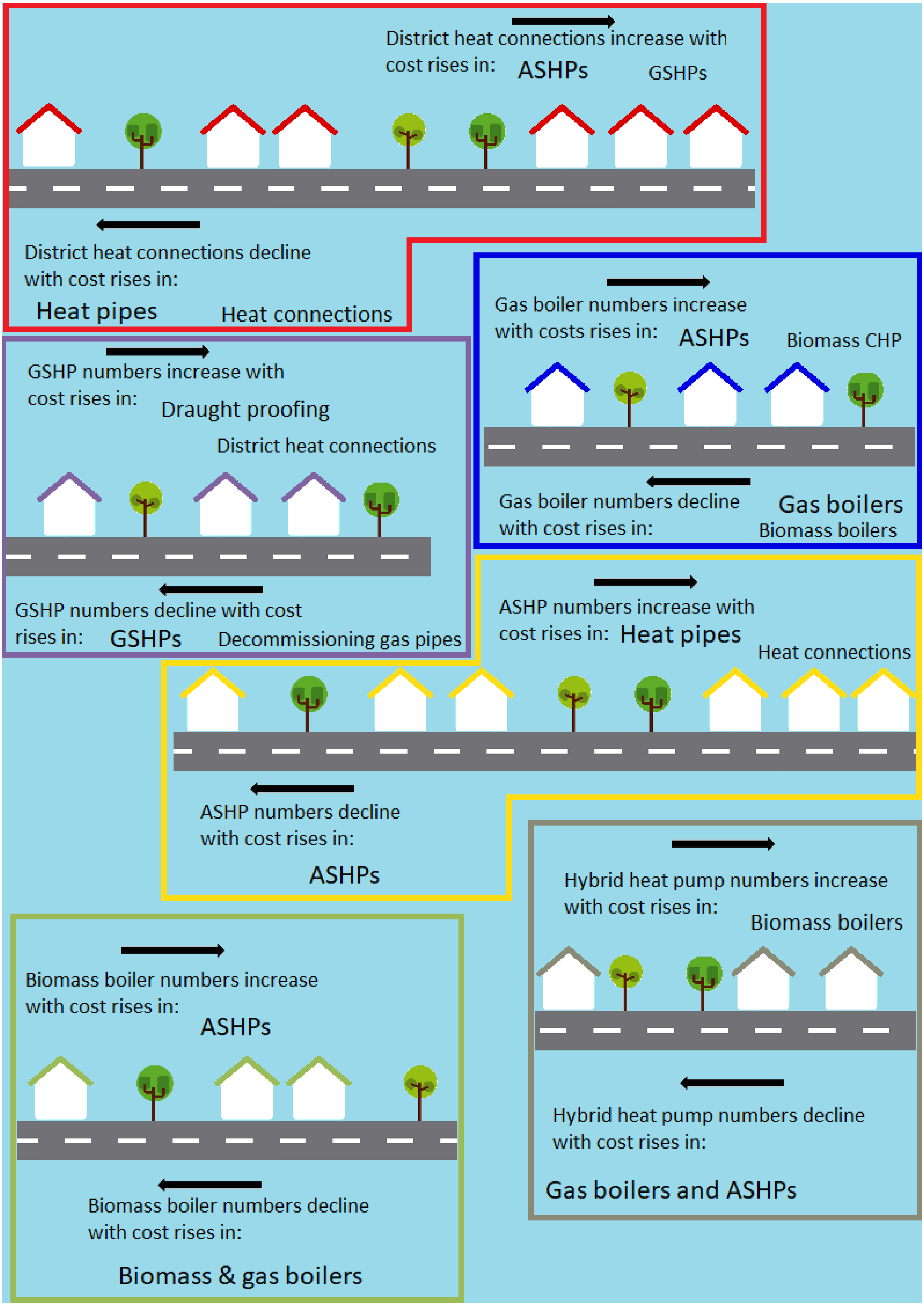


Figure 5-21 Heating System Cost Trends (Note: Size of Text Represents Magnitude of Influence)

5.6.4 Energy Network Capacity Trends

The level of use of a heat solution influences the capacity of energy networks that are required. As electric solutions become more prevalent in a modelled scenario then electricity network capacity must rise to support the increased demand. Similarly, as more buildings are connected to heat networks in the local area the total heat network capacity must increase. This means that there is a close link between network capacities and the costs of the technologies which use energy from those networks.

- Decreasing heat pump costs lead into increased heat pump deployment and, hence, increased electricity network capacity, as well as decreased heat network capacity.
- Conversely, high heat pump costs lead to greater numbers of buildings being connected to heat networks and an increase in heat network capacity.
- The primary driver of modelled heat network uptake is the cost of building the networks. Reducing the cost of installing heat interface units for heat network connections into houses also increases the heat network capacity required. The cost of the technologies which provide heat to networks does not significantly influence the network capacity built.
- High heat network costs mean that more electricity network upgrade is required, since more electric heating systems are installed. Heat network costs are a bigger influencer on electricity network upgrade than electricity upgrade costs.

Non-domestic building demands are a significant contributor to requirements for electricity network reinforcement. This means that electricity network capacity varies much less than heat network capacity across all the runs as a certain level of electricity network reinforcement is always required to meet the anticipated increase in demand from the non-domestic sector.

Recall that EnergyPath Networks does not consider any impact of smart network solutions being pursued by the Network Operators. This would need to be factored in as part of more detailed development of pipeline projects.

5.6.5 Retrofit Installation

The decisions of whether to make building fabric improvements in the EnergyPath Networks modelling is primarily driven by the costs of retrofit measures. However, in the first transition, the amount of insulation is also dependent on the cost of gas boilers and gas energy centre technologies. That is, as the cost of gas technologies (centralised and in homes) rise more building fabric improvements take place. This suggests that, when gas technologies are more expensive, improving building fabric and transitioning to some other heating solution is a more cost-effective option. For example, a low temperature ASHP may be installed alongside cavity wall and loft insulation. This raises the question: “why not install a larger ASHP and avoid retrofit costs?”. There are two possible answers to this question:

1. It could be genuinely less expensive to improve building performance through fabric retrofit than to install a larger heating system. This is more likely to be the case in small properties where costs of retrofit are low.
2. The current building performance could make it impossible for the ASHP to meet demand, regardless of the size of the ASHP.

Answer 2. is far more likely since the marginal building fabric costs are much higher than the marginal costs of heating systems. For example, the cost of cavity wall insulation is very much dependent on the amount of wall that needs to be filled, whereas the cost of a new heating system will be dominated by the cost of installation, rather than the cost to install an extra kW of capacity.

The carbon reduction trajectory means that the costs of gas technologies has no significant influence on the uptake of building fabric improvements in transition two.

Note that the EnergyPath Networks tool makes purely economic decisions whereas fabric retrofit, in particular, might be appropriate for a range of social reasons.

5.6.6 Energy Centre Technology Choices

As expected, the installed capacity of heat generation technologies in energy centres generally increases as the demand for heat from networks increases. As illustrated in Figure 5-21 the uptake of district heat is largely driven by the cost of district heat pipes, heat pumps and heat connections. Therefore, it is not surprising that these are also the biggest influencers of installed energy centre capacity. The costs of the technologies themselves also have an impact, for example as the cost of biomass CHP increases, the installed capacity of biomass CHP decreases. However, the influence of district heat pipe, heat pump and heat connection costs are greater

There are some energy centre technologies for which uptake increases as district heat pipe costs increase. This seems counterintuitive on first glance, but the important point is that these technologies are not being connected to a heat network. When electric heating system deployments increase, and the demand for heat from networks decreases, there is a switch from providing heat to networks using low carbon solutions such as large-scale heat pumps to increased use of gas powered combined heat and power plants. These are built to provide some locally generated electricity to meet demand. This has the potential to reduce the need for electricity network reinforcement at higher voltages and provides a cost-effective option to meet demand at peak times when imported electricity prices are highest.

5.6.7 Key Points

- The biggest influencer of transition costs is the cost of district heat pipes. Gas boiler costs also have a significant influence on the total costs but have a limited impact on the heating system results in transition two because of the presence of a carbon target in the analysis.
- District heating is always the most common method of providing heat to domestic buildings with electric heat pumps as the second most common solution. In general, if the deployment of district heating increases then electric heat pump use decreases.
- The capacity of energy networks is influenced by the level of deployment of the heating solutions that use energy from those networks. However, CHP technologies are sometimes used to produce local electricity whilst leaving the generated heat unused.
- The primary driver of heat network deployment is the cost of building those networks.

5.7 Impacts of Restricting Storage Charging

5.7.1 Context

One of the key factors that triggers electricity network reinforcement is the peak network demand. All household electric heating technologies in EnergyPath Networks (except hybrid heat pumps) have a thermal store. Charging the thermal energy stores puts a large load on the electricity network, this can be problematic if charged during peak times such as early in the morning before work and early evening after work. Charging during these times could trigger electricity network reinforcements.

The restricted storage sensitivity looks at curtailing the charging of thermal storage, between the times of 05:30 - 09:00 and 16:00 - 19:30 every day, see Figure 5-22.

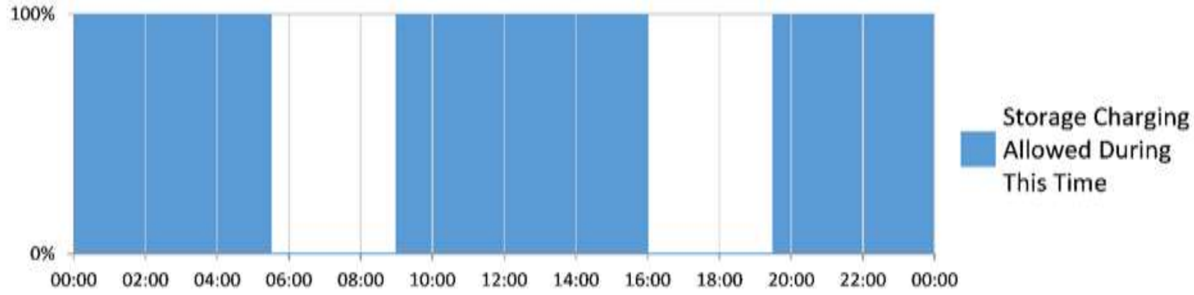


Figure 5-22 Permitted Within-Day Storage Charging Times

5.7.2 Results

The household heating system technologies for the base run and restricted storage are in show in Figure 5-23.

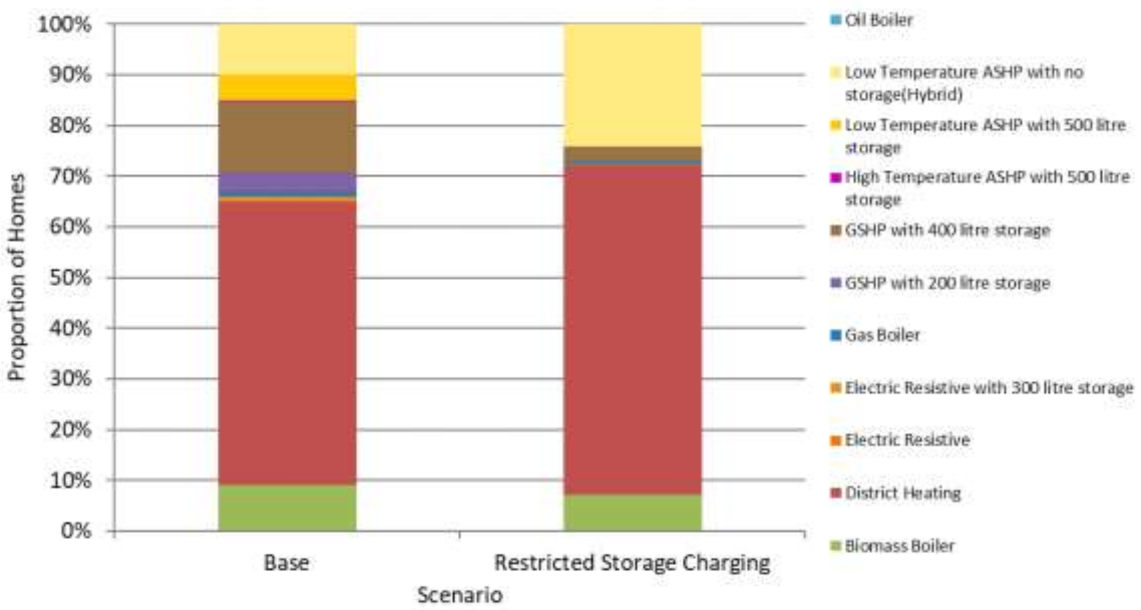


Figure 5-23 Heating System Comparison Between the Base Run and Restricted Storage Scenario

The biggest change in household heating systems between the runs is the reduction in the number of electric heating technologies (with storage) in the restricted storage scenario and subsequent increase in district heating connections and hybrid heat pumps. This leads to a 74% reduction in peak electricity demand for the heating of domestic buildings. There were circa 13,500 fewer electric heat pumps with storage, and an increase of 5,700 district heating connections and 9,400 hybrid heat pumps. This is because in many cases, EnergyPath Networks can no longer size the electric heating systems (with storage) large enough to meet heat demand, given the restrictions to storage charging. Recall that this heat demand is simulated as described in Section 4.4.2 with assumed building target temperature profiles, which represents the household's desired comfort levels. If these comfort levels were changed, there could be an impact on the heating system's ability to meet household demand.

By restricting the storage charging times, it was envisaged that the peak electricity network demand would be greatly reduced, however this does not seem to be the case as can be seen in Figure 5-24. In both the base and restricted storage runs the peak electricity demand is very similar. Even with a 74% reduction in domestic peak electricity demand for heating, total domestic peak demand (including lighting and appliances) only decreases by 32% relative to the base run. Furthermore, in both scenarios there is a large amount of electricity demand from non-domestic buildings so total peak demand across the local area remains relatively unchanged. Recall that, in the EnergyPath Networks modelling, heat network connection was only considered an option for non-domestic buildings that currently use gas as a fuel. Transition of electrically fed non-domestic buildings to a heat network is a much more involved task since changes would need to be made to the internal radiator systems.

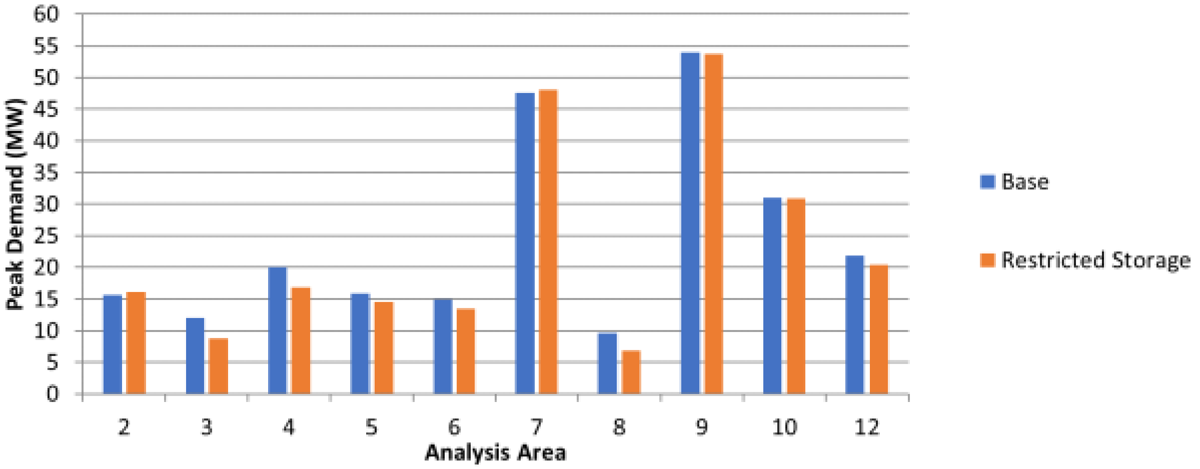


Figure 5-24 Peak Electricity Demand by Analysis Area in the Base Run and Restricted Storage Scenario

5.7.3 Key Points

- Far less domestic electric heating options chosen at domestic level, resulting in an increase in district heat connections.
- The total system cost for the restricted storage scenario is £25m more expensive than the base run, this is down to the big increase in heat network costs. The modelling suggests that efforts to reduce cost in one part of the system often results in additional (and higher costs) elsewhere in the system.
- Electricity resource costs are lower in the restricted storage scenario due to the reduction in the number of electric heating systems.
- Electricity peak demand for heating has reduced by 74% in domestic properties due to a vast reduction in the number of electric heating solutions chosen. However, due to the non-domestic electricity demands, this does not significantly reduce peak demand on the electricity network. Note that non-domestic and domestic peak electricity demand occurs at different times of day – non-domestic electricity demand will be greatest during the work hours on weekdays whereas domestic electricity demand will be higher in the mornings and evenings when people are at home. The large non-domestic peak electricity demand in Bridgend means that the total peak demand occurs during the work hours on weekdays. Therefore decreases in domestic peak demands will not have much of an impact on the overall peak.

5.8 Impacts of Green Gas Availability

5.8.1 Context

Decarbonisation of heat has predominately focused on heating system changes switching away from natural gas boilers to alternatives such as electric heat pumps, district heating solutions and biomass boilers. Whilst these solutions have numerous benefits and offer a great potential for decarbonisation of heat, they are costly and involve significant disruption to household consumers.

The UK has a world class gas grid infrastructure with over 80% of properties using gas to provide their heating and cooking needs. Gas boilers provide easy heating controls that allow rapid ramping up of temperatures offering flexibility, ease of use and are relatively inexpensive compared to alternative heating solutions. The potential for a non-fossil based gas source derived from domestic bioenergy feedstock, utilising the existing gas network infrastructure, and not requiring household heating system changes is therefore appealing. In addition, certain industrial processes cannot transition to current electrical or district heating sources, so a lower carbon gas blend may be the only alternative to reduce emissions from these buildings. Although a highly attractive proposal, the potential uptake of this energy source is severely limited due to a lack of available feedstock. Where feedstock is available there are other issues such as available capacity in the local gas distribution network to accept additional volume. The substitution of "standard" gas for green gas is not a simple process because of the difference in available capacity at the injection points. Operationally, the gas Network Operators have not yet identified a method for allowing uncapped injection of green gas in places with restricted capacity. Therefore, any green gas is assumed to be an additional load. Some sites that are allowed to inject green gas into the network where there are capacity issues have terms under their network connection offer whereby during the summer months they have to decrease the amount of green gas they can inject into the local gas grid.

There are also alternative end uses for green gas for example biomethane as fuel for CNG powered heavy duty vehicles has become increasingly popular and many view this as a better use of a limited renewable resource. Another alternative use is utilising biomass for power generation with CCS resulting in negative emissions, this would allow headroom for sectors that are costlier to decarbonise such as aviation and shipping.

The term 'Green Gas' is given to methane (CH_4) that has been derived from biomass and waste feedstock. There are two process fuels known that can be classified as green gas – biomethane and bio-Synthetic Natural Gas (SNG).

A green gas sensitivity shows the extent to which the role of a lower carbon gas option could play in contributing to the most cost-effective plan for reducing carbon emission in Bridgend. Furthermore, the sensitivity will identify the optimum location(s) to use green gas (i.e. in households, non-domestic buildings and/or energy centres for heat networks) in line with the other decarbonisation technologies available to the tool.

5.8.2 Methodology and Availability of Green Gas

Biomethane is produced from anaerobic digestion of organic material such as biomass (energy crops such as maize), animal waste/remains and food waste. Once the gas meets gas safety management regulations it is injected into the local gas distribution or transmission network. Since the first biomethane plant in 2010 there were 84 plants injecting biomethane into the gas grid as of May 2017 [38].

Bio-SNG is produced from gasification of household waste (typical black bin bag waste – municipal solid waste). Currently there are no commercial scale bio-SNG plants in operation but significant research has been ongoing, the first full scale plant is projected to go online in the early 2020s. Bio-SNG offers a greater potential than biomethane due to the greater availability of black bin bag waste feedstock.

National Grid's 2017 Future Energy Scenarios states that green gas can contribute up to 13% of total gas supply by 2050 in their two degrees scenario[39]. In addition, Wales and West Utilities provided data for green gas projections for the whole of the UK out to 2050, leading to an assumed availability of 87 TWh/y for grid injection by 2050.

[38] http://www.cngservices.co.uk/images/BiomethaneDay/2017/John-Baldwin--UK-Biomethane-Market--the-Capacity-Question.pdf
[39] http://fes.nationalgrid.com/media/1253/final-fes-2017-updated-interactive-pdf-44-amended.pdf

Currently green gas is injected into the existing gas network where it is blended with the fossil based natural gas. The gas mixture reaching customers is a blend of mostly natural gas with a small amount of green gas. To represent the blend of green gas plus natural gas within the EnergyPath Networks modelling for Bridgend, the carbon content of the existing natural gas is lowered to account for the green gas component. Green House Gas (GHG) company reporting guidelines from BEIS defines scope 1 biomethane emissions as net 0 to account for the CO_2 absorbed by fast growing bioenergy sources during their growth.

Bridgend's share of the UK's total gas consumption was 0.16% calculated from BEIS local authority electricity and gas meter point data analytical tool[40].

Projections for UK wide gas consumption for each year were taken from the ETI's ESME model, 0.16% of this yearly figure was assigned to Bridgend as its maximum amount of green gas blend available. The carbon content for that amount was corrected to account for the green gas component.

To factor in the additional cost of the green gas component the cost to produce bio-SNG[41] from gasification and biomethane from anaerobic digestion were calculated separately. This additional cost was added on top of the conventional gas prices in EPN to reflect the cost of the green gas component in the gas vector.

Figure 5-25 shows the cost and carbon content of the green gas mixture used in this sensitivity.

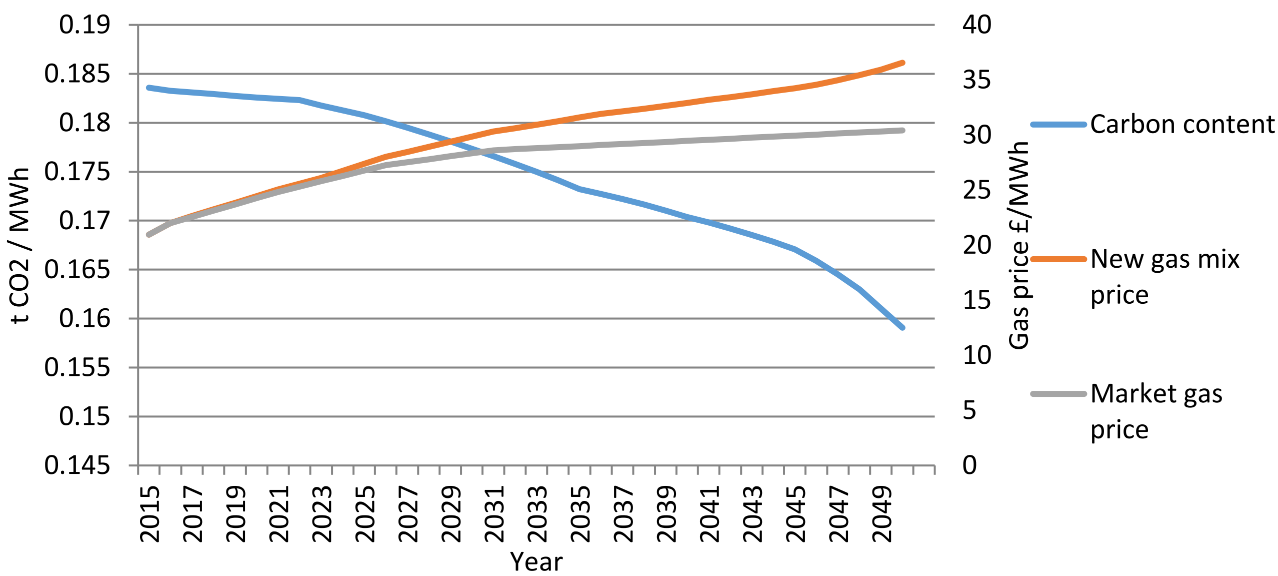


Figure 5-25 Carbon Content and Gas Price of Green Gas Blend

5.8.3 Results

Figure 5-26 and Figure 5-27 show the difference in gas consumption by sector (green gas sensitivity minus base run), first as percentages of base gas consumption by sector and second as absolute values. These illustrate how EnergyPath Networks is choosing to utilise low carbon green gas in this sensitivity. Though non-domestic gas consumption values do differ between the two runs, the change is quite insignificant compared to other sectors. Figure 5-27 illustrates that the majority of the extra gas use occurs in energy centres. That is, when gas has a lower carbon content, EnergyPath Networks chooses to build gas energy centres earlier than in the base run and utilises them more often. Figure 5-26 shows that change in gas

[40] https://www.gov.uk/government/publications/sub-national-electricity-and-gas-consumption-statistics-analysis-tool-2005-to-2009
[41] http://www.biogas.org.uk/images/upload/news_7_Bio-SNG-Feasibility-Study.pdf

consumption (as a percentage of base gas consumption) is over 300% in 2050.

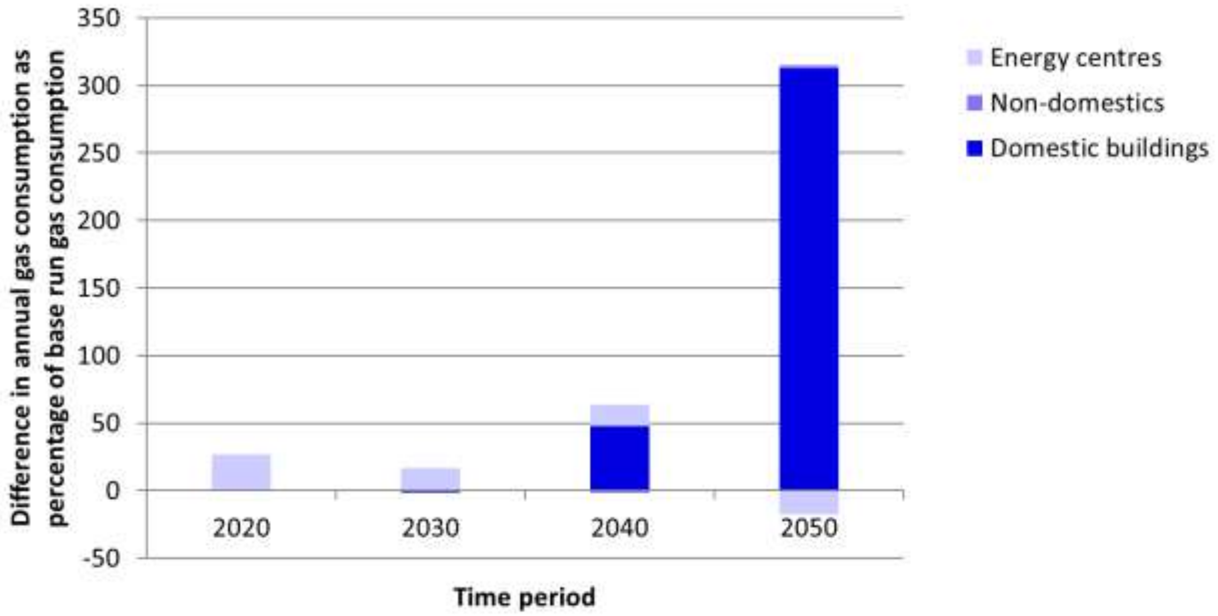


Figure 5-26 Percentage Difference in Gas Consumption by Sector (Positive Numbers show Increased Percentage Gas Demand in Green Gas Scenario)

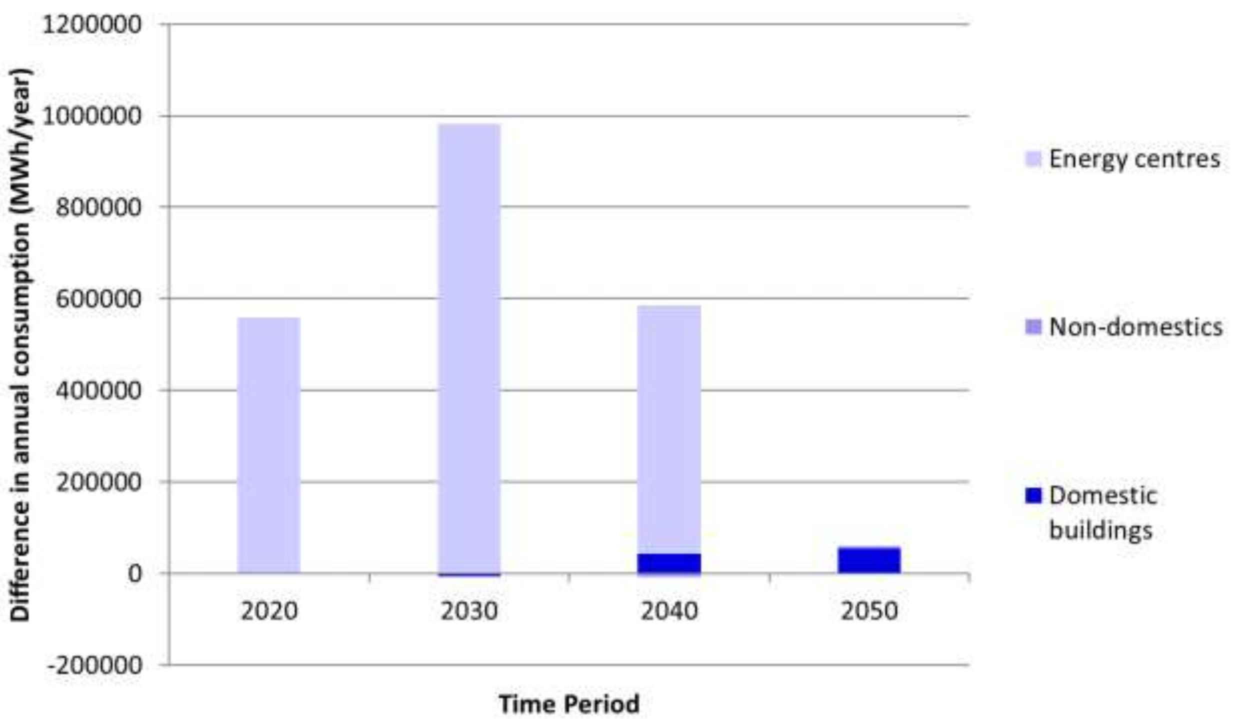


Figure 5-27 Difference in Gas Consumption by Sector (Positive Numbers show Increased Gas Demand in Green Gas Scenario)

Figure 5 28 shows the different heating systems installed in homes in the base run and the green gas run by 2050. There are an additional circa 10,300 gas boilers in the green gas sensitivity in comparison to the base run. In the base run only around 670 homes remained on a gas boiler by 2050, in the same time period the green gas run had circa 11,000 homes on a gas boiler. This explains the rise is gas consumption seen above.

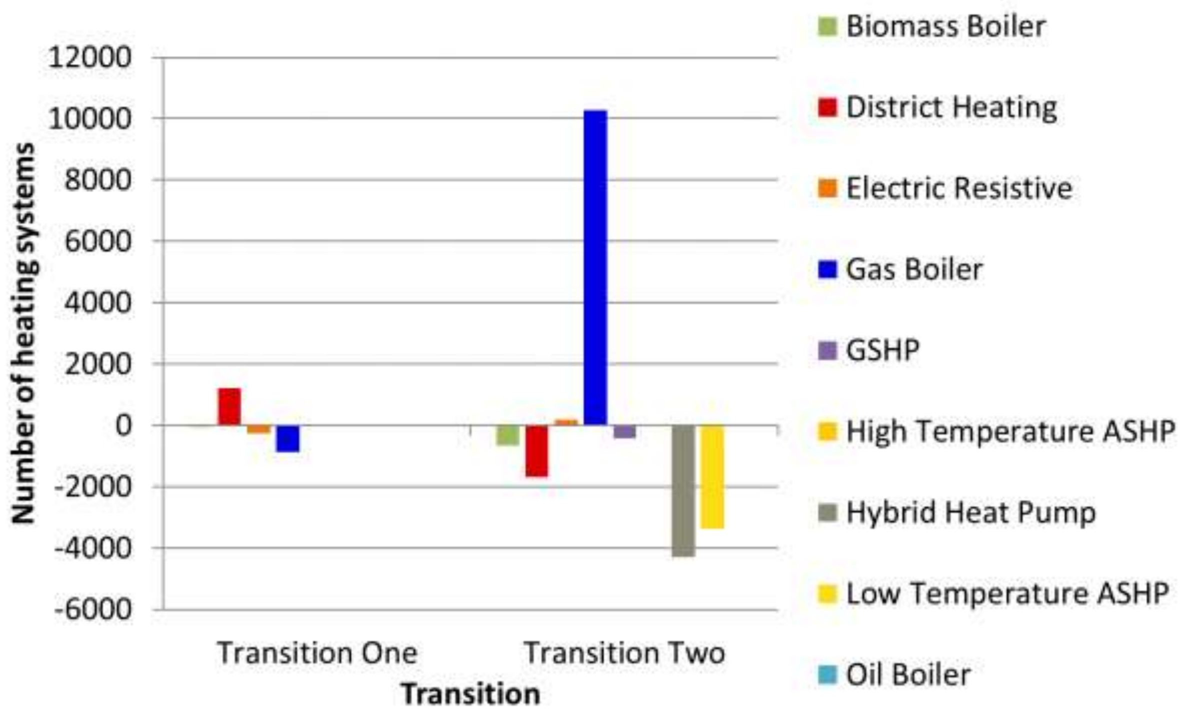


Figure 5-28 Difference in the Numbers of Heating Systems Installed Between the "Green Gas" & Base Scenarios (Positive Numbers show Increased Deployment under "Green Gas" Scenario)

Overall 83% of buildings had a heating system transitions in the green gas run compared to 98% in the base run, since the push to move away from gas technologies is not as great when gas has a lower carbon content.

Figure 5-29 and Figure 5-30 show the aggregated capacity (MW) for energy centre technologies in the green gas and base run scenarios. In the green gas scenario, there is greater gas generation capacity in the energy centres in comparison to the base run in the 2020 and 2030 time periods. This change in capacity is shown in Figure 5-31.

During 2020, in the green gas scenario, there is an additional 45MW provided from gas boilers and 8MW from gas CHP technologies in comparison to those technologies in the base run. As these technologies are chosen in the early time periods, subsequently they are retired earlier. This leads to a decrease in capacity of gas generation technologies in the later time periods. The gas CHP technologies could be replaced at their end of life with identical technologies. However, it is important to note that, even with green gas, the national gas input into the local area does have a carbon content and so there is a limit to how much gas can be utilised. This is particularly in later years when the carbon target, which the model has to meet, is more stringent.

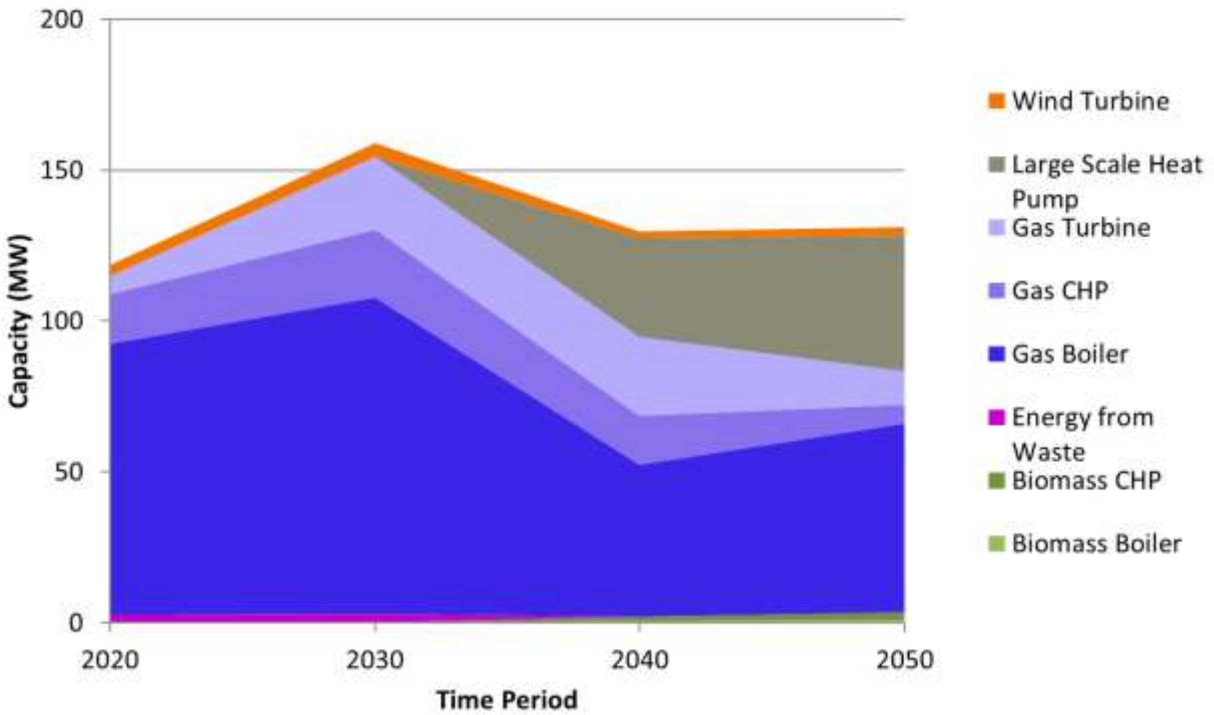


Figure 5-29 Aggregated Capacity of Energy Centre Technologies in the Green Gas Scenario

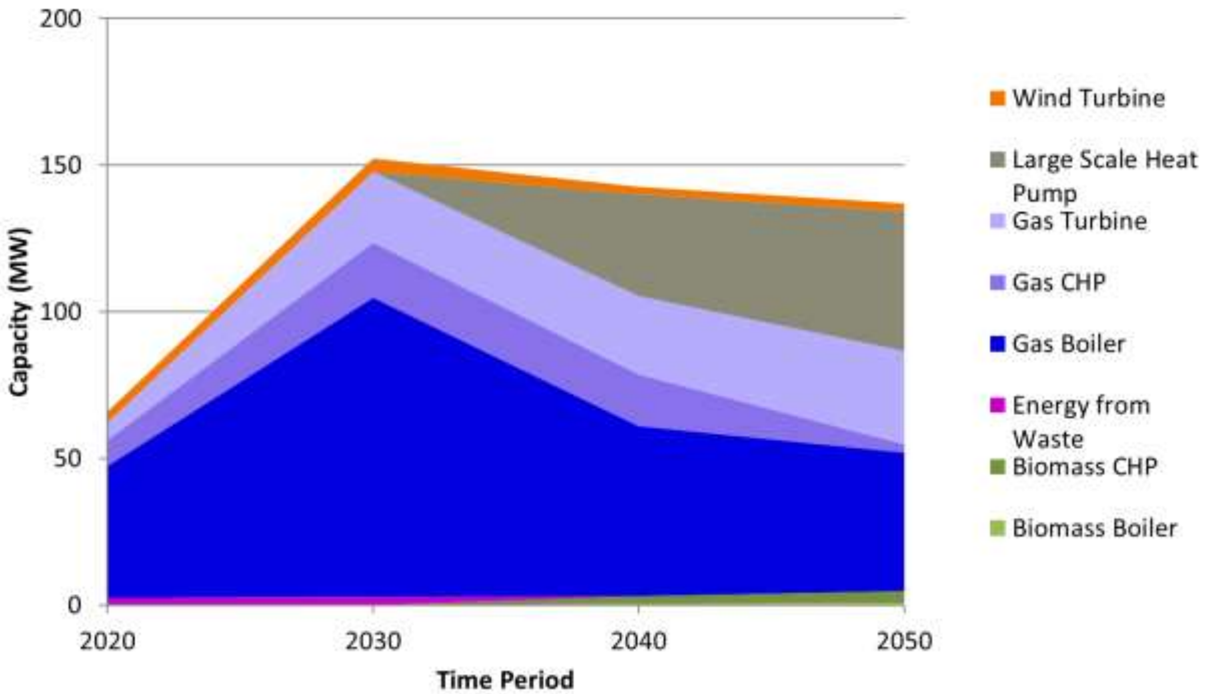


Figure 5-30 Aggregated Capacity of Energy Centre Technologies in the Base Run

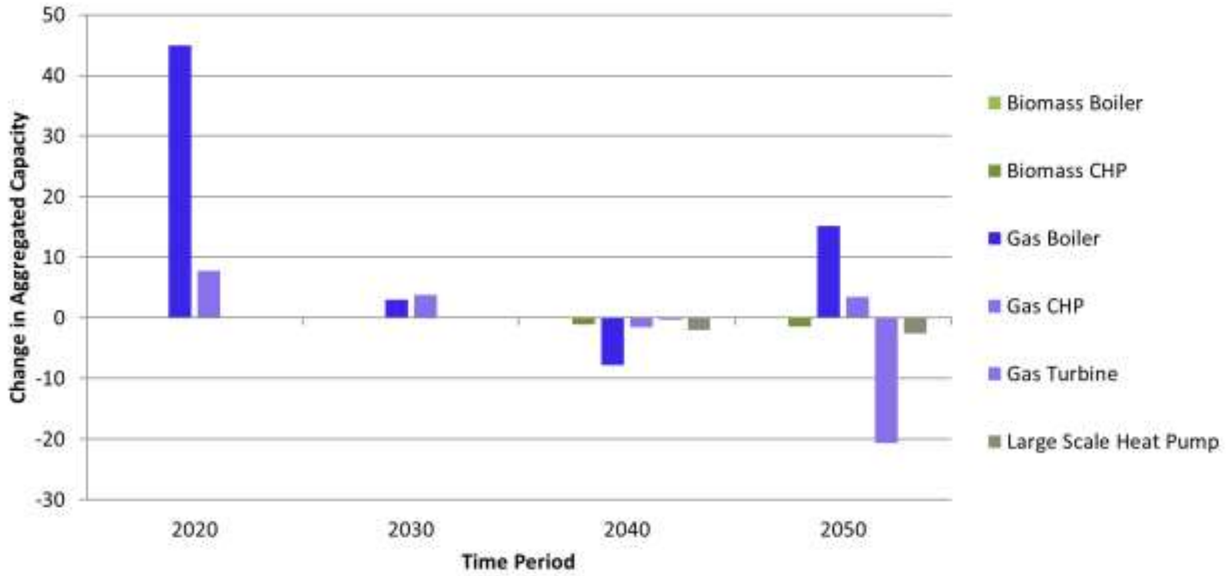


Figure 5-31 Change in Aggregated Energy Centre Capacities between the Green Gas Scenario and Base Run

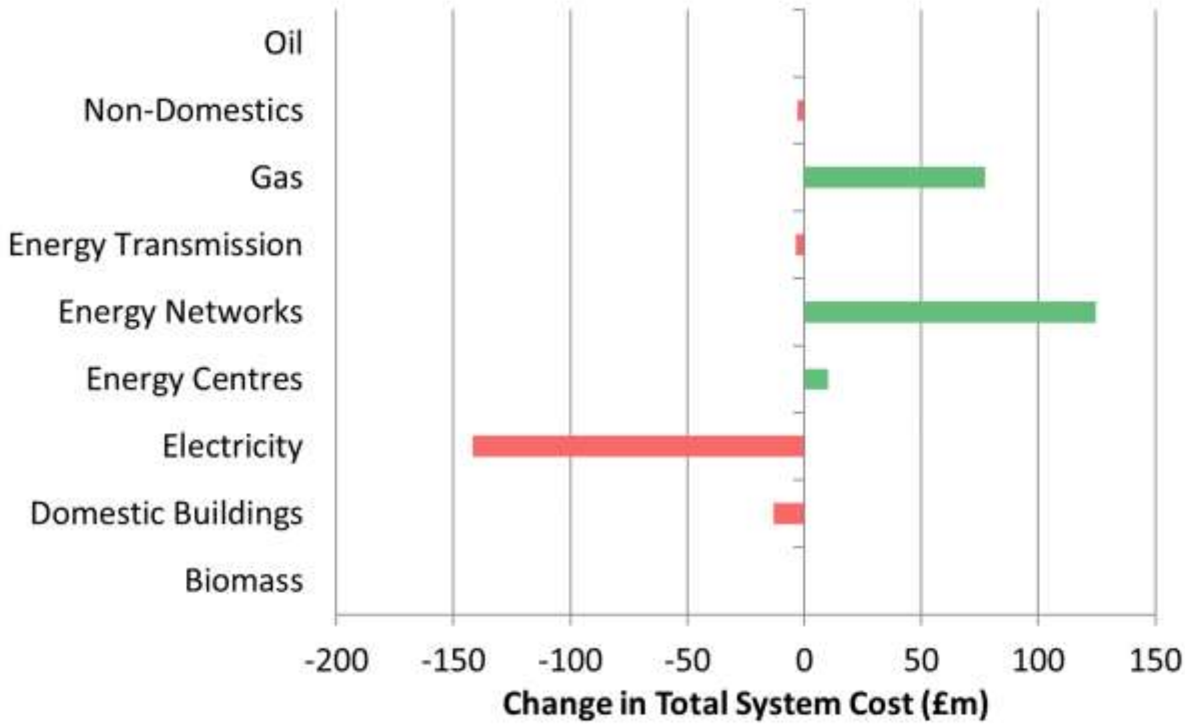


Figure 5-32 Total System Cost Difference from 2015 - 2050 in 2015£ (Positive Green Bars Indicate More Money Spent under Green Gas Scenario)

Figure 5-32 shows the differences in heating system costs by sector between the base run and green gas scenario. This indicates that, although more money is spent on gas when green gas is available, the biggest difference is in the amount of money spent on additional district heating pipes due to an increase in the build and utilisation of gas energy centres.

5.8.4 Key Points

There are important implications of this sensitivity for a variety of stakeholders, including policy makers and investors. If it is incorrectly assumed that green gas will not be widely available in the future, then local area transition could involve making unnecessary changes to buildings and networks. On the other hand, if green gas is assumed to be available and then is not, further investment would be necessary to get back on track, and carbon targets could be missed altogether. This presents some uncertainty given the fact that biomass and waste feedstocks will be in high demand in alternative sectors, as discussed earlier.

EnergyPath Networks modelling indicated that, when green gas is available, it can be utilised in the following ways:

- Decreased heating system transitions in domestic buildings.
- Increased levels of gas energy centre technologies.
- More local electricity production via energy centre technologies.
- Availability of green gas will influence choices, but it is unlikely to be available in Bridgend at volumes large enough to avoid significant change. The additional cost of producing green gas will be important when considering where and how it should be used to best advantage.

There is an additional spend of £51m in the green gas scenario in comparison to the base run. More money is spent on additional district heating pipes, imported gas and gas energy centres. However, less money is spent on imported electricity as it used less in heating systems and energy centres.

5.9 Impacts of Forcing the Mine Water Heating Project

5.9.1 Context

Bridgend Council are investigating a district heating network that utilises the heat from an abandoned coal mine that has been flooded with water. One of the proposed scheme consists of extracting low temperature water from the mines, which is then upgraded at each individual household using heat pumps to 55 °C as depicted in Figure 5-33. Alternative configurations are also being considered with a heat pump being placed close to the mine water boreholes (at the energy centre). Recent findings from bore holes have shown the mine water temperature to be higher than initially anticipated, circa 20 °C, in light of these findings a definite heat pump configuration (centralised or decentralised) has yet to be finalised.

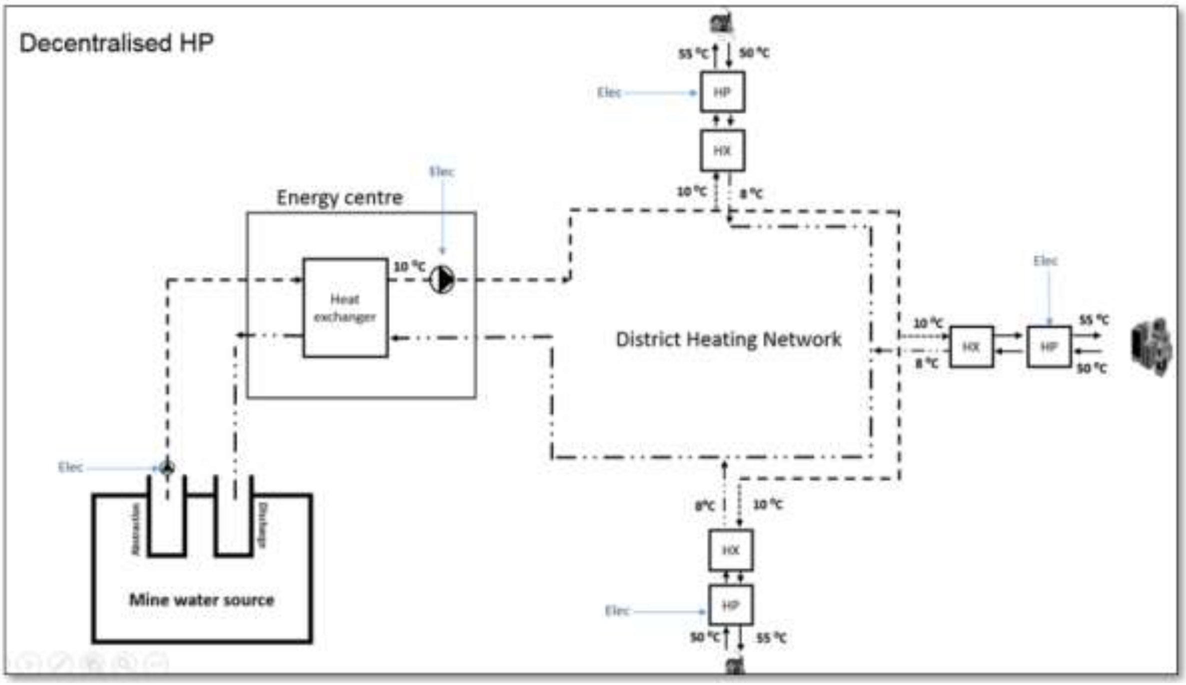


Figure 5-33 Proposed Mine Water Decentralised Heat Pump Scheme

EnergyPath Networks could not be configured to represent the decentralised scheme with individual heat pumps upgrading low temperature water. The scheme was represented in the modelling using a single heat pump at the energy centre and a high temperature heat network connecting to the properties identified by the council. Buildings that do not have adequate insulation were forced to have retrofit insulation applied to them. To align the modelling with the proposed scheme, the cost of the central heat pump scheme in EPN was based upon individual household heat pumps scaled up. Circa 900 properties were identified to be connected to the proposed mine water scheme. With the low heat network temperature, all connected properties would require suitable building retrofit measures.

5.9.2 Results

The mine water scheme costs modelled were based upon figures from the latest feasibility study findings provided. The discounted 2015 costs of the scheme which includes the energy centre (heat pump), heat network components (pipes) and building conversion (heat exchanger and insulation) are shown in Figure 5-34. Note that, as previously mentioned, the energy centre costs here actually represent the sum of the costs of the individual building level heat pumps. The pipes modelled will have much more insulation than the decentralised scheme so the heat network costs in Figure 5-34 are overestimated. However, the largest cost of building a heat network is associated with digging the trench.

Note that the energy centre is built once (at just under £17 million total), i.e. it is not replaced at its end of life. In reality, the energy centre or building level heat pumps would need replacing after around 15-20 years. In the model run, the energy centre was replaced with a large scale ASHP. This cost is not included in Figure 5-34 so that this graph is representative of the "true" proposed mine water scheme.

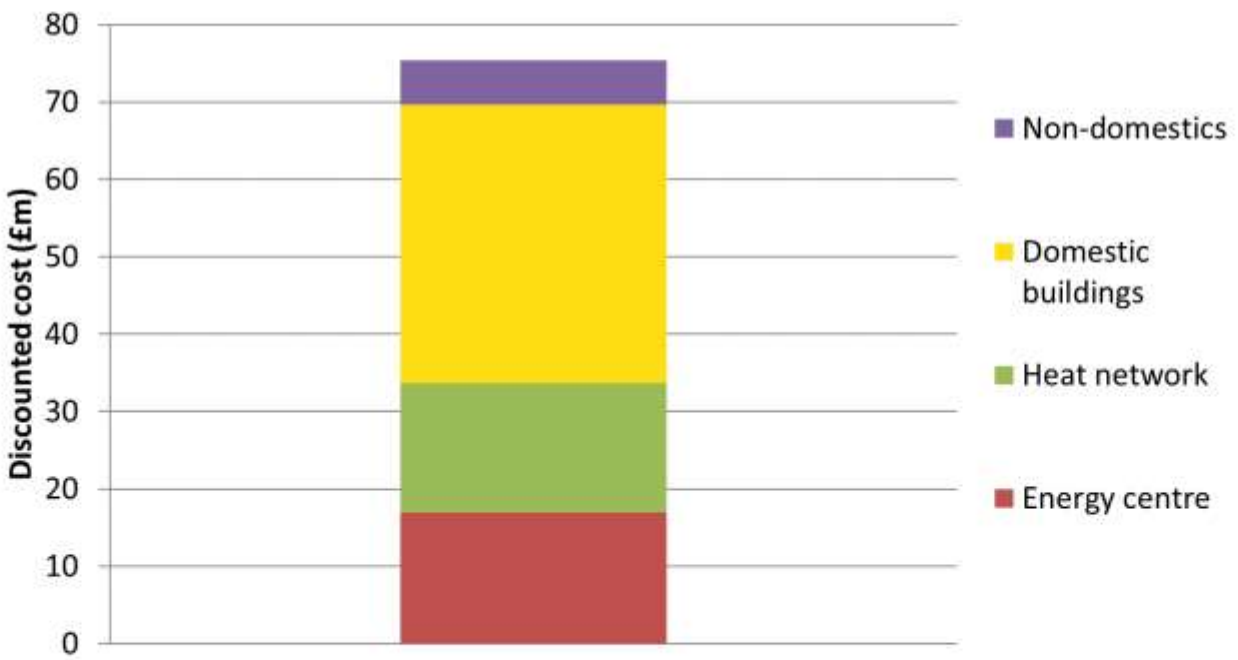


Figure 5-34 Mine Water Heat Network Scheme Costs

A significant outcome of the mine water scheme is energy reduction in buildings, as shown in Figure 5-35 Average. The typical average decrease in demand per property overall is circa 800 – 1000 kWh/yr. The energy saved on heating increases with floor area, from just 400 kWh/yr for the smallest properties to just under 2000 kWh/yr for the largest.

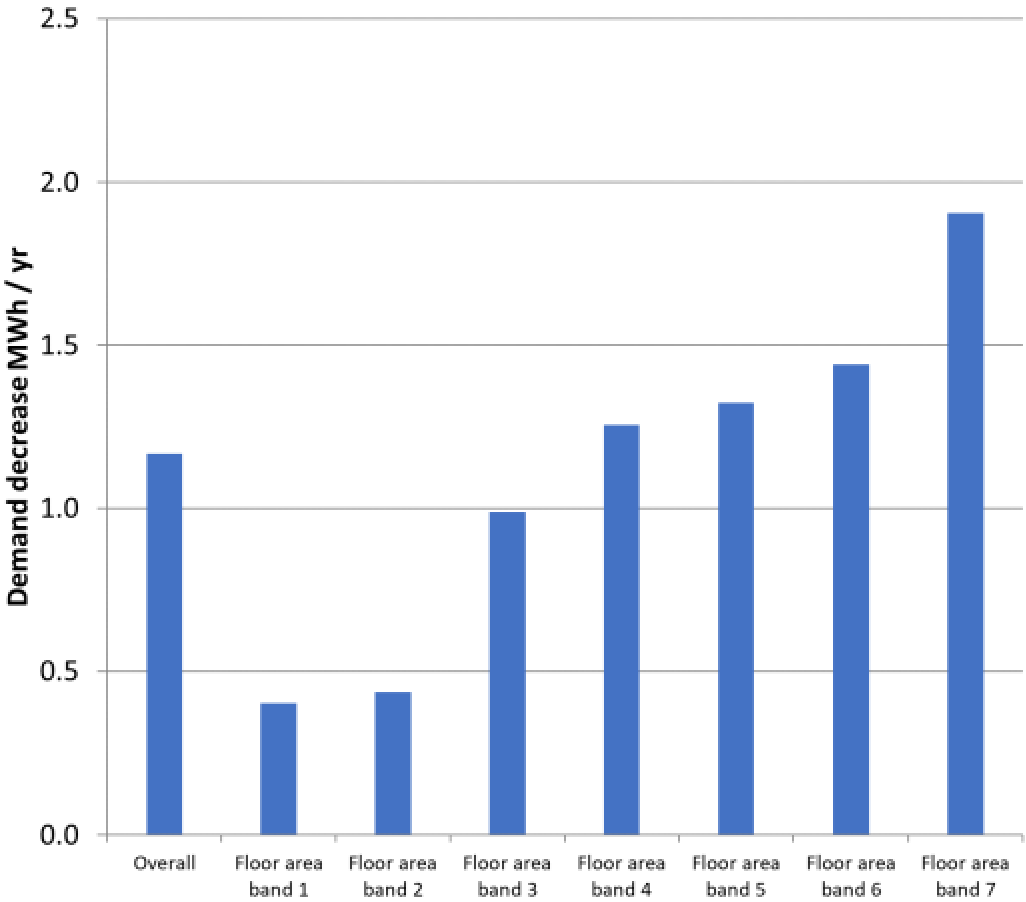


Figure 5-35 Average Decrease in Energy Demand Post Retrofit

The change in carbon emissions with and without the mine water scheme are shown in Figure 5-36.

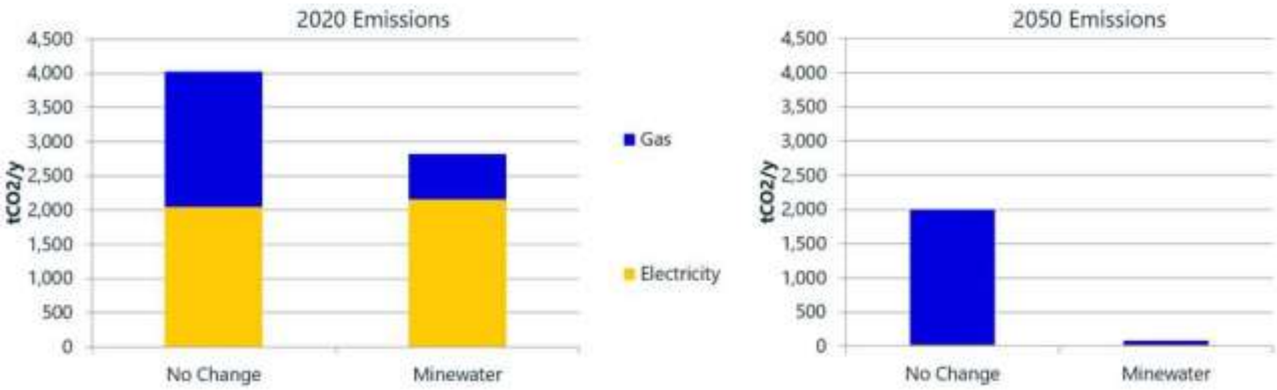


Figure 5-36 Change in Emissions with and without the Mine Water Scheme Implementation

The "No Change" plot assumes that buildings have the original heating system and building fabric levels. The emissions here include carbon associated with demand for heating and electricity usage for appliances. Note that, in 2050, there is still a reduction in the "No Change" scenario due to decarbonisation of national electricity. Installation of the mine water scheme in 2022 reduces carbon emissions immediately by around 30% relative to the "No Change" scenario. The main reduction is caused by buildings moving away from gas boilers and connecting to the mine water heat network. Carbon emissions are cut by 98% in 2050 in the mine water scheme compared to 2015 levels.

5.9.3 Key Points

- The mine water project costs, as modelled, are just over £75 million. If the heat pumps were to be replaced at their end of life this could cost an additional ~£17 million for the ~900 building connections. However, recall that the mine water project representation modelled here is different to the decentralised heat network plus heat pump scheme being considered by BCBC.
- A gas CHP of the same capacity with a gas boiler back-up would cost around £15million in 2020 and 2030 compared to ~£17million for the mine water energy centre.
- The district heat project and retrofit installations lead to a 98% reduction in carbon emissions compared to a BAU scenario. This assumes that the carbon intensity of national electricity decreases over time.

Note that the general analysis across all model runs in Section 6.3 suggest that Caerau is an area that is suitable for heat network transition.

5.10 Impacts of a Town Heat Network

5.10.1 Context

BCBC has been assessing the prospect of installing of a heat network in Bridgend town. This is referred to the "Town Heat" project. The Town Heat network consists of an energy centre at the Bridgend Life Centre powered by gas boilers and a gas CHP. Initially it is envisaged that only non-domestic buildings will be connected to this heat network, which could later be extended to surrounding domestic buildings. On the recommendation of BCBC, it was decided to force the installation of this heat network in the base run of the model. That is, EnergyPath Networks is forced to include the building of the heat network and energy centre, as opposed to it being presented as one of a set of options. Four non-domestic buildings (Prince of Wales and Glanrhyd hospitals, town hall and the leisure centre) were forced to connect to the energy centre. This acts as a seed for a larger heat network, since the peak heat demand of the four connected buildings is around 0.35MW less than the capacity of the Town Heat energy centre.

In this sensitivity, the stakeholder working group were keen to understand whether the Town Heat network is modelled as a cost effective network choice to decarbonise homes and buildings in the Town Centre in the context of the whole energy system.

5.10.2 Results

The 2050 domestic heating system combinations for the base run and "Town Heat impact" scenarios are shown in Figure 5-37.

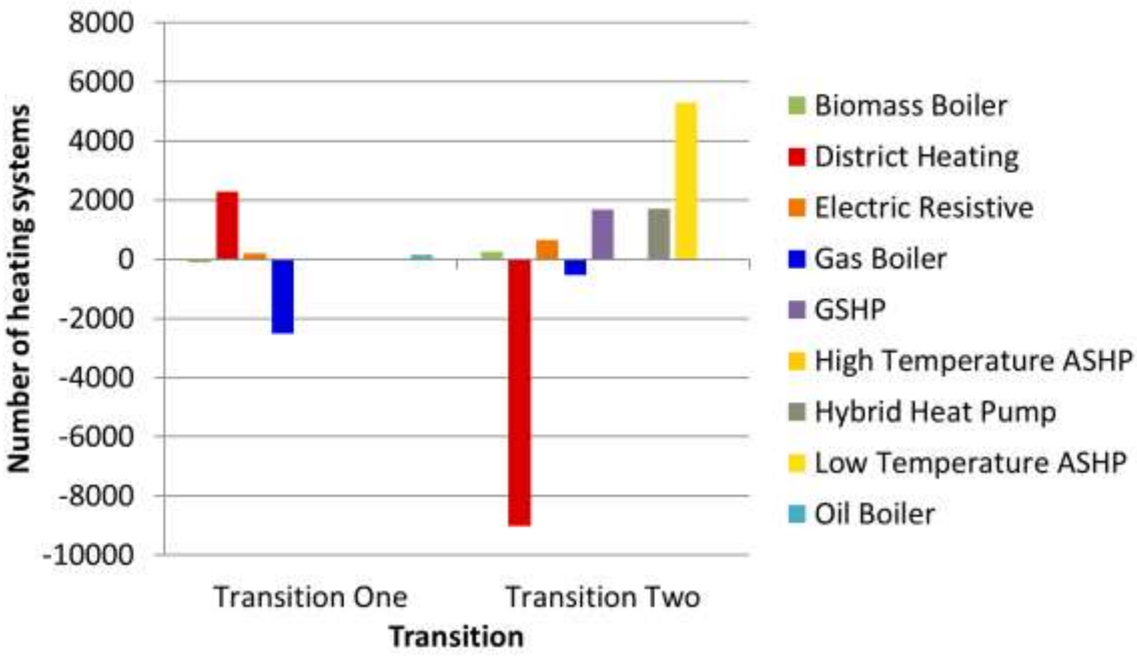


Figure 5-37 Difference in the Numbers of Heating Systems Installed Between the "Town Heat Impact" & Base Scenarios (Positive Numbers show Increased Deployment when the Town Heat Scheme is Optional)

Crucially, in the "Town Heat impact" run, the model still chooses to build the energy centre at the Prince of Wales hospital but it does not connect the exact same buildings. There are circa 9,000 fewer domestic heating connections across Bridgend in the "Town Heat impact" scenario. In contrast, the is a 5% increase in non-domestic building floor area heat connections in comparison to the base run. However, it is important to note that the EnergyPath Networks analysis is aimed at providing evidence for high level decisions. It does not replace detailed feasibility studies prior to installation that would identify which buildings to connect specifically.

Alongside a decrease in district heat, there is a significant increase in electric heating solutions in the "Town Heat impact" run, namely (circa):

- 5,300 low temperature ASHPs.
- 2,200 additional GSHPs.
- 1,700 additional hybrid heat pumps.
- 650 extra buildings with electric resistive.

The change in total system cost between the base run and "Town Heat impact" run is shown in Figure 5-38. The "Town Heat impact" scenario is circa £97m cheaper in comparison to the base run. The majority of this cost reduction is due to the decrease in heat network costs. There is increased electricity network reinforcement in the "Town Heat impact" results due to an increase in electrical heating systems but this does not outweigh the savings in heat network costs. It is important to note that the way that the local area is divided up in EPN can lead to choices in the optimiser being different to the choices that are available in real life. Therefore, it should not be concluded that the four non-domestic connections proposed by Aecom should not be connected. The important insight is that the energy centre is built in this scenario.

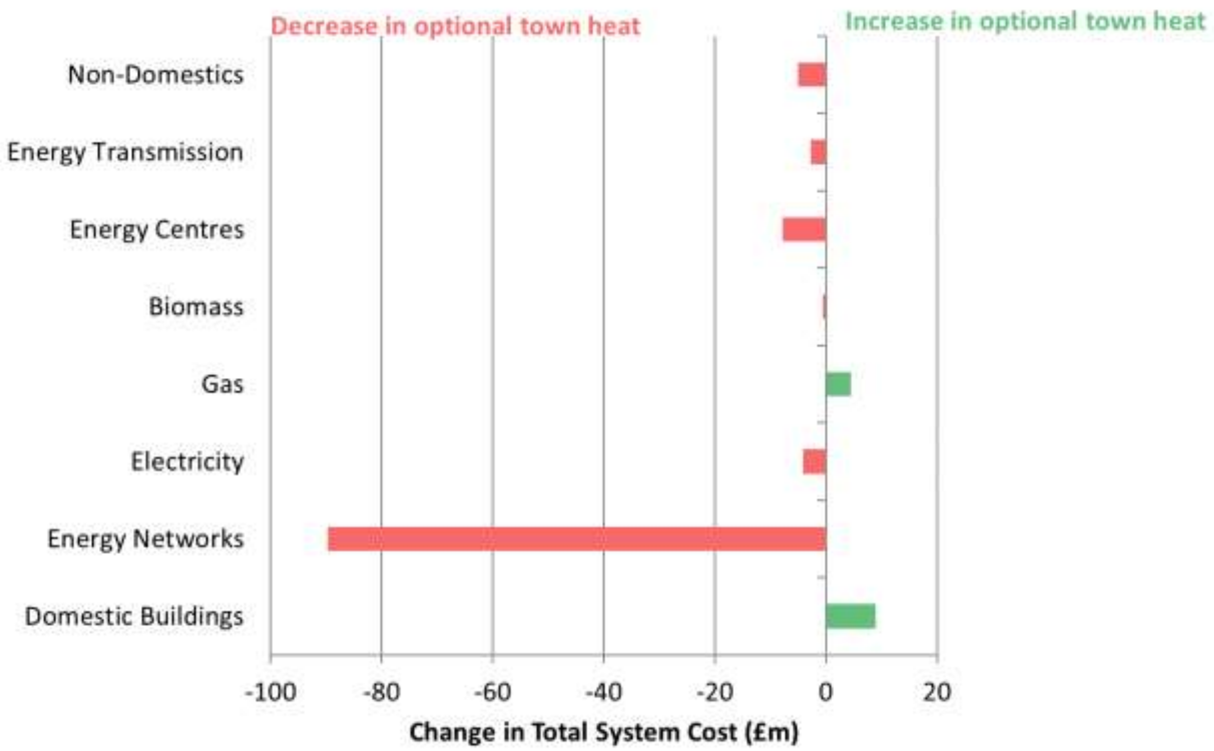


Figure 5-38 Change in Total System Cost (£m) to 2050 - Discounted to 2015 Prices (Positive Numbers show Increased Costs when the Town Heat Scheme is Optional)

5.10.3 Key Points

- The Town Heat energy centre is installed even when it is not forced in the analysis. A heat network is also built, i.e. the CHP technology is not installed to generate local electricity only.
- Overall, there are around 9000 less domestic district heat connections but there is ~5% more non-domestic floor area connected to district heat.
- The “Town Heat impact” run is circa £97m cheaper in comparison to the base run. However, this is a less than 1.5% decrease in costs.

5.11 Impacts of Restricting Large-Scale Heat Pumps

Energy centre technologies play a key role in decarbonisation of a local area. It is often the case in EPN that gas CHPs and boilers provide local distributed electricity and heat generation in early time periods. Then, in later years, these gas technologies are replaced with large scale heat pumps as the national electricity grid decarbonises. In reality, there are limited examples of large scale (MW capacity) heat pumps to be deployed in the UK and in Europe.

A sensitivity in which availability of large scale heat pumps were restricted was carried out to see the impact of not having these technologies. **EnergyPath Networks failed to find to find a solution in reaching the desired carbon target.** This was still the case when the Town Heat network project was not forced, which highlights the key role large scale heat pumps have in contributing to decarbonisation.

If development of large scale heat pumps was to stop, the alternative options to achieve a carbon target would require a greater uptake of household heat pumps and/or increased availability of alternative low carbon heating solutions such as green gas or hydrogen. If large scale heat pumps and neither green gas / hydrogen was available in significant quantities, then the local carbon target would need to be downscaled.

Fortunately, there is progression on all three of these fronts, green gas availability is set to increase with the preparation of a commercial scale bio-SNG plant that produces green gas via gasification of household waste[42]. Blending of hydrogen with natural gas looks to be gathering greater momentum with the HyDeploy project[43] and the identification of the Liverpool-Manchester hydrogen cluster by Cadent[44].

There have been several large-scale heat pump projects in the UK recently. For example, Wandsworth Riverside Quarter in London, uses an Aquifer Thermal Energy Store (ATES) consisting of heat pumps that supply 1.2MW of peak heating output and 2.25MW of peak cooling capacity for 504 apartments and significant commercial and leisure space. In addition, Islington Borough Council commissioned Ramboll to extend a district heat network scheme for an additional 500 dwellings. In the existing heat network 850 dwellings were connected to a gas CHP powered energy centre. The scheme was extended using heat pumps to upgrade heat (from 18-28 °C to 80 °C) from a London Underground ventilation shaft and a UK power networks transformer cooling system[45].

[42] https://cadentgas.com/Media/Press-releases/2017/From-trash-to-gas-Cadent%E2%80%99s-revolutionary-green-ga
[43] https://cadentgas.com/Media/Press-releases/archive/2016/Boost-for-low-carbon-future-as-National-Grid-scoop
[44] https://cadentgas.com/About-us/Innovation/Projects/Liverpool-Manchester-Hydrogen-Cluster
[45] http://www.ramboll.co.uk/projects/ruk/heating-up-london

6 Future Local Energy Scenarios

Following the assessment of the options and choices for a Low Carbon Local Energy System, a series of two future local energy scenarios for Bridgend were developed:

1. Assuming that green gas is not available to meet heating demand in Bridgend.
2. Assuming that green gas is available to meet heating demand in Bridgend.[46]

The inputs for the run without green gas are analogous to the base run, whereas the inputs for the run with green gas are analogous to those for the green gas sensitivity as described in Section 3.9. The Future local energy scenarios developed for Bridgend are compared with the Business as Usual scenario. Note that this is not the same as the Business as Usual modelling discussed in Section 5.2 since it includes the changes listed above. A new Business as Usual is required since, comparing with the Business as Usual sensitivity described in Section 5.2, would not be a direct comparison and could be misleading. However, it does assume that no carbon target is enforced for the local area. The results from the post-sensitivity scenarios should not be directly compared with the base run since the inputs are not consistent. That is, it is not possible to determine which input(s) drive each change in the results because a number of data changes have been made at once.

Following the initial analysis and sensitivities the stakeholder group were consulted on optional input changes to inform the development of the final future local energy scenarios. The key decision points were:

- The Town Heat Network energy centre should be presented as an option to the model, rather than forced.
- Mine water heating project costs should be updated based on latest available data.
- The ESME Patchwork scenario should still be used to represent the national energy system.
- Building level storage charging times should not be restricted.
- Gas energy centre costs should be updated to reflect the l cost of building additional gas network for connection. These costs have been provided by Wales and West Utilities.

Furthermore, the following changes were made based on assessment of practical restrictions to domestic heating systems and network infrastructure:

- Biomass boilers are restricted from terrace properties due to difficulties with access.
- A heat link between analysis areas 10 and 6 was removed to avoid crossing a motorway and gas transmission pipe, which would make heat network installation much more difficult and expensive.
- Certain energy centre technologies were resized as some technologies were underutilised.

Furthermore, characteristic weather days (i.e. days that represent "typical" seasonal days plus peak demand, very cold days on which the networks are sized) were modified after comparison with BEIS demand data.

[46] The inputs for the run without green gas are analogous to the base run, whereas the inputs for the run with green gas are analogous to those for the green gas sensitivity as described in Section 3.9.

6.1.1 Future Local Energy Scenario 1 Results - A World Without Green Gas

This scenario assumes a carbon target of a 95% reduction from 1990 building emissions. It is informed by a practical engineering review of barriers to low carbon technology deployment within specific local areas which examined the outputs of the analysis and project stakeholder group feedback as described above.

Figure 6-1 and Figure 6-2 show the difference in the number of heating systems installed (BAU minus "Without Green Gas") and the proportion of 2050 heating systems under the two scenarios. It is worth noting that there is some district heat in the BAU scenario (~1,100 buildings) even though the Town Heat network was not forced. However, as with the base run, it is clear that decarbonisation is not achieved in the modelling in the absence of a carbon target. Indeed, almost all of the energy centre capacity (circa 98% in 2050) consumes gas.

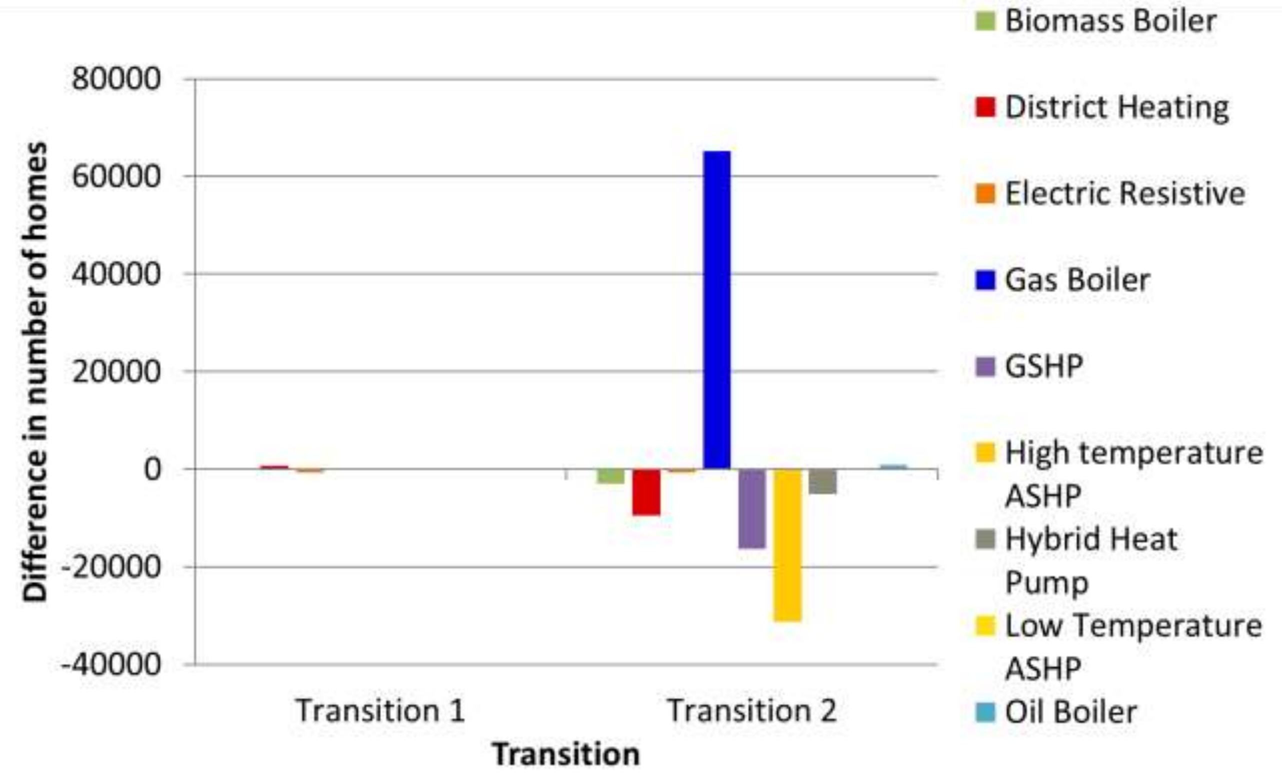


Figure 6-1 Difference in the Numbers of Heating Systems Installed Between the "Without Green Gas" & BAU Scenarios (Positive Numbers show Increased Deployment under BAU)

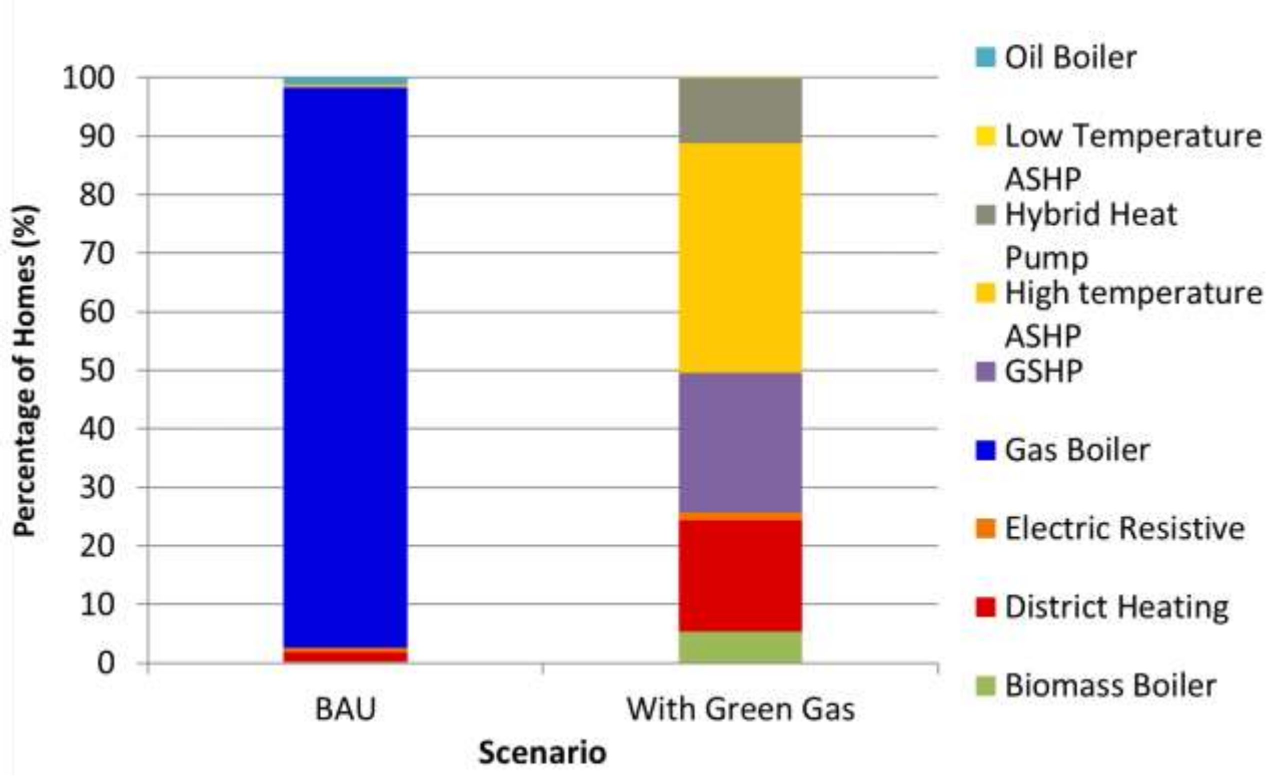


Figure 6-2 Proportion of Household Heating Systems Installed in the "Without Green Gas" and BAU Scenarios

In the "Without Green Gas" future local energy scenario, Bridgend is predominantly electrically heated with almost 80% of buildings having heat pumps or electric resistive as primary heating systems. Figure 6-3 shows the proportion of buildings with heat pumps (low temperature, high temperature or hybrid) by analysis area.

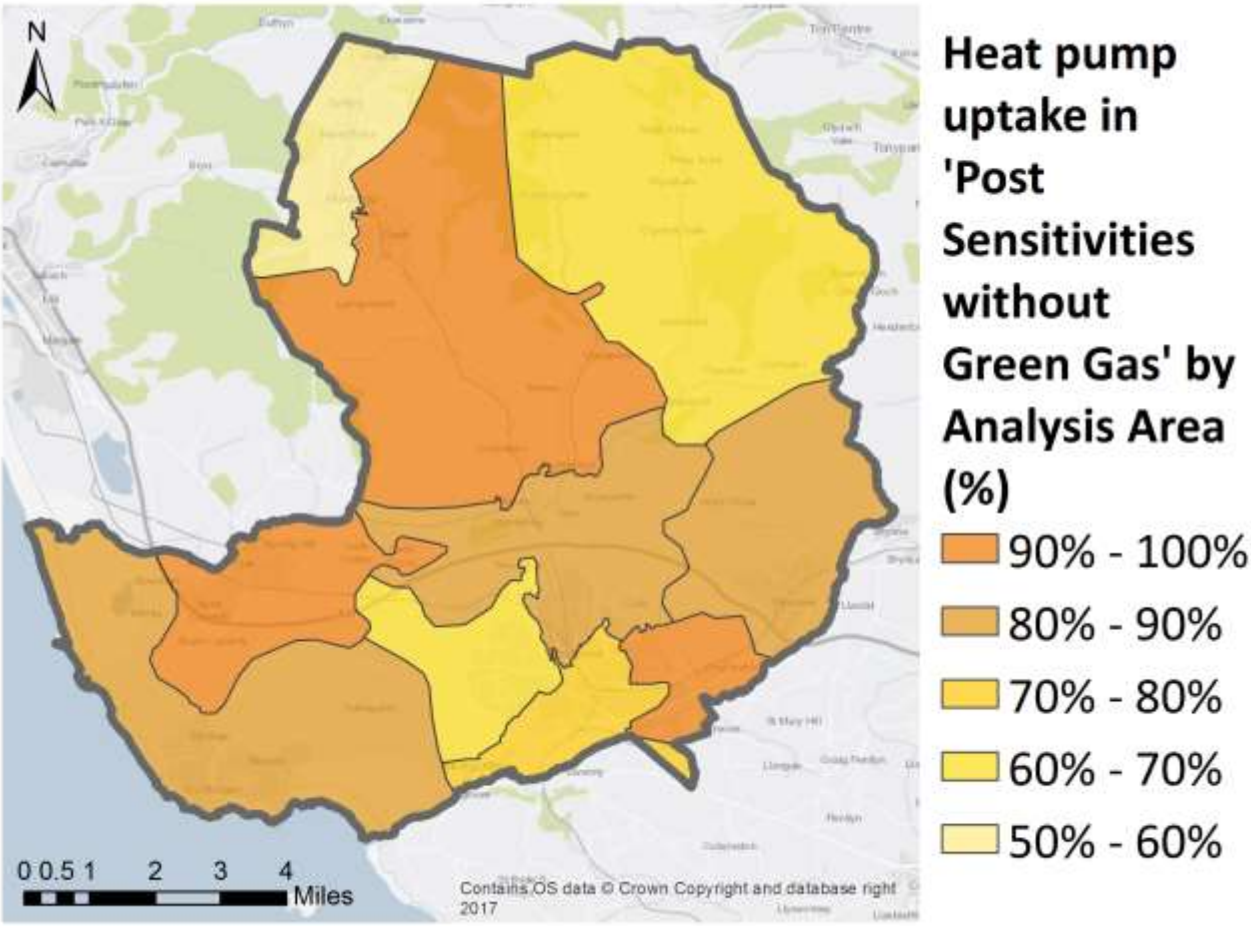


Figure 6-3 Proportion of Heat Pumps by Analysis Area under "Without Green Gas" Scenario

This increase in electrical heating systems has implications for electricity network reinforcement. Figure 6-4 shows the difference in capacity (Business as Usual minus "Without Green Gas" scenario) in HV feeder and heat pipe components (similar reinforcement is required on other components). Note that district heat uptake under BAU is quicker. However, as mentioned, the energy centres are predominantly gas CHP so have associated carbon emissions. Figure 6-5 illustrates the variation in total electricity demand (domestic & non-domestic buildings). This increase in demand leads to almost 85MW of electricity network reinforcement at the HV feeder level.

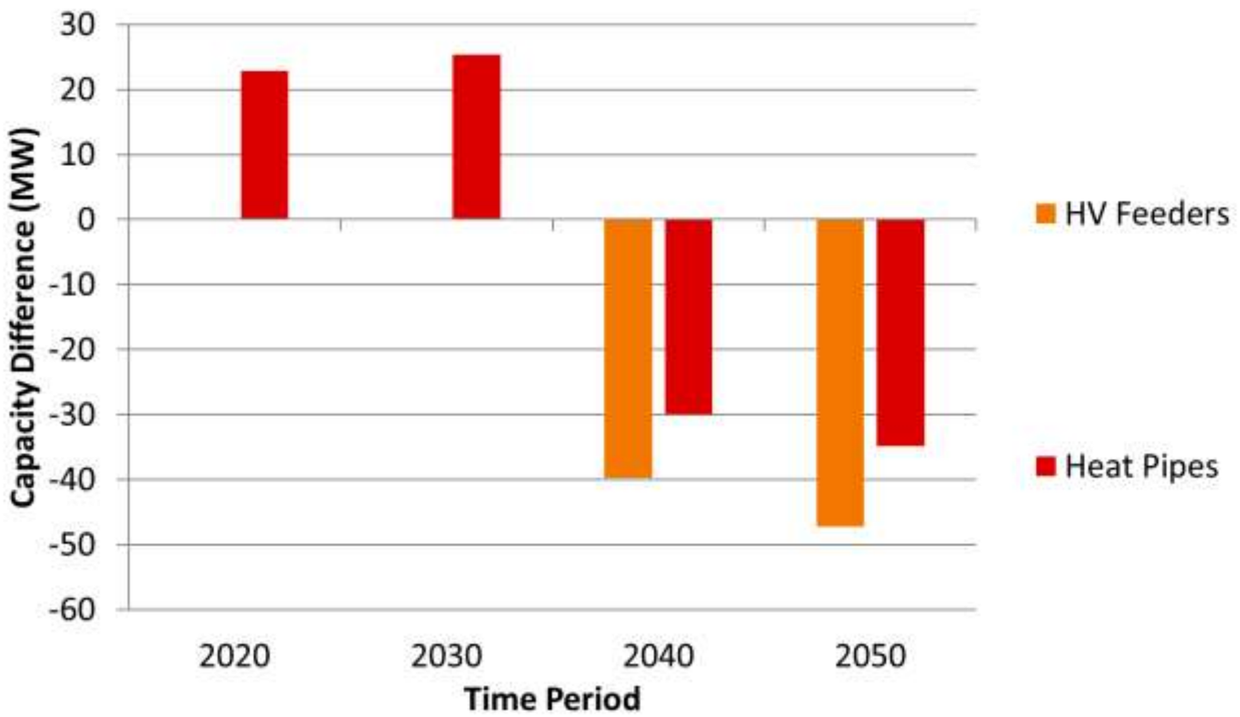


Figure 6-4 Network Capacity Difference (Positive Numbers show Increased Capacities under BAU Scenario)

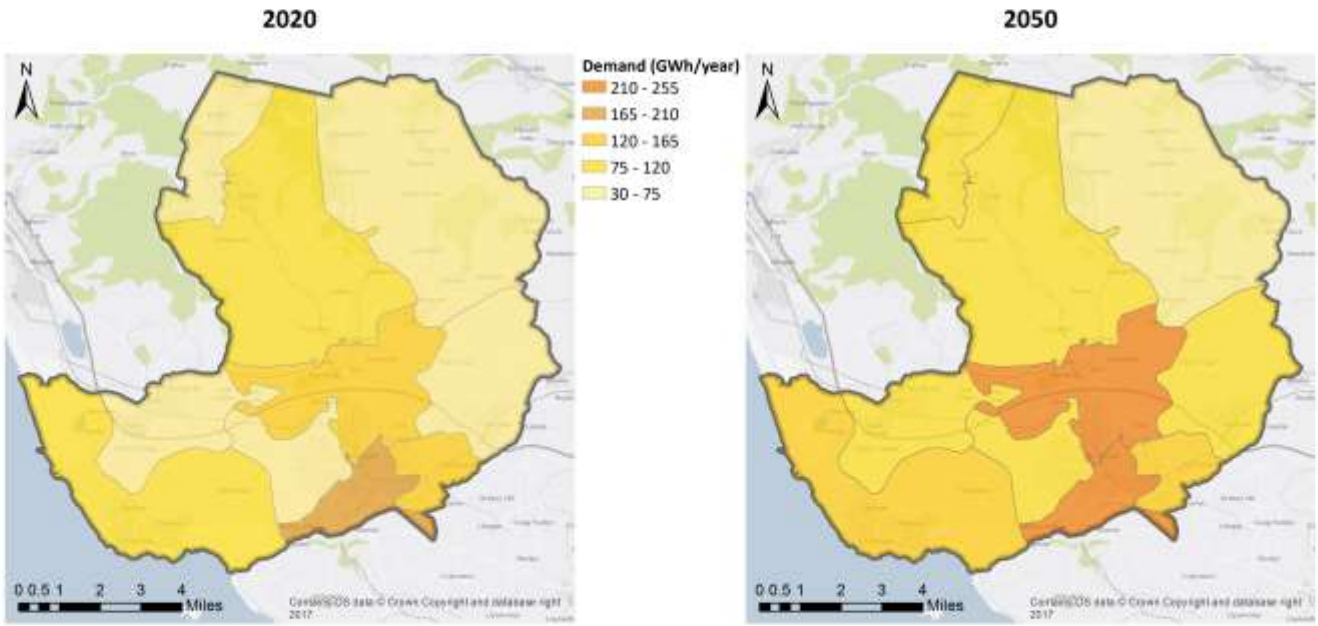


Figure 6-5 Electrical demand by Analysis Area for "Without Green Gas" Scenario

Figure 6-6 shows the change in total system costs (BAU minus "Without Green Gas").

The total system costs of the "Without Green Gas" is around £7.4 billion, whereas BAU costs around £6.6 billion. The emissions associated with the "Without Green Gas" scenario are shown in Figure 6-7. As in previous scenarios, any remaining emissions predominantly lie in the non-domestic buildings, suggesting that this is the most expensive sector to decarbonise. Recall that some heavy industry buildings have been prevented from transitioning to district heat but this does not account for all of the of the non-domestic building emissions.

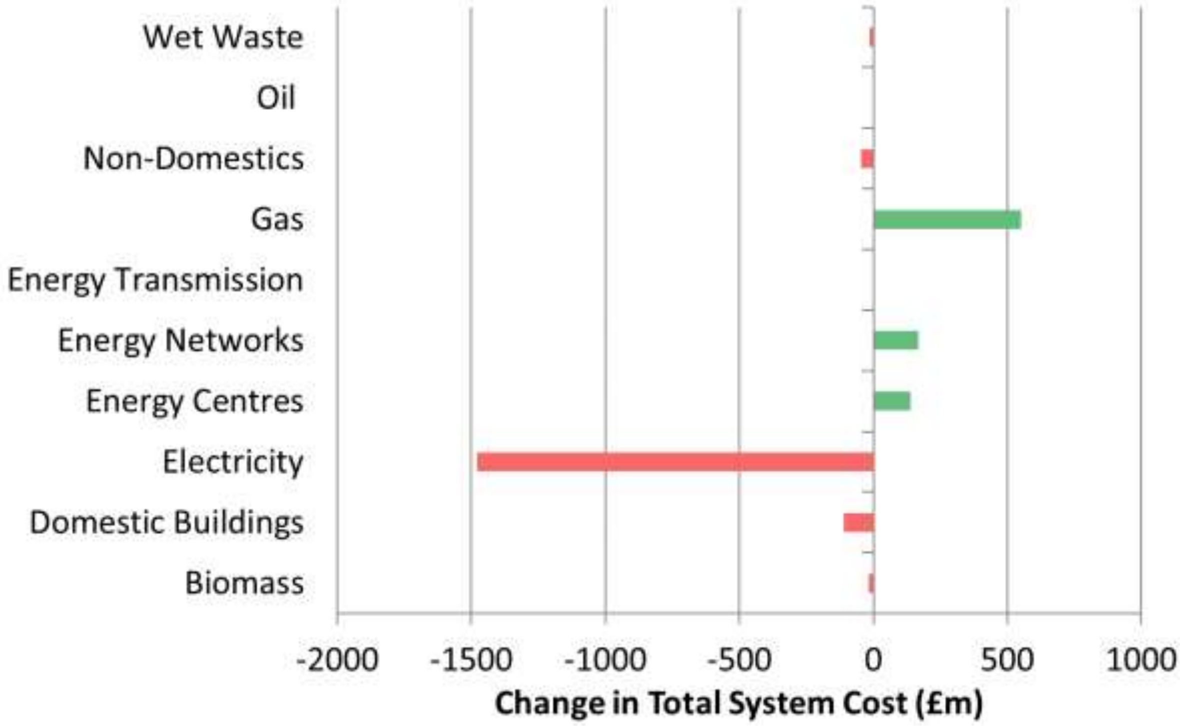


Figure 6-6 Change in Total System Cost (£m) to 2050 - Discounted to 2015 Prices (Positive Numbers show Increased Costs under BAU Scenario

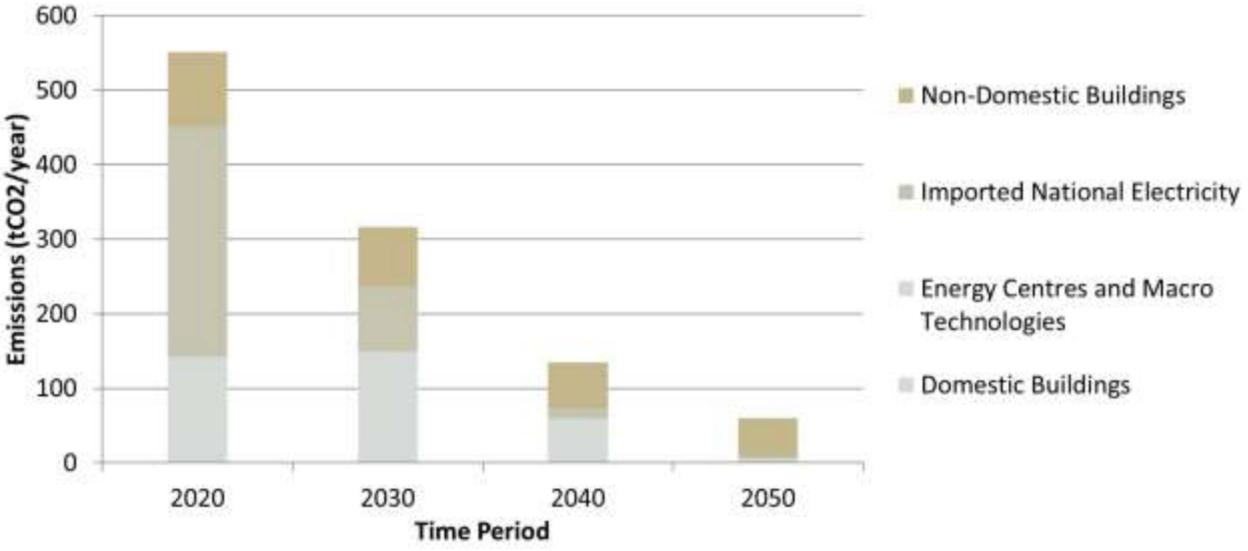


Figure 6-7 Carbon Emissions under "Without Green Gas" Scenario by Sector

6.1.2 Future Local Energy Scenario 2 Results - A World With Green Gas

Again, working to a carbon target of a 95% reduction from 1990 building emissions but provides an alternative view, based on assessing the potential availability of Green Gas[47]. This scenario considers what role blending low carbon gas with natural gas could play in contributing to the cost-effective reduction of emissions.

Recall that EnergyPath Networks can choose to utilise gas in different ways, namely in domestic gas boilers, non-domestic gas boilers and gas fed energy centres for district heat. In the "green gas availability" sensitivity extra gas was primarily utilised in domestic buildings. However, in this scenario, the lower carbon content of gas allows higher gas consumption in energy centres – compare Figure 6-8. It is impossible to precisely identify the reason for this change since a series of input changes have been made at once. However, it is interesting that in both scenarios non-domestic buildings results have remained largely unchanged. This is partially because there is so much heavy industry in Bridgend, which is not able to transition to district heat in the modelling. However, there is an extra ~60,000m^2 that could continue to be fed by gas, as shown in Figure 6-9.

Figure 6-10 shows the differences in domestic heating systems between the post-sensitivity runs. Here, the reduction in the carbon content of gas has led to increased hybrid heat pump systems and district heat fed by gas energy centres, instead of standard heat pumps. Note that there is very little change between the scenarios in transition 1, despite the decrease in gas energy centres in the 2020 time period. This is due to higher levels of gas CHP, when green gas is not available, built purely for electricity production to avoid the rising costs of national electricity. This still happens when green gas is available but to a lesser extent. The 2020 energy centre production is shown in Figure 6-11, which shows a difference in annual electricity production of almost 16,000 MWh/year. Figure 6-12 shows the resulting difference in HV feeder and heat pipe components between the two scenarios. This shows that the changes between capacities only occur in

[47] Green Gas derived from biomethane and bio-Synthetic Natural Gas (SNG). The methodology for assessing and determining the availability of Green Gas is discussed in the supporting Evidence Base.

transition 2, where increased capacities of both electricity and heat network components are required when green gas is not available.

The availability of green gas does not affect 76% of off-gas properties but there are around 200 more off-gas district heat connections when green gas is available. This suggests that, for these buildings, it is the carbon content of standard gas and/or the cost of the low carbon alternative that prevents them from connecting to district heat, rather than high heat pipe costs due to the rurality of the buildings.

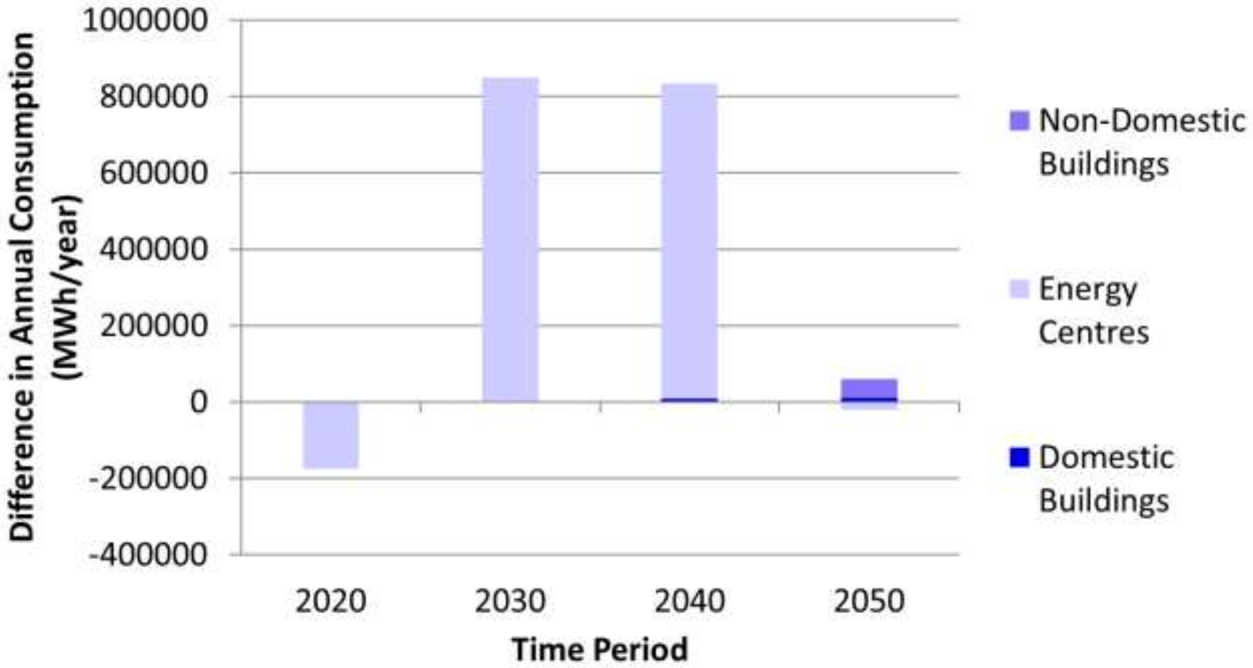


Figure 6-8 Difference in Gas Consumption by Sector (Positive Numbers show Increased Consumption under "Green Gas" Scenario)

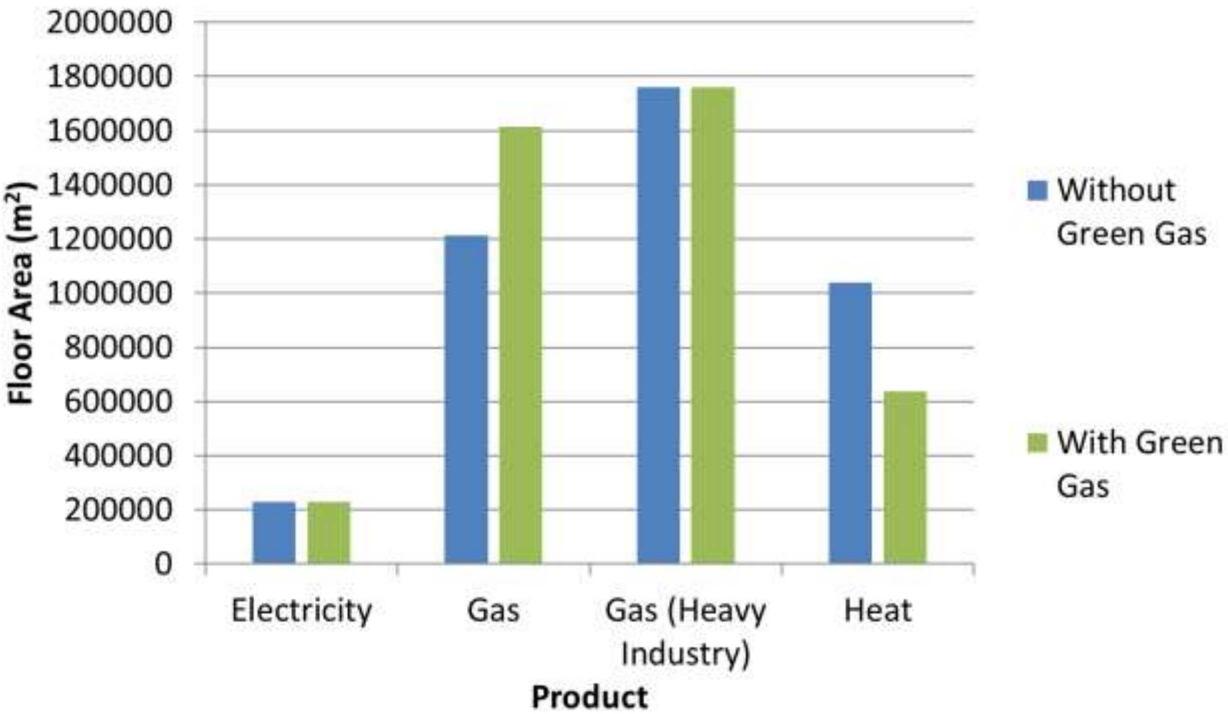


Figure 6-9 Non-Domestic Floor Area by Consumption Product

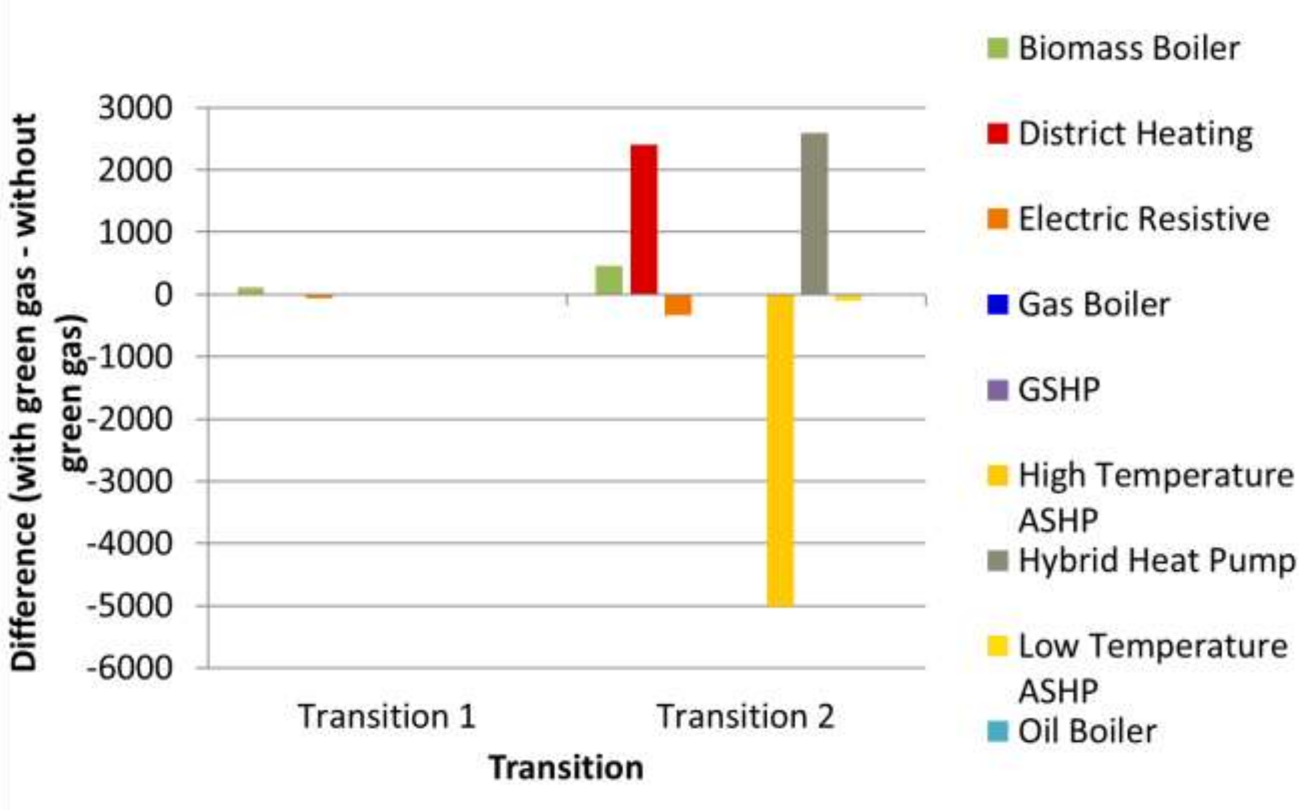


Figure 6-10 Differences in Household Heating Systems Installed in the Post-Sensitivity Runs (Positive Numbers show Increased Deployment when Green Gas is available)

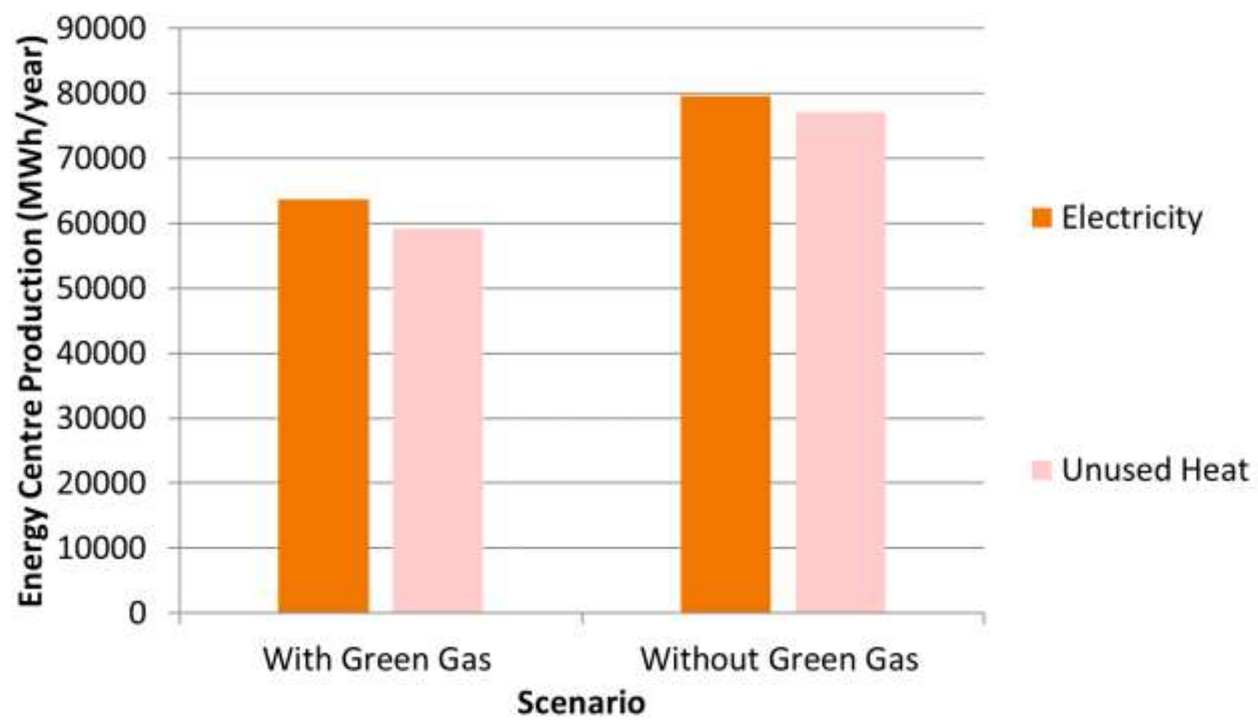


Figure 6-11 2020 Energy Centre Production

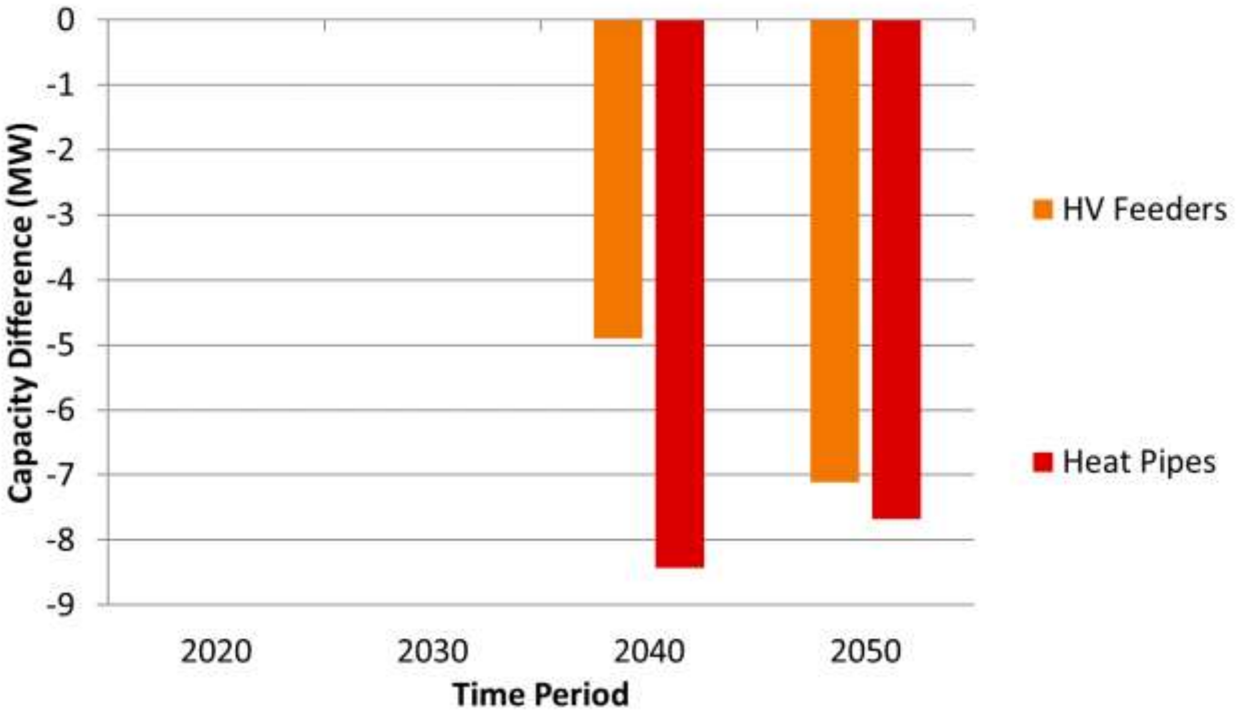


Figure 6-12 Network Capacity Difference (Positive Numbers show Increased Capacities when Green Gas is Available)

The change in heating systems between the two scenarios also has implications for building fabric levels, as in Figure 6-13. When green gas is not available more building fabric is needed to ensure that heat pumps can meet the necessary heating demands. In total around 6% more of the total building stock have some level of building fabric retrofit when green gas is not available.

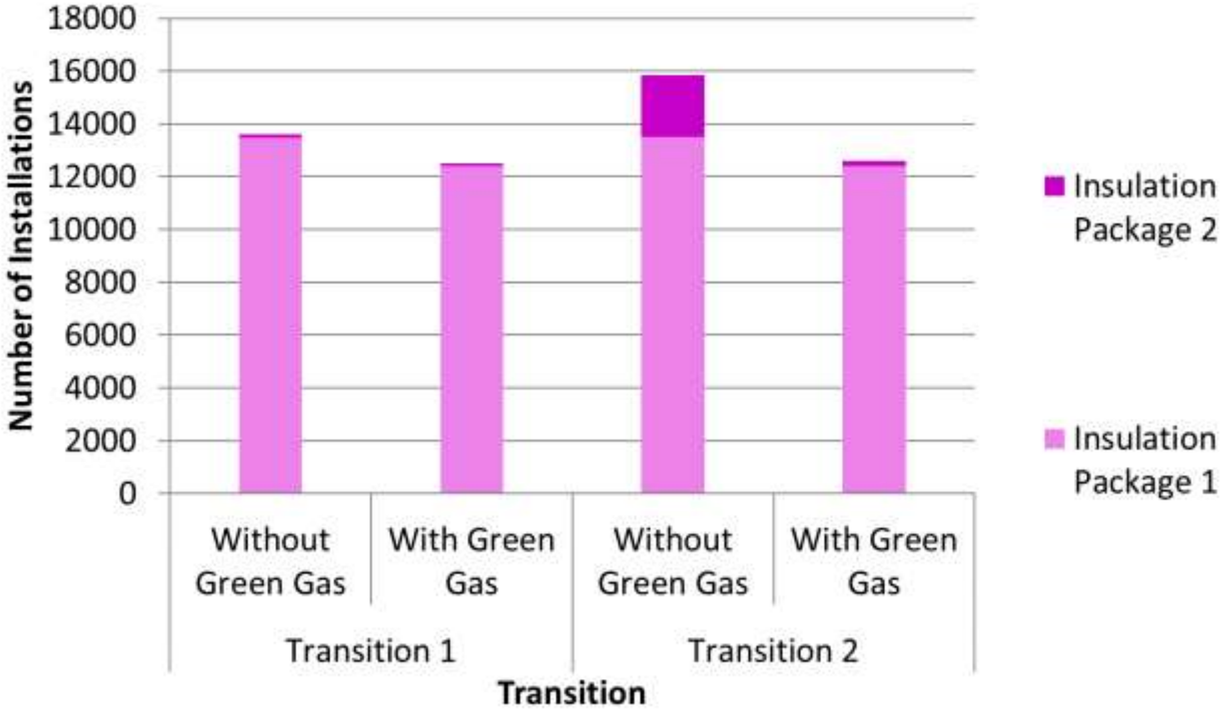


Figure 6-13 Building Fabric Retrofit Levels for Post Sensitivity Scenarios

Figure 6-14 and Figure 6-15 show the difference in costs and emissions respectively between the two post sensitivity scenarios. Under the "With Green Gas" scenario total transition costs (in 2015 money) are £7.3 billion compared to "Without Green Gas" costs of around £7.4 billion. The most significant difference is the money spent on electricity necessary to run the increased number of heat pumps when green gas is not available. The differences in emissions within each sector are all less than 15ktonnes of CO_2 annually for every time period.

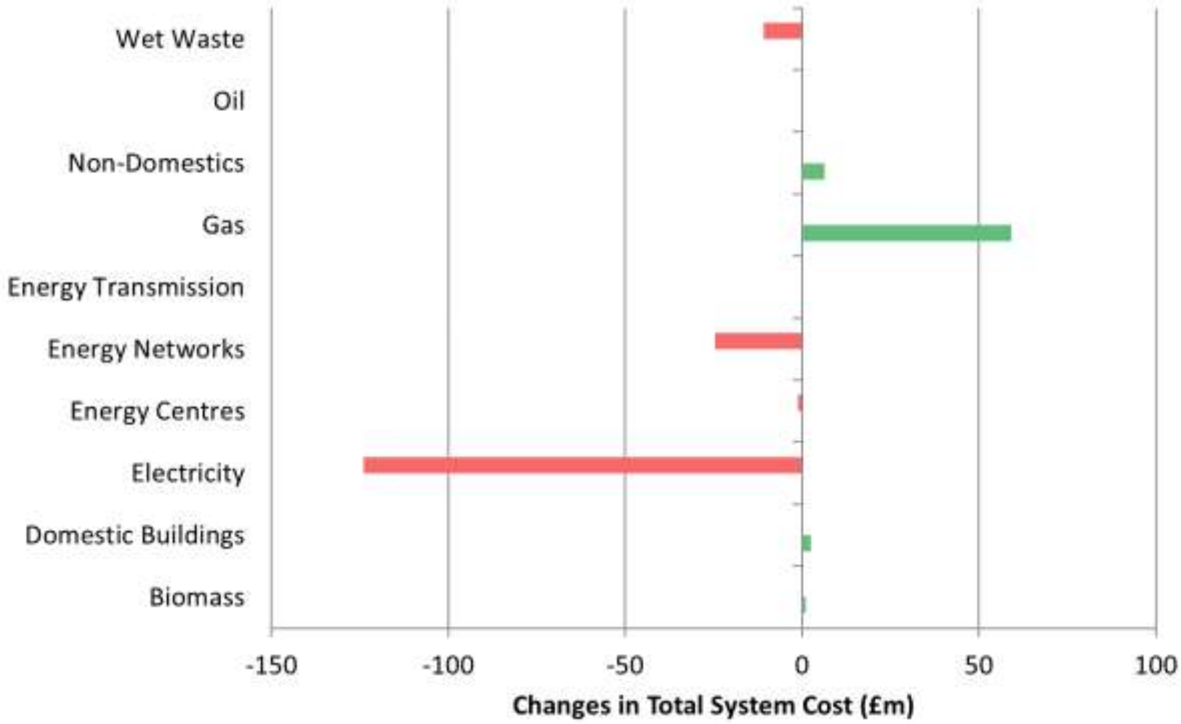


Figure 6-14 Change in Total System Cost (£m) to 2050 - Discounted to 2015 Prices ("With Green Gas" Minus "Without Green Gas" Costs)

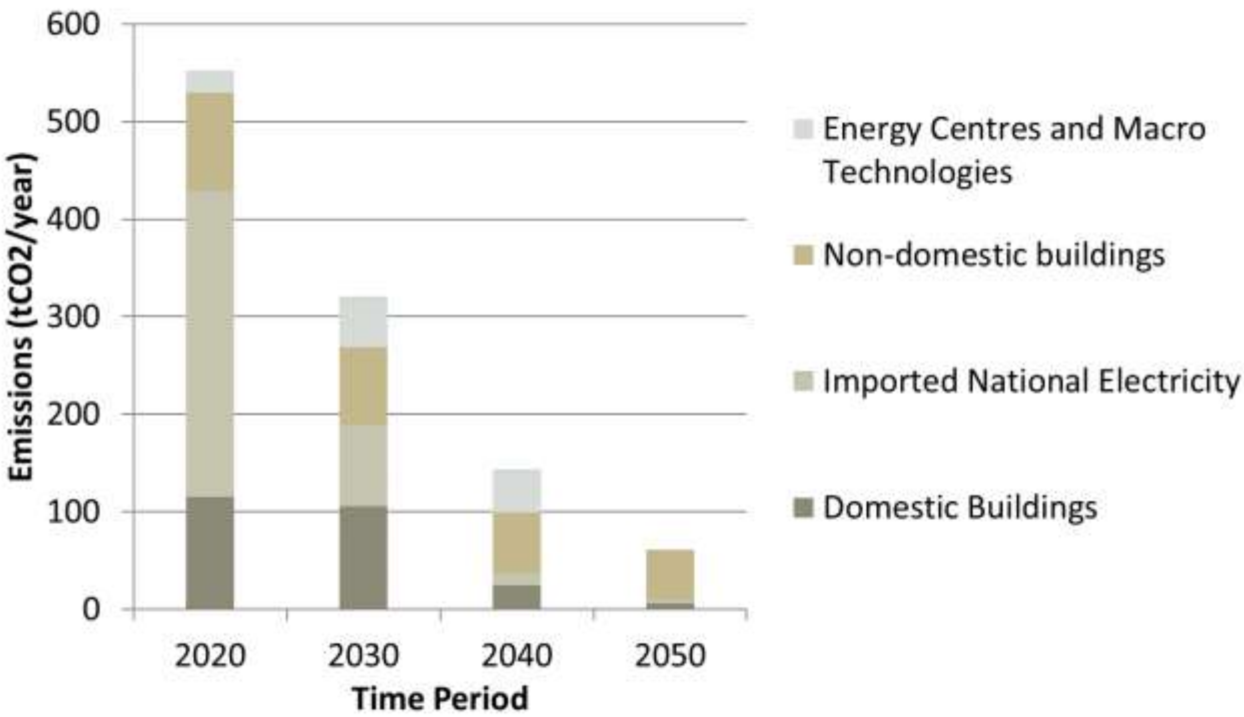


Figure 6-15 Carbon Emissions under "With Green Gas" Scenario by Sector

6.1.3 Key Points

- When green gas is available there are around 2,400 more domestic district heat connections and 2,600 more hybrid heat pumps deployed.
- Around 1.6km^2 of extra non-domestic floor area remains on gas when green gas is available.
- When green gas is not available there are more electric heating systems. In particular, there are around 5,100 more heat pumps (excluding hybrids). When green gas is available, there are almost 2,600 mores homes with hybrid heat pumps (compared with Scenario 1).
- Total transition costs are £100 million cheaper when green gas is available.

6.2 Implications for Network Choices

So far, this document has drawn insights from individual decarbonisation pathways developed using EnergyPath Networks. In this chapter, analysis across all the developed scenarios is described[48]. This provides an understanding of the most valuable combinations of technologies under different conditions, and which combination of network choices occur consistently across a wide range of input assumptions. For example, heat networks may always appear in a particular area regardless of differences in input parameters.

This document provides analysis behind the projects themes and their initial development. The Strategy document discusses the project themes with emphasis on their associated real-world opportunities and challenges (relating to consumer, commercial and policy/regulatory factors). This recognises that a “low regret” option from an EnergyPath Networks perspective in not necessarily “low regret” in reality and that significant pilot demonstrations may be required. For example, a least cost model solution might not be a solution that consumers would currently accept or there might not be an existing supply chain. These barriers are explored as project themes, with a particular emphasis on themes that are of most interest to the Key Stakeholder Group.

It is also important to recognise that the analysis is not suggesting that all buildings in an area would transition to one type of system choice, as there are many aspects to consider regarding suitability of system and technology to building type. For example, if an area is highlighted as transitioning to a heat network, it doesn’t mean that the analysis is suggesting a heat network is built to serve all buildings in the area.

The analysis has explored the number of heating system transitions to heat network and electric heat pump solutions under different input assumptions. This has identified areas where heat network and electric heat pump transition occurs under a wide variety of circumstances. **These outputs provide a vision of Bridgend’s future energy system, based on current information.** In addition, there are areas where there is a much greater degree of uncertainty about network choices , i.e. the model sometimes chooses heat networks and sometimes chooses electric heating using heat pump-based systems, depending on the inputs. The different areas discussed in this section are shown in Figure 6-16. The yellow areas are areas with high proportions of electric heating systems in the majority of runs, whereas the red areas have high

[48] Note that the restricted storage and mine water analyses are excluded because the resulting solutions provided such extreme outliers.

proportions of district heat in most cases. Areas that switch between electric and heat solutions are shown in blue.

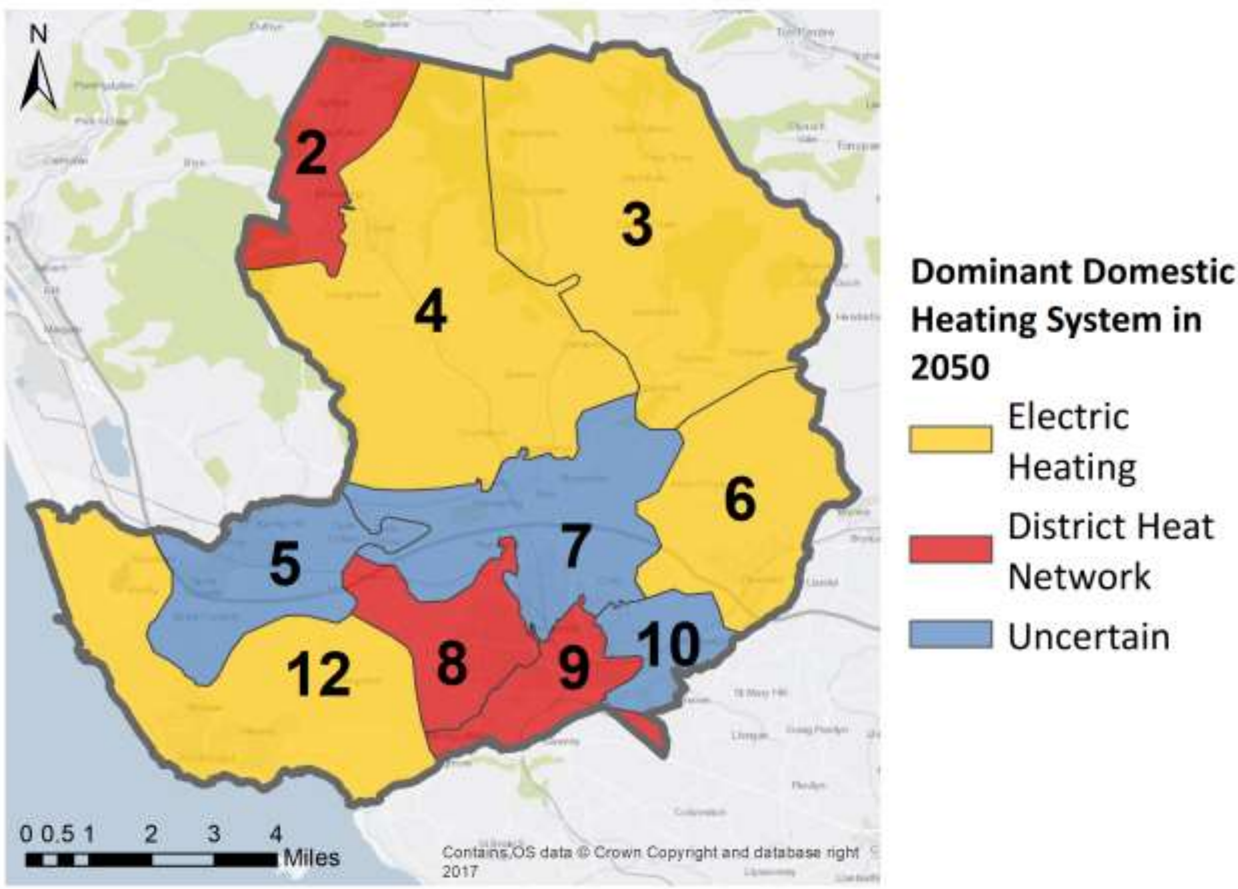


Figure 6-16 Dominant Heating Solution by Analysis Area

Whatever future energy system transpires, important decisions will need to be made regarding the adaptation of the Bridgend's electricity and gas networks, along with the major development of new energy infrastructure. The key stakeholders will need to work together to ensure that collaborative local area energy planning decisions can be made in the future.

6.3 Network Choice Rationale

This section provides the detail of the analysis behind Figure 6-16 by illustrating average and range of solutions across the sensitivity runs. In the subsequent graphs the bars illustrate the average proportion of heating systems by analysis area, and the whiskers represent the range across all scenarios.

6.3.1 Heat Pumps

Figure 6-17 illustrates the heat pump uptake across all scenarios, which includes all ASHPs, hybrid heat pumps and GSHPs. This forms the basis for the electric areas defined in Figure 6-16. Analysis areas 3, 4, 6 and 12 all have at least 20% of buildings with heat pumps of some description. This is also true of analysis area 8 but has this area has a higher proportion of district heat connections (see Section 6.3.2).

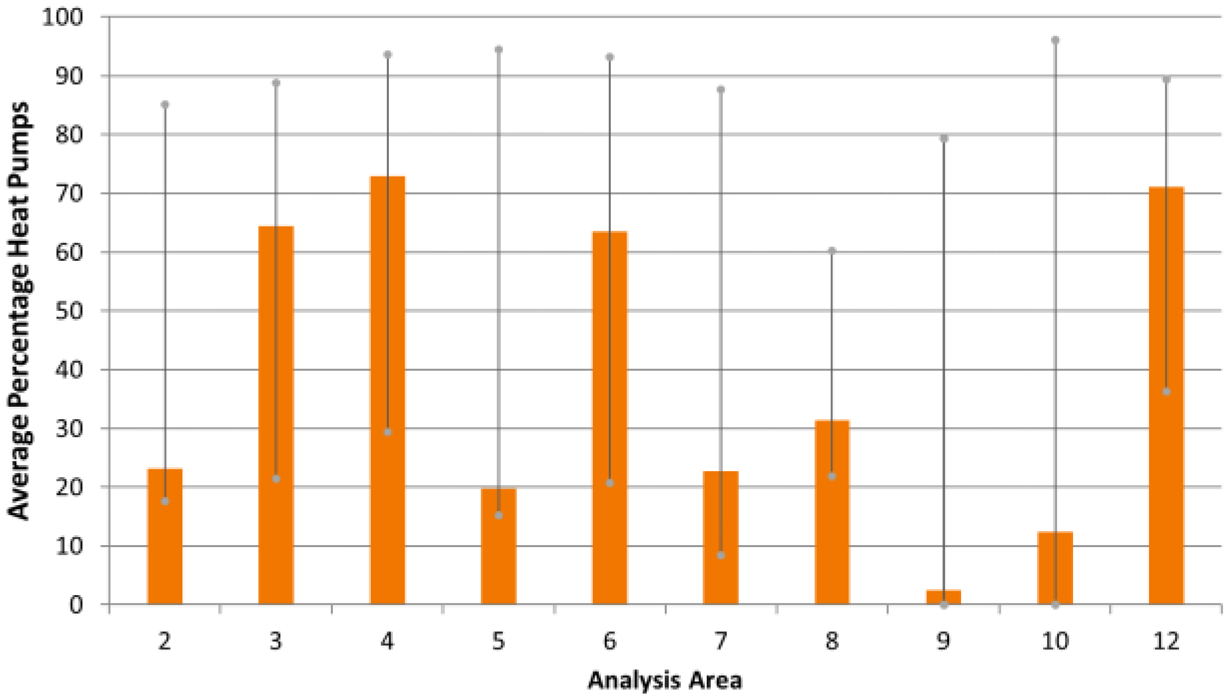


Figure 6-17 Average Heat Pump Uptake by Analysis Area

Figure 6-18 to Figure 6-20 show the breakdown of the different types of heat pumps by analysis area. The key factors driving these results will be explained in the next section but, note that GSHPs are restricted to use in detached buildings due to access and land restrictions. The whole life costs of GSHPs in the model are generally marginally cheaper than ASHPs. Therefore GSHPs tend to be installed in preference to ASHPs when possible. This is evident in Figure 6-18 and Figure 6-20, where GSHPs are consistently installed in analysis area 12 where there is a high proportion of large detached houses.

In some ways, it is more helpful to think of the yellow “electric” areas in Figure 6-16 as general heat pump areas where further feasibility studies and research need to be completed to assess exactly which types of heat pumps are most appropriate. In particular, hybrid heat pumps only tend to be chosen for buildings with poor efficiency ratings where the extra cost of the gas boiler backup is necessary to meet demand in buildings with poor performance. However, from a consumer perspective, hybrid heat pumps could be a successful transitional technology in a country where most people have never heard of a heat pump before. Furthermore, installing mixes of hybrid systems and standard heat pumps in a street, raises questions regarding the necessity of operating the gas network for fewer customers that will only require gas in peak periods. Barriers like this are discussed further in the Strategy document.

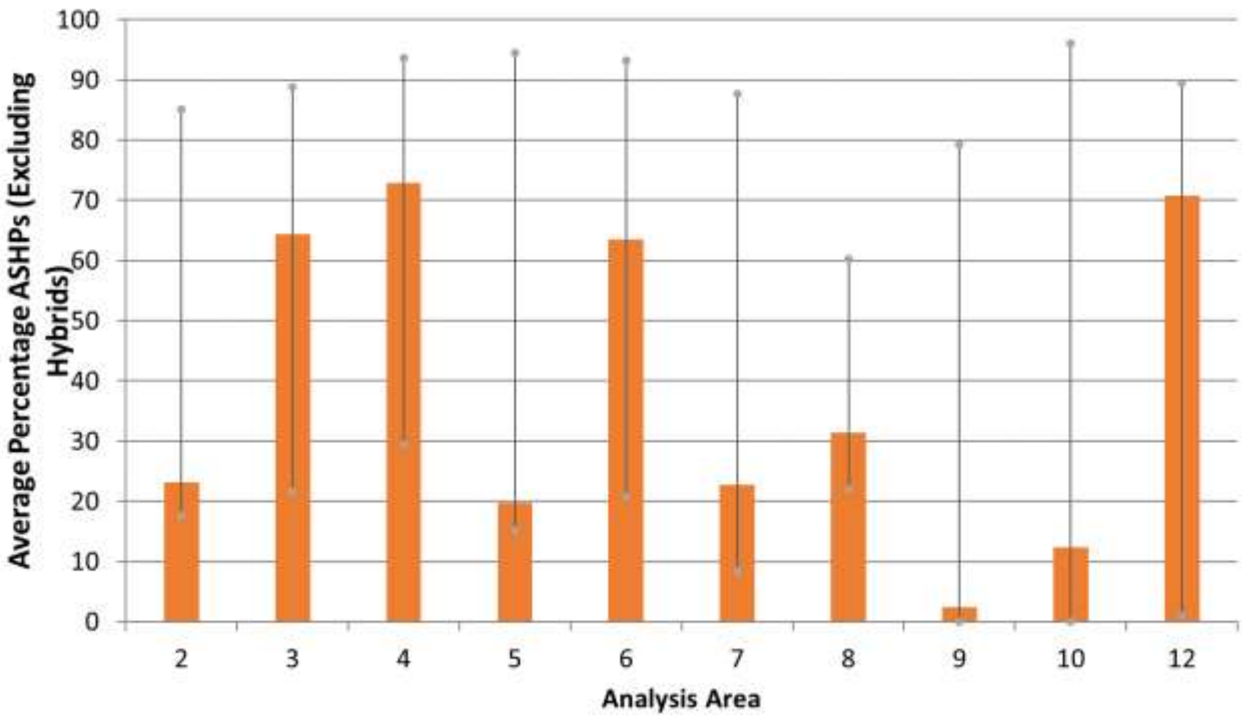


Figure 6-18 Average ASHP Uptake by Analysis Area

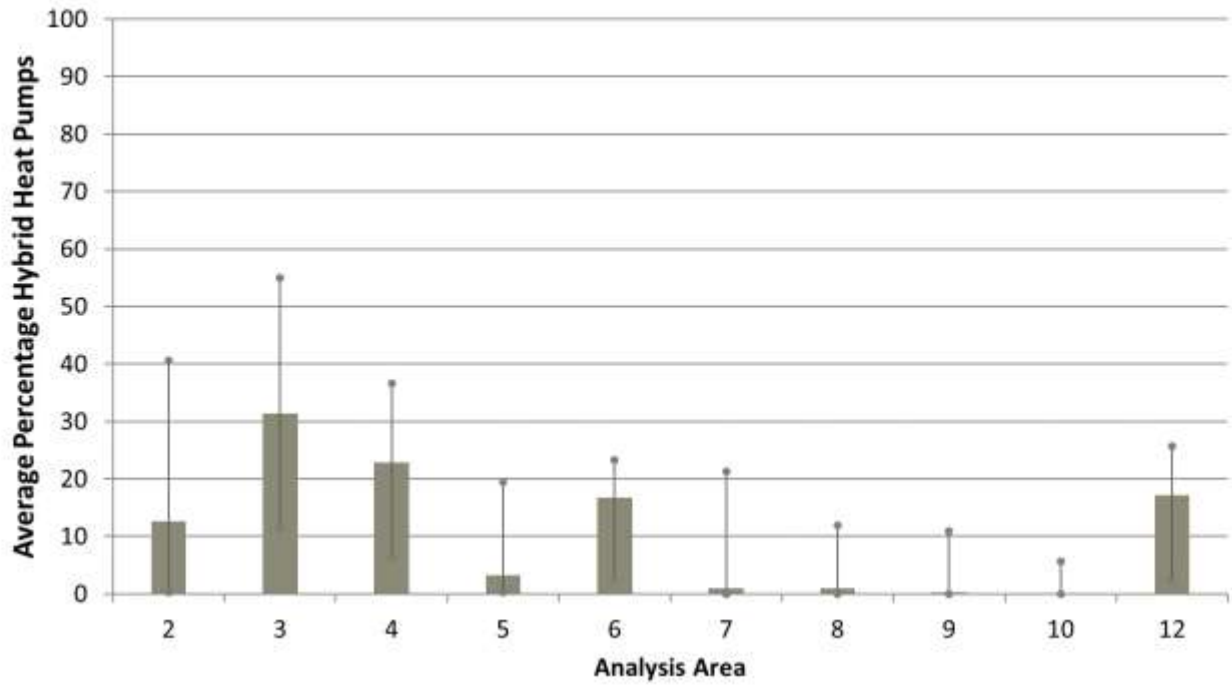


Figure 6-19 Average Hybrid ASHP Uptake by Analysis Area

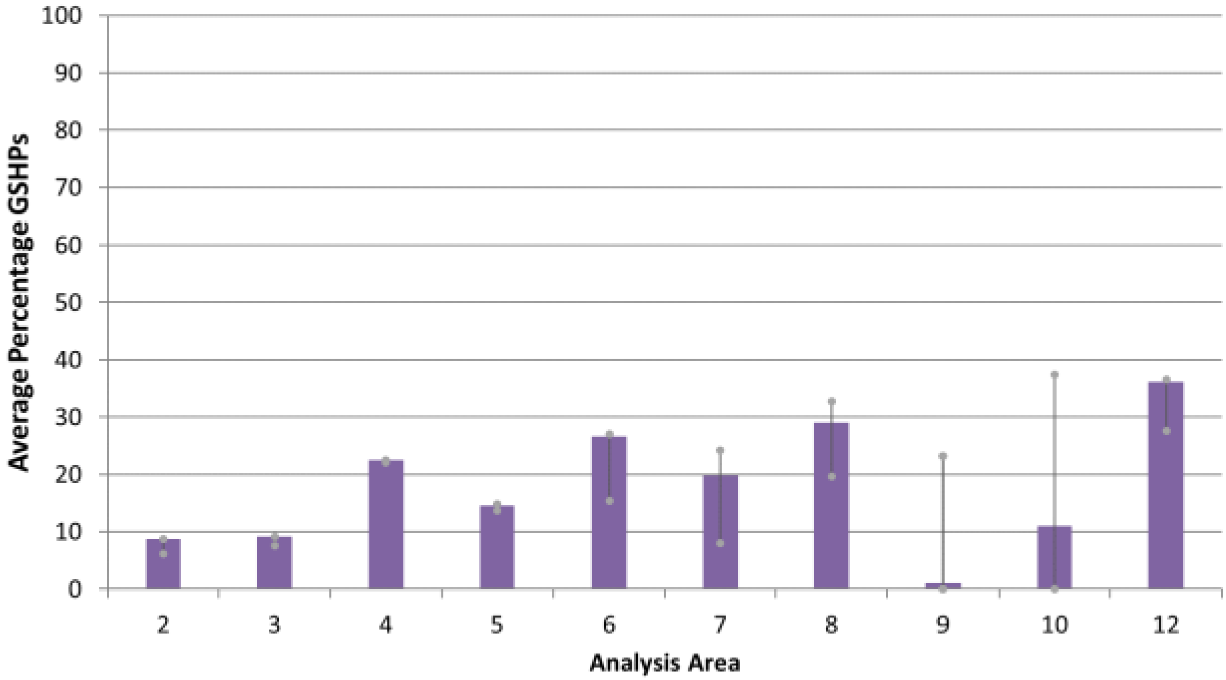


Figure 6-20 Average GSHP Uptake by Analysis Area

Considering the range and average heat pump uptake across scenarios is a useful method for determining potential project themes. However, this could miss analysis areas for which heat pump uptake is significant in 99% of scenarios. This is assessed in Figure 6-21, which shows the percentage heat pump uptake by the percentage of scenarios that include them. For example, consider analysis area 4 shown in purple. This shows that no scenarios have more than ~94% heat pumps. However, 90% of scenarios have more than ~62% of heat pump uptake in analysis area 4 and all scenarios have more than ~30% heat pump uptake. This supports the representation of analysis area 3, 4, 6 and 12 as “electric areas”.

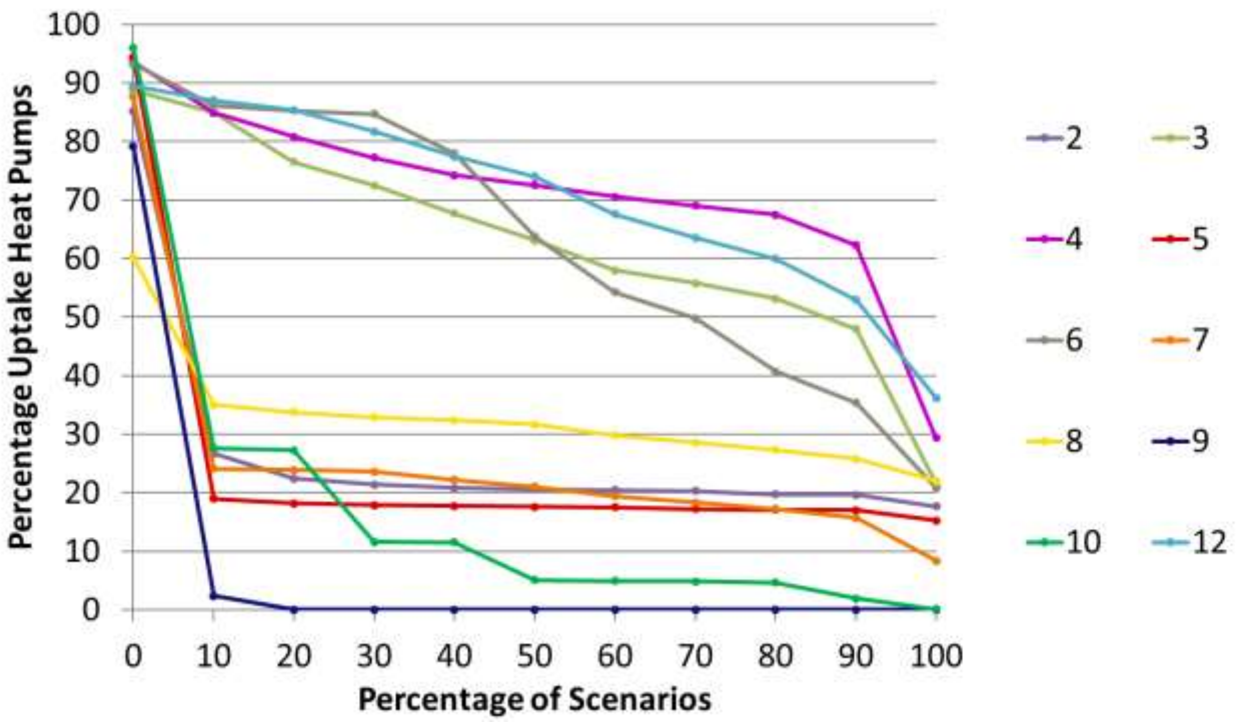


Figure 6-21 Percentage of Scenarios versus Percentage Uptake of Heat Pumps

6.3.2 Heat Networks

The minimum values in Figure 6-22 suggest that analysis areas 8 and 9 are potential district heat locations. This coincides with the Town Heat project that BCBC are already considering. Recall that in most model runs the Town Heat energy centre and four non-domestic connections were forced. However, this was not the case for the ““Town Heat impact”” and post-sensitivity runs. Therefore, even when the Town Heat project is not forced, EnergyPath Networks still chooses to connect around 40% of domestic buildings in analysis area 8 and 20% of domestic buildings in analysis area 9. Furthermore, non-domestic buildings are consistently connected to district heat in analysis area 9 as shown in Figure 6-23. Analysis area 2 has also been highlighted as a potential district heat area since, in most runs, over 40% of buildings were connected to district heat.

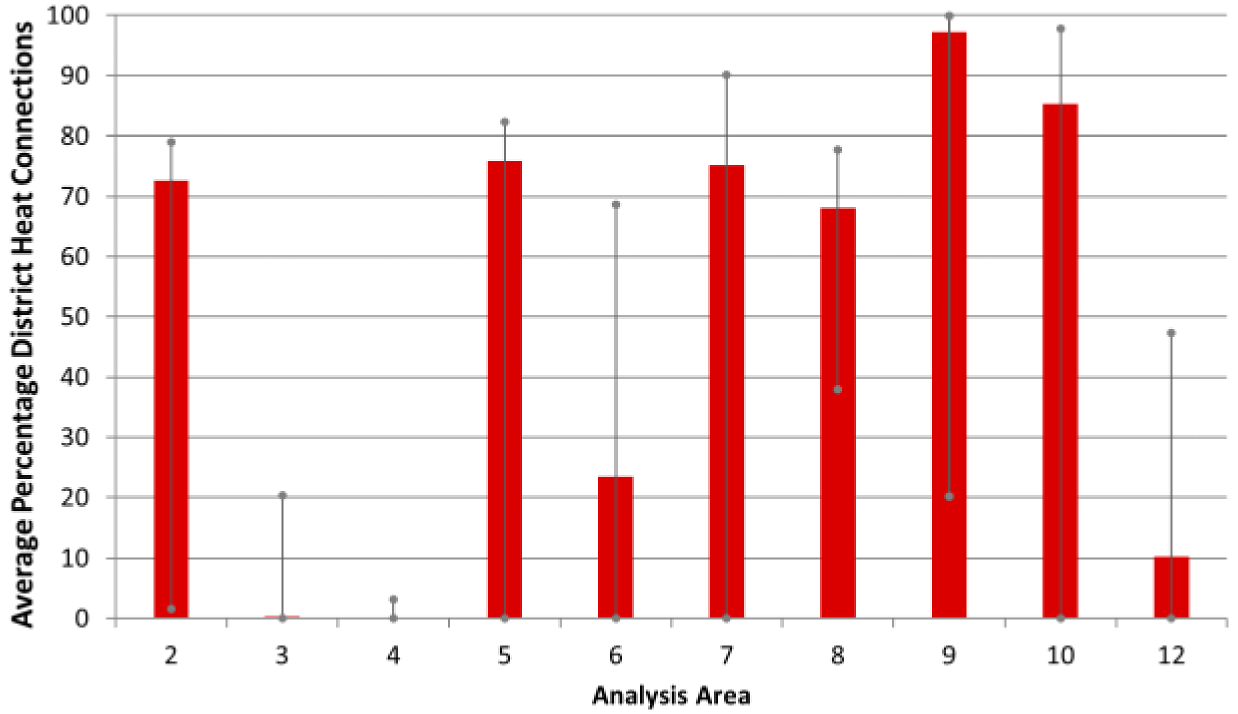


Figure 6-22 Average District Heat Uptake by Analysis Area

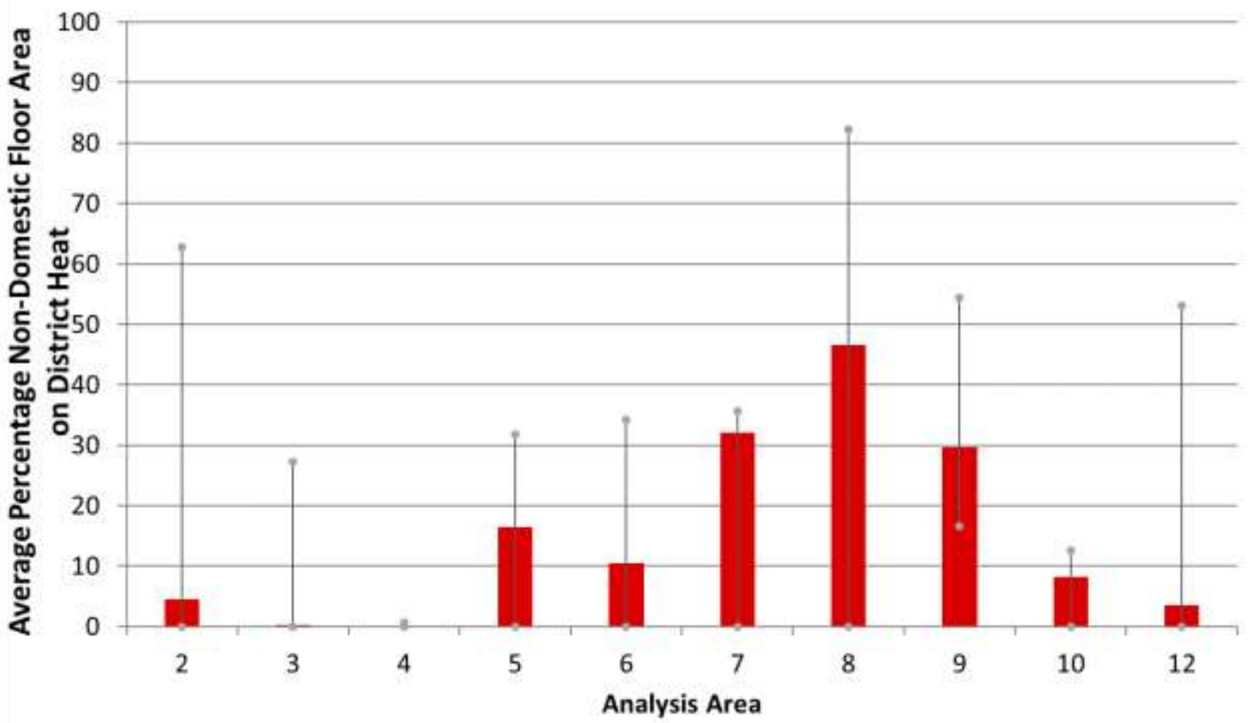


Figure 6-23 Average Non-Domestic District Heat Floor Area by Analysis Area

Figure 6-24 shows the percentage of district heat scenarios by the percentage of scenarios that include them. For example, consider analysis area 9 shown in blue. This illustrates that in 80% of scenarios ~100% of buildings are connected to district heat and 90% of scenarios have close to 100% district heat uptake. This graph confirms that analysis areas 8 and 9 should be given further consideration for heat network project themes. As mentioned previously, district heat appears in almost all scenarios (~98%). It also suggests that analysis areas 5, 7 and 10 could provide potential project themes since 90% of scenarios have over 60% of buildings connected to district heat. In the near term, it appears sensible to focus on analysis areas 2, 8 and 9 since they have more than 20% district heat connection in at least 98% of scenarios. Furthermore, these areas coincide with the Town Heat and mine water projects that are already being considered by BCBC. Furthermore, analysis areas 5 and 10 do not have significant levels of district heat in the post-sensitivity runs. These results should be given more weight than the previous runs, since the post-sensitivity scenarios includes an improved Bridgend representation.

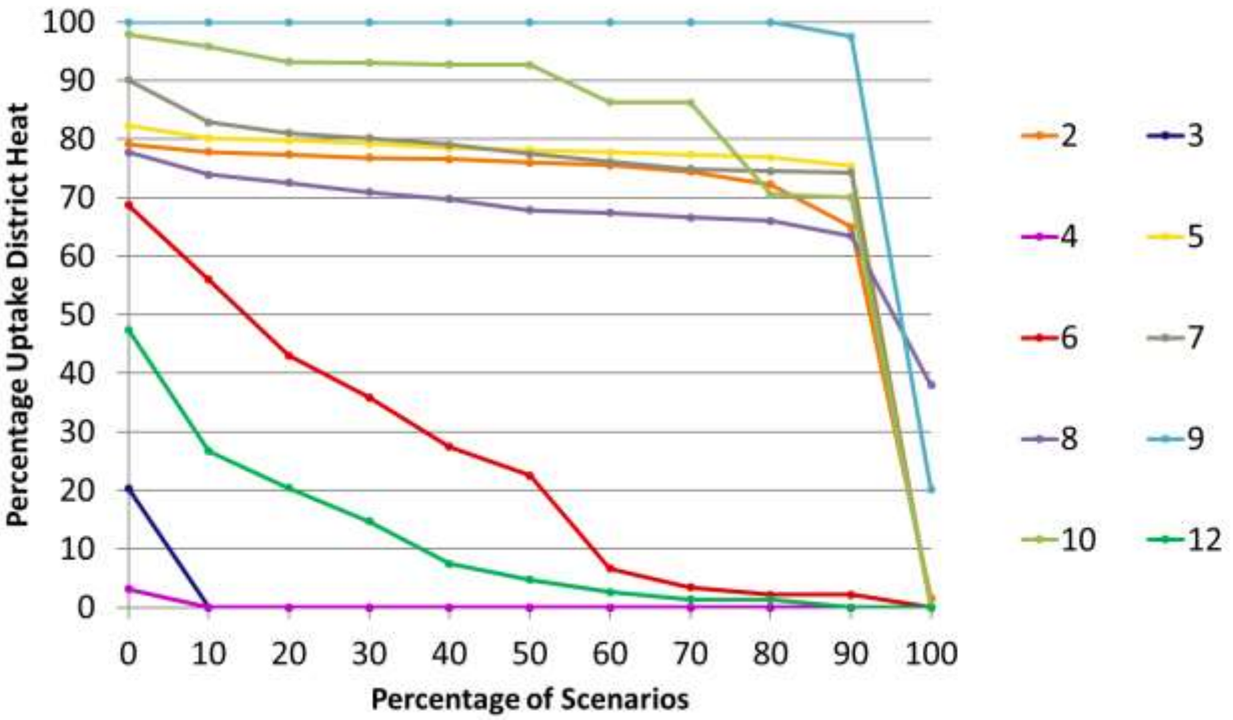


Figure 6-24 Percentage of Scenarios versus Percentage Uptake of Domestic District Heat

6.3.3 Biomass Boilers

Figure 6-25 shows that biomass boiler uptake is extremely variable in the model runs. However, generally over 6% and 4% of domestic buildings in analysis area 3 and 4 respectively have biomass boilers installed. The exception is the alternative national scenario because biomass is more expensive in this case. Bridgend does not contain any Air Quality Management Areas (AQMAs) and analysis areas 3 and 4 are considered to be rural. On the other hand, the housing in these areas is quite dense and could be described as compact villages. Therefore, increased use of biomass could lead to pockets of air pollution. Furthermore, there could be issues with security of supply and biomass may be better used elsewhere in the energy system. Therefore, deploying biomass boilers could expose residents to a significant risk of being tied in to an expensive energy source. Again, these points will be addressed further in the Strategy document. In most cases, the buildings identified for biomass are not off-gas.

A strategy for off-gas buildings does need consideration since around 3% of the building stock (10% of postcodes[49]) are off the gas grid. At some point it will be necessary to implement a solution for these "hard to treat" properties.

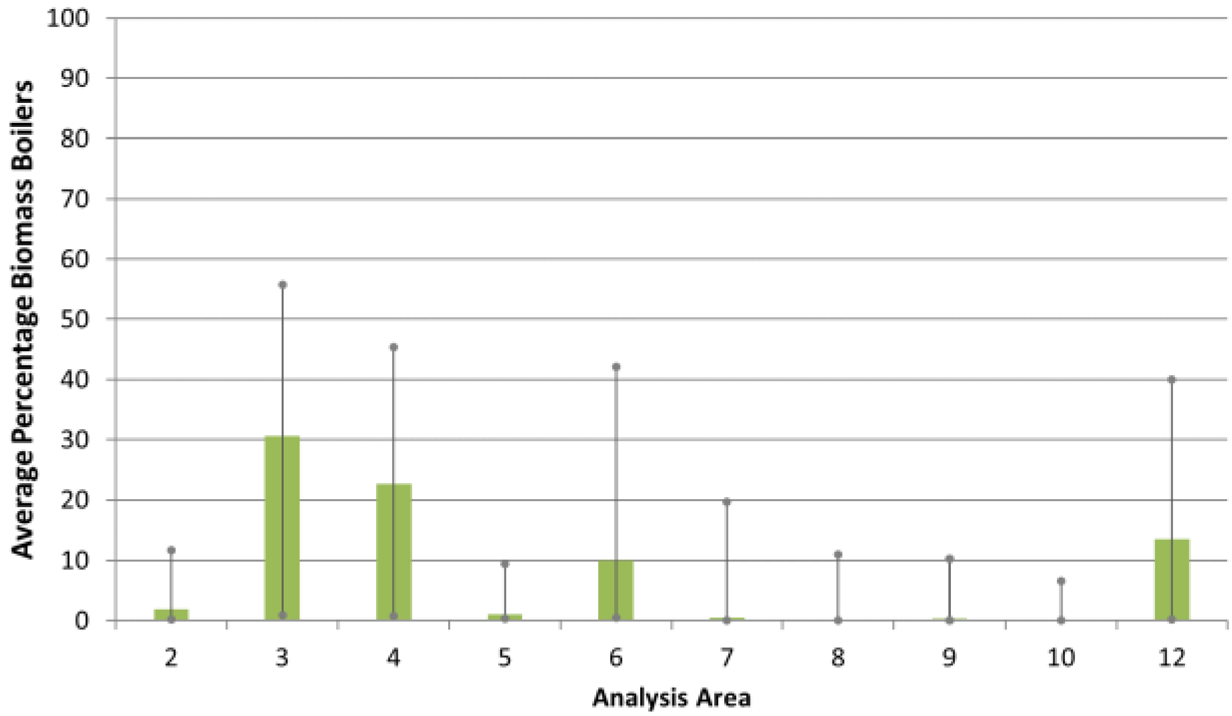


Figure 6-25 Average Biomass Boiler Uptake by Analysis Area

6.3.4 Insulation

Insulation levels across all runs are summarised in Figure 6-26. Recall that insulation package one includes cavity wall and loft insulation. These results are slightly skewed by the runs that include green gas. This suggests that, when more gas can be utilised for longer in domestic buildings, insulation is not as necessary. However, building fabric retrofit can be seen as an "easy win" since a supply chain exists and it is familiar to many consumers. Also, it can tackle other issues such as fuel poverty. In the EnergyPath Networks BAU run, some insulation was performed in analysis areas 3 and 4 suggesting that this can be a cost-effective action – even in the absence of a carbon target.

[49] Based on Xoserve data

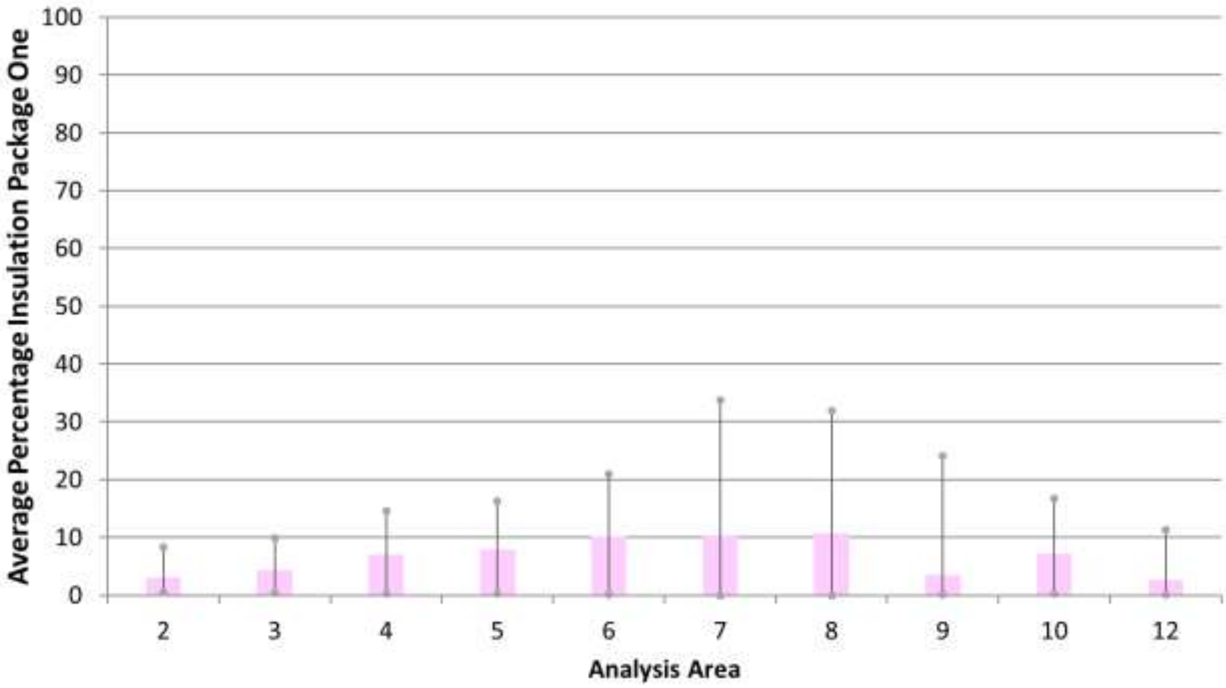


Figure 6-26 Average Insulation Uptake by Analysis Area

6.4 Area by Area Influences on Network Choices

In reality, there are many factors that contribute to a solution presented by the EnergyPath Networks modelling. As discussed in Chapter 4, EnergyPath Networks is a complicated model that trades off domestic & non-domestic building level options, network options and energy centre & macro level technology options. Therefore, it is impossible to conclude that a particular project theme is completely dependent on one or two inputs. However, it is useful to consider potential contributing metrics – not only because it can help to aid further understanding of the solution but also because it can support broader thinking around project themes. **Appendix B – Fact Files by Area** highlight some of the key descriptors are influencers for each analysis area.

Figure 6-27 and Figure 6-28 shows the building types and ages respectively in relation to the analysis areas and their most dominant network option. Figure 6-29 then shows the building density relative to the heating systems deployed. This can be used to draw further insights by comparing inputs and outputs across analysis areas. However, again, this cannot tell the whole story since EnergyPath Networks has tens of thousands of inputs. Note that:

- District heat areas have higher levels of semi-detached and terrace buildings than detached buildings. This is also true of areas 3, 4 and 6, but these areas are much larger and the building density is sparser as shown in Figure 6-29.
- With careful consideration a heat network might prove viable within small areas of analysis area 3 (within one of its more densely-populated villages of Ogmore Vale or Pontycymer, for example). However, over the entire analysis area, EnergyPath Networks has disregarded district heating as cost-ineffective.

- Biomass boilers account for an average of around a third of uptake across all runs for analysis area 3, which could be explained by its rural nature and suitability of buildings for biomass boiler installation. However, there are potential barriers here as discussed previously.
- Analysis area 12 consistently has GSHPs installed, which can be related to the proportion of detached properties shown.
- Building age and condition does have a significant impact on heating system choice but the heating system aggregation used here does not reveal this. In particular, building age will impact what type of electric solution is chosen. For example, low temperature ASHPs may not be able to meet the heat demand of inefficient properties that are very costly to retrofit (e.g. large pre-1914 buildings with uninsulated solid walls). Instead, a high temperature system or a hybrid system may be necessary.

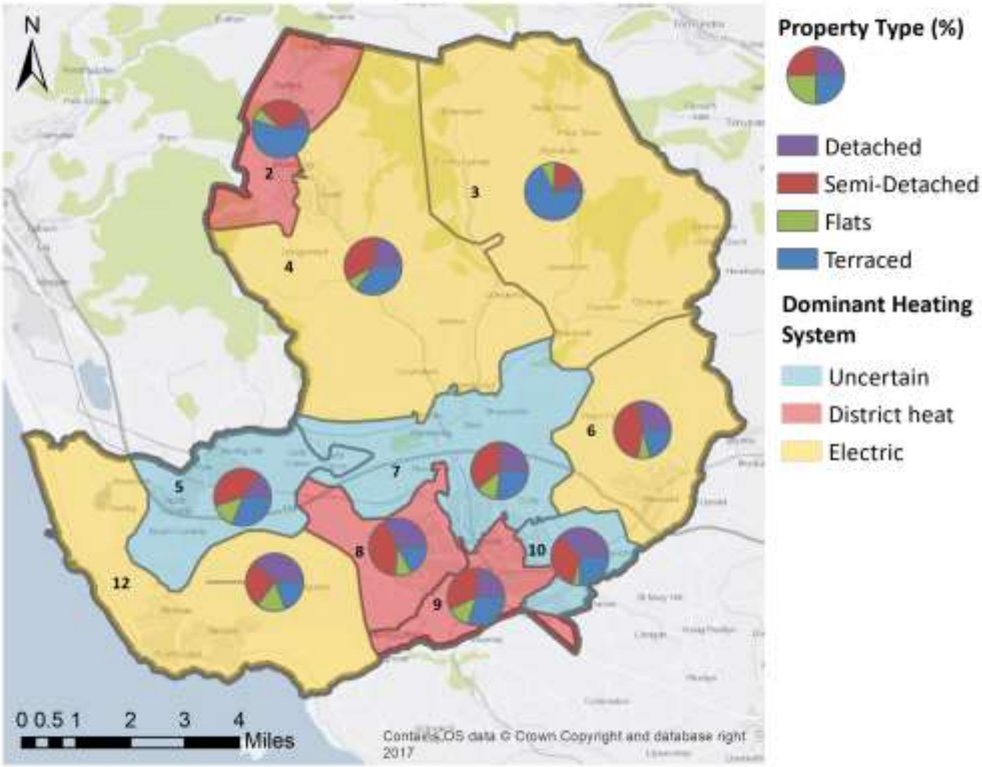


Figure 6-27 Property Type Relative to Dominant Heating System

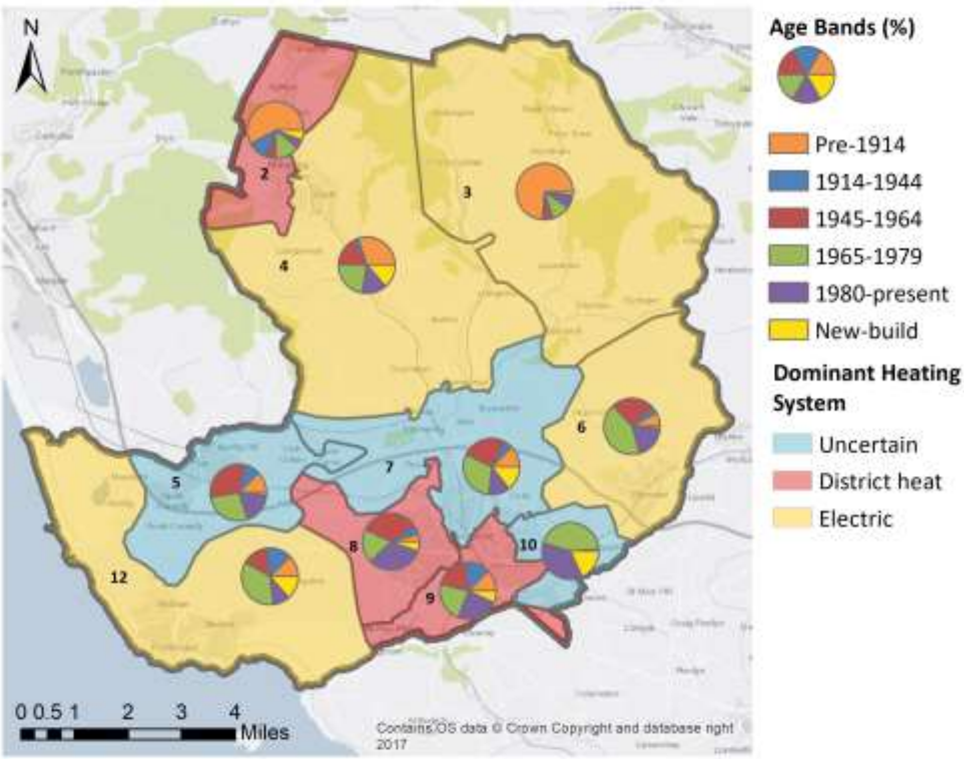


Figure 6-28 Property Age Relative to Dominant Heating System

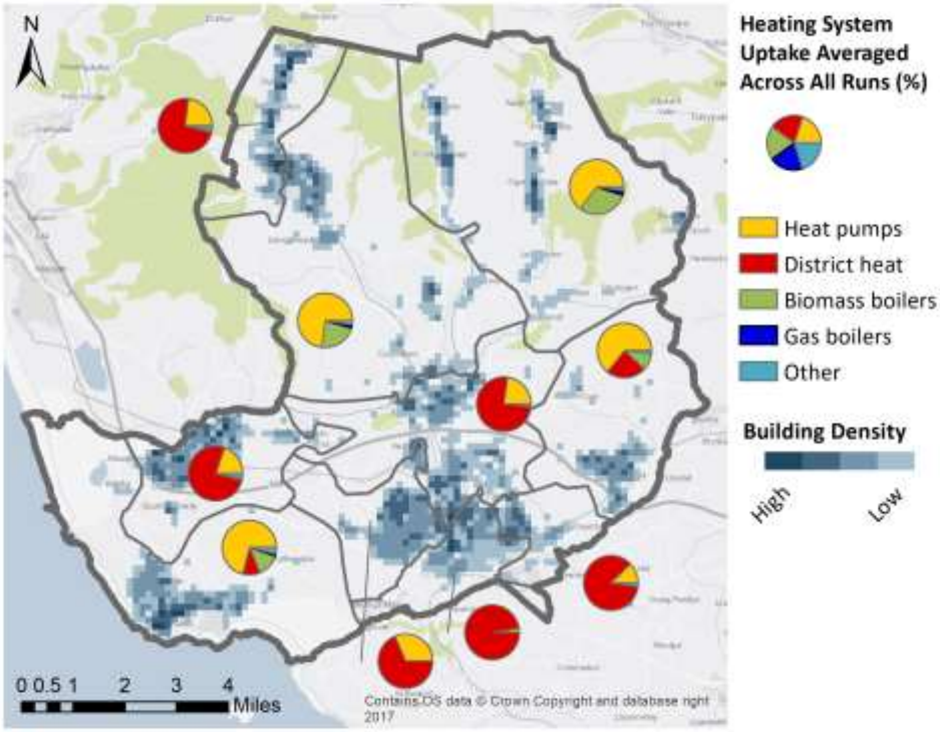


Figure 6-29 Building Density Relative to Heating System Uptake

7 Conclusion

Bridgend has taken a whole systems approach to local area energy planning using the EnergyPath Networks modelling framework. This has found that a significant reduction in carbon emissions (related to heating) can be achieved with known technologies by 2050. However, there are a number of technical, commercial and regulatory barriers to be overcome.

A variety of local energy system designs are possible to decarbonise the local community and meet national and any future local emissions reduction targets. The possible future local energy scenarios developed for Bridgend and presented in this report should not be read as predictions or forecasts of the most probable outcomes. They are plausible and cost-effective pathways to decarbonise the local energy system and provide insight to the network and building choices that will be needed but will require considerable co-ordination and planning as well as wider consumer and network operator engagement.

These scenarios are designed to support an on-going process of local area energy planning and to inform the choices and actions that need to be taken at a local level.

7.1 Costs

Across all model runs, the average total system costs were **£7.23 billion**. However, the BAU scenario costs were **£6.59 billion**, suggesting that decarbonisation costs **£0.66 billion**. Note that the BAU scenario still includes replacement of assets, e.g. gas boilers and double glazing, at their end of life[50].

Changes in costs between scenarios are based on many factors. However, it is worth discussing a few key drivers:

- The three least cost scenarios developed in this project were all scenarios where the national system was varied, namely the low electricity price scenario, the alternative national pathway scenario and the low gas price scenario. This suggests that, **the national picture needs to be monitored carefully and both the Evidence Base and Strategy need to be revisited in the future.**
- In terms of technology costs, the biggest influencer on total costs of transition are the costs of district heating pipes. **If the cost of installing heat network pipes could be decreased, it could have a major impact on the viability and uptake of district heat[51].**
- Recall that this project has focused on the decarbonisation of heat but **there are other locally produced emissions that will need further consideration.** In particular, although assumptions have been made about the uptake of electric vehicles, this report does not provide evidence for a decarbonisation pathway for Bridgend's transport sector.

Applying constraints to save costs in one part of the system, can cause costs to rise in another part of the system by an amount that is more than that saved by applying the constraint. For example, restricted building storage charging in peak times leads to decreased electricity network reinforcement and electricity costs but increased heat network costs and a higher total cost of transition.

[50] Recall that total system costs include fixed and marginal capital and operational & maintenance costs of all technologies, and fuel costs up until 2050, discounted to 2015 costs.
[51] http://www.eti.co.uk/programmes/energy-storage-distribution/heat-infrastructure-development/

7.2 National versus Local – Opportunities, Challenges and Trade-offs

In general, it will be important for the Local Authority to be aware of national energy system changes. **Planning locally based on one particular national picture and continuing regardless could have major financial implications later**. In particular, the energy price, national scenario & green gas sensitivities show that there are major differences to the optimal local solution for varying future national energy scenarios. In the case of green gas, the changes were less significant because of the assumed limit on green gas available to Bridgend. **If more green gas were to become available, or hydrogen were proven at scale, the Strategy should be revisited.**

Furthermore, the analysis in this report assumes that the national electricity grid is going to decarbonise in the run up to 2050. This national decarbonisation means that some carbon can remain in the local non-domestic sector. **If this does not happen, the non-domestic building sector may have to decarbonise further to meet a 95% carbon reduction target**. The only option for non-domestic buildings transition considered in the modelling is district heat so, again, if other credible transition options became available, the Strategy would need to be revisited. **When district heat is the only option for non-domestic transition, the non-domestic sector is the most expensive area to decarbonise.** Recall that in Bridgend, many non-domestic buildings could not transition to district heat because they require gas for industrial purposes.

In the modelling EnergyPath Networks consistently squeezes out most of the carbon from domestic buildings and energy centres. Non-domestic emissions are reduced but this is the sector that decarbonises the least. This is partially because Bridgend has around half a square mile (~1.3km^2) of floor area of factories, of which a portion use gas for industrial purposes. Furthermore, 0.2km^2 of non-domestic buildings have their heat demand met via electricity. Moving these buildings to district heat is not considered to be a credible option since it would involve changes to the internal heat delivery system. Even so, on average around 0.6 square mile (~1.6km^2) of non-domestic buildings that could move to district heat, remain on gas. This suggests that the total cost of connecting these non-domestic buildings (heat network of necessary capacity to the building plus building connection costs) are high relative to other decarbonisation options. If a higher carbon reduction target was used in the analysis, it is likely that more of these buildings would be forced to move to district heat.

Policy makers need to take note of local projects when considering new policy and regulation for decarbonisation. BCBC is in a privileged position, since Welsh Government have been involved throughout the development of the Strategy and this supporting Evidence Base document. Welsh Government view the Bridgend study area as a "mini-Wales", since its housing stock, heating systems (including off-grid) and social statistics broadly match Wales as a whole. **Both Welsh Government and BCBC could make the most of this opportunity moving forward and support each other to implement test projects in Bridgend that benefit both parties.** There are several opportunities that could be investigated by BCBC with support from Welsh Government or private investment. For example:

- Bridgend has 3% off-gas buildings. In the analysis, these buildings tend to either move to a heat pump or biomass boiler solution. Biomass may not be a desirable solution for air quality reasons and could be viewed as being more valuable to other sectors. **Determining the right mix of technologies for off-gas consumers in Bridgend would bring valuable lessons for other off-gas areas in the rest of the Wales.**
- Similarly, in rural areas of Bridgend, there is often a mix of heat pumps and biomass solutions but hybrids are also present. **Though this might be the least total system cost option, it may**

not be viable to maintain and operate sections of the gas network for decreased customers during peak demand periods.

- **Where heat networks are going to be considered, it is important to focus on high levels of connection uptake in the area where the heat network is deployed in order to minimise the cost of delivered heat**, recognising that due to the high cost of providing a new form of energy infrastructure, the cost should be spread across the greatest number of users. Therefore, encouraging wide scale uptake should be a core focus.

The analysis has indicated that gas boilers will continue as the dominant form of heating technology in homes (remaining in around 85% to 90% of homes until circa 2025) until suitable solutions are available for building owners and individuals to switch to. Carbon reduction prior to this is mostly achieved through national electricity decarbonisation. **This highlights that there is a realistic timeframe to effectively plan for local decarbonisation.**

7.3 Consumers

It is important to consider constraints that are not assessed by EnergyPath Networks (such as consumer, policy, commercial, skills and supply chain aspects), since they can have a significant impact on the decarbonisation process. These are discussed in the Strategy. However, the analysis presented in this report has led to several consumer-related questions and opportunities that are note-worthy:

- **Most consumers are not currently familiar with the transitional technologies discussed in this report.** For example, the "Energy and Climate Change Public Attitude Tracker" suggests that around 37% of UK residents are aware of ASHPs. Currently, around 96% of Bridgend properties have gas boilers. The remaining household heating systems are predominantly split between electric heating systems, oil & LPG boilers. Consumers understand these technologies and the commercial arrangements involved in buying and operating one. A wide range of heating system and retrofit options will be required to be able to make the largest carbon reductions so **organisations will need to develop corresponding products and services that individuals want to use.** If households were to buy energy as a service, for instance a warm home instead of kwh of fuel, then our research[52] shows they would be more open to non-gas boilers as long as they were confident they would get the level of service they wanted. After all, if you enjoy a meal, you don't ask what oven it was cooked in.

- **Most consumers avoid replacing their heating systems until they break down beyond repair, even if a new system would save them money overall.** The analysis in this report assumes there will only be two opportunities to replace heating systems, on average, until 2050. This could of course be influenced by new policies and business models.

- **Even familiar technologies cannot be assumed to be easy to implement.** For example, many building fabric retrofit measures are not high on consumers' wish lists. Thought will need to be given on how to encourage residents to take up insulation when they have been settled in their homes for a number of years and are not making any other home improvements. Some Local Authorities have struggled to sign residents up for insulation measures, even when those measures are free.

[52] https://es.catapult.org.uk/publications/how-can-people-get-the-heat-they-want-at-home-without-the-carbon/
https://es.catapult.org.uk/publications/domestic-energy-services/

- **Building fabric retrofit could be a quick win in areas of Bridgend where fuel poverty is high.** Across the scenarios considered (excluding Business as Usual), the average uptake of cavity wall and loft insulation was 17% in Bridgend by 2050. In the Business as Usual scenario, retrofit uptake still occurs in some areas of high fuel poverty.

- **Transitional technologies could help to tackle some of these consumer issues**. For example, hybrid heat pumps would allow consumers:

    - Time to get used to operating new heat pump technologies whilst having the gas boiler back-up to deliver heat in peak times.

    - Back-up for times when the heat pump is not able to deliver sufficient heat to meet demand, for example when the weather is very cold.

    - To avoid giving up space for a hot water tank. The viability of using domestic electric heat pumps depends critically on the ability to use them in conjunction with heat storage, which may not be agreeable to consumers that do not currently have a hot water tank.

  it is important to consider hybrids in general “electric” areas from the analysis since EnergyPath Networks does not recognise these benefits and simply sees hybrids as more expensive systems. Therefore, the model will only choose them in properties where thermal efficiency is poor and demand cannot be met by a standard heat pump. Both standard and hybrid heat pumps will require effective control systems and strategies to be competitive with other options and to realise their potential benefits to network operators.

- **The relative future costs of fuels, heating systems and fabric retrofit options closely influence which options are likely to be preferable.** The cheapest option is not necessarily the “right” solution in reality. For example, installing a powerful heat pump with a hot water tank may be cheaper than improving building performance. However, consumers may object if this involves reinstalling a hot water tank and digging up a driveway to increase the capacity of the electricity feed into the building.

- **The level, and cost, of network new build and reinforcement is projected to be different depending on location in Bridgend**, demonstrating why local area energy planning is needed to manage the process. If network costs are allocated only to the people connected to the parts of the network where costs accrue then there are likely to be large variations in energy bills. Whilst network costs are already socialised for gas and electricity networks this is not true for heat networks. **Consideration will need to be given to how heat network costs are socialised across the local area.**

8 Appendix A – Detailed New Build Data

Building types allocated based on https://democratic.bridgend.gov.uk/documents/s10059/290916%20-%20JHLAS%202016%20INCLUDING%20APPENDIX.pdf?LLL=0 where details available. Otherwise, breakdown suggested by BCBC planning department was used.

Table 8-1 Breakdown of Proposed Domestic New Builds

	Detached	End terrace	Mid terrace	Purpose-built flat	Semi-detached	Total	Proportion of ward (%)
Aberkenfig	129	61	22	22	105	339	25
Bettws	36	12	8	12	53	121	12
Blackmill	14	2	21	8	20	65	6
Bryncethin	43	8	5	5	98	159	20
Bryncoch	17		17	11	60	105	9
Bryntirion, Laleston and Merthyr Mawr	80	34	23	23	68	228	6
Caerau	88	21	14	44	61	228	7
Cefn Cribwr				12		12	2
Coity	448	69	86	48	266	917	44
Cornelly	22	6	20	8	31	87	3
Coychurch Lower	320	119	79	121	261	900	60
Felindre				4	3	7	1
Hendre	7		8	7	6	28	2
Litchard	13	38	22	22	70	165	14
Llangeinor	10					10	2
Llangynwyd	7	3	2	2	6	20	2
Maesteg East	28	26	18	18	45	135	6
Maesteg West	85	37	32	42	73	269	9
Morfa	49	7	2	26	42	126	5

Nant-y-moel	22	6	6	4	12	50	4
Newcastle	55	3	26	83	75	242	9
Ogmore Vale					7	7	0
Oldcastle	7		8	34	9	58	3
Pendre	19		18		22	59	6
Penprysg	9	4	3	3	8	27	2
Porthcawl East Central	381	157	106	118	323	1085	42
Rest Bay	12	5	4	72	11	104	9
Ynysawdre	129	38	45	45	93	350	18
Total	2030	656	595	794	1828	5903	

Table 8-2 Breakdown of Proposed Non-Domestic New Builds

	Factory	Hospitality	Office	Shop	Warehouse	Other	Total	Proportion of ward (%)
Aberkenfig	11562		1130	1200	293	113	14298	23
Blackmill	988		2241	293	293	251	4066	7
Bryncethin	34669		34669	1600	34669	1351	106958	46
Bryntirion, Laleston and Merthyr Mawr		4000	6400	17500		2500	30400	31
Caerau	17109		17467		16843		51419	43
Coity	2500	3748		4694		2801	13743	9
Cornelly			22553			500	23053	32
Coychurch Lower	141337	356	44831	384	85840	2159	274907	22
Felindre			11598			100	11698	6
Llangynwyd	21100						21100	11
Maesteg West		6223	16705	1021		1323	25272	21

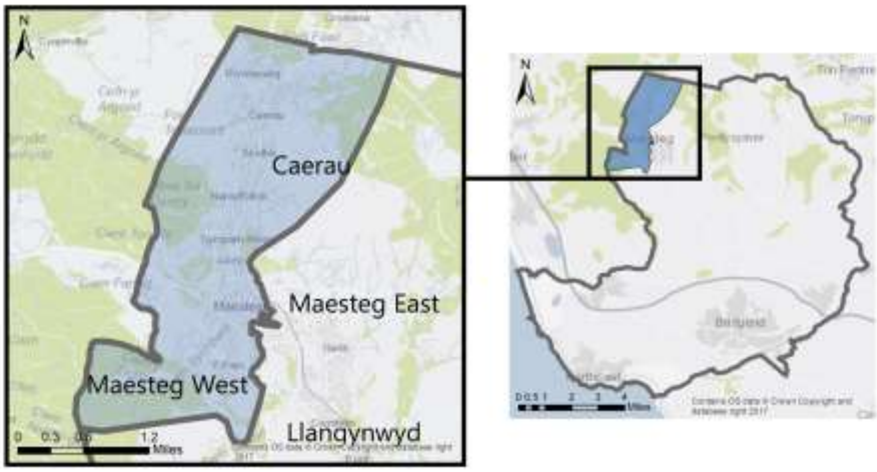
Morfa	2706	1500	2750		2930	11250[53]	21136	11
Newcastle		2013	2000	7440			11453	14
Ogmore Vale	14100		14100		14100		42300	50
Oldcastle	738	5930	13486	3880	879	4700	29613	11
Pendre	7500		40002				47502	39
Porthcawl East Central		760	7006	17145		2144	27055	29
Pyle	17168		17168		17168		51504	25
Sarn			33500				33500	32
Ynysawdre	10578	900	5250	100	1862	900	19590	29
Grand Total	282055	25430	292856	55257	174877	30092	860567	

[53] Around a quarter of the total new build floor area in Morfa is for agricultural purposes.

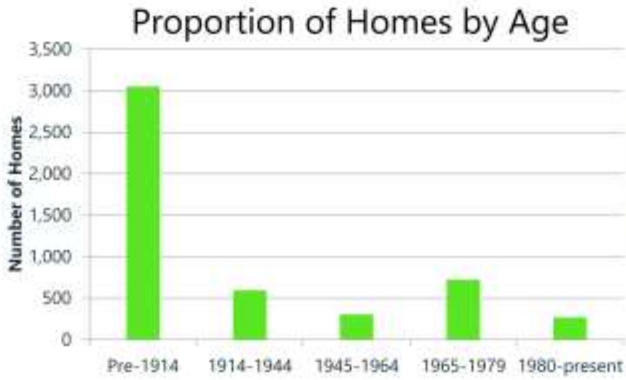
9 Appendix B – Fact Files by Area

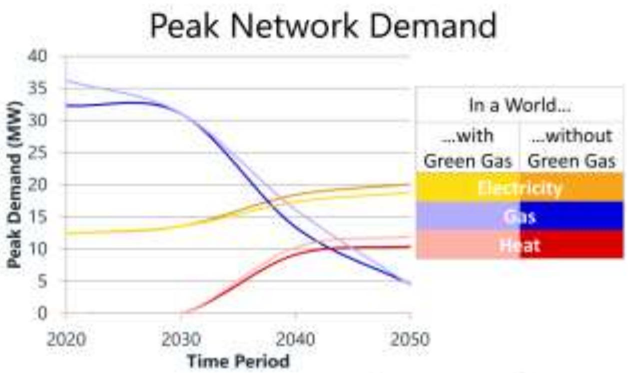
The following fact files aim to give a snap shot of some of these key influencers and the EnergyPath Networks results.

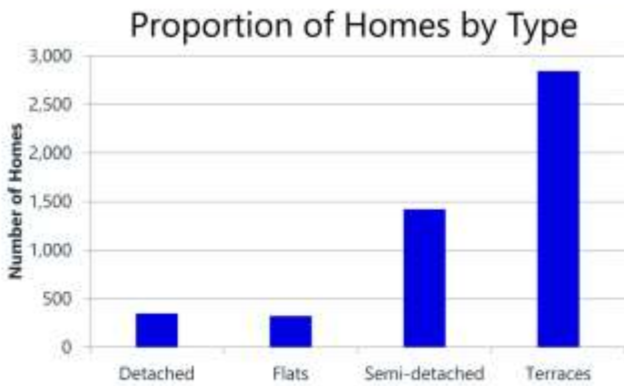
Analysis Area 2 Fact File

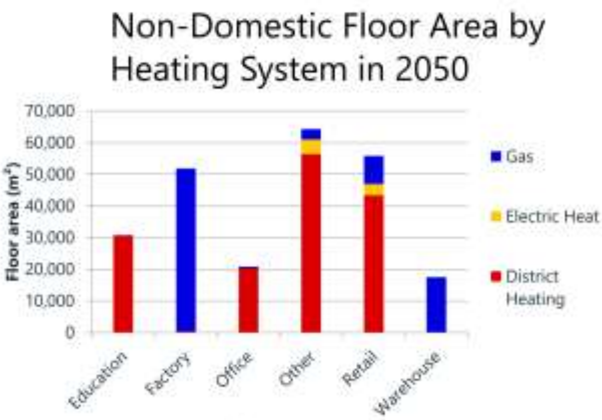


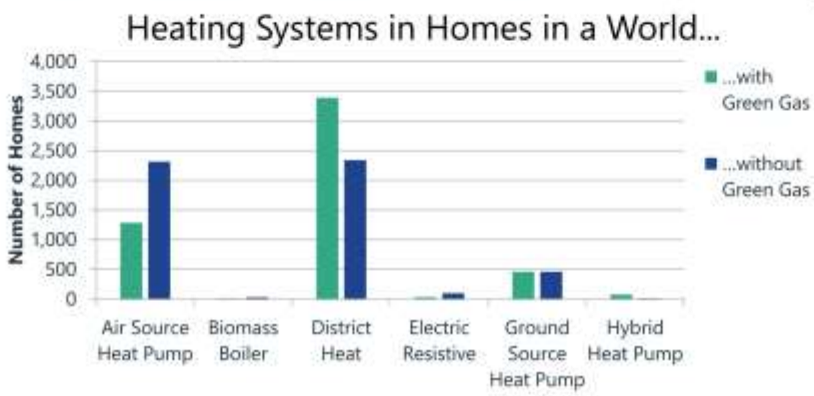
Located in the North of BCBC, analysis area 2 covers Caerau and Maesteg, and the A4063 running North to South, finishing before Garth.



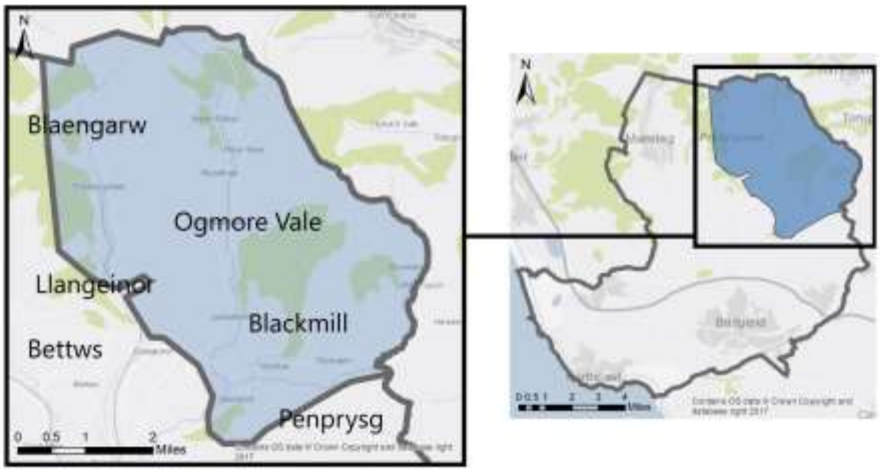




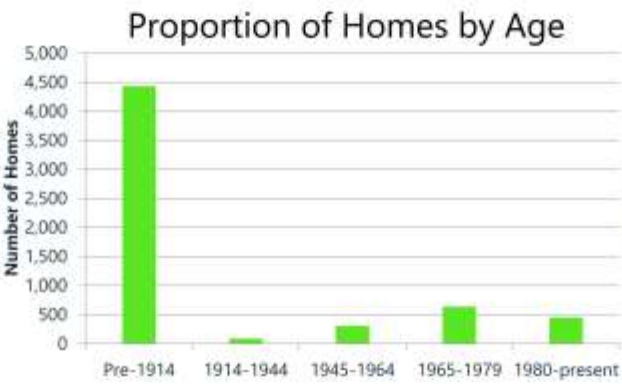


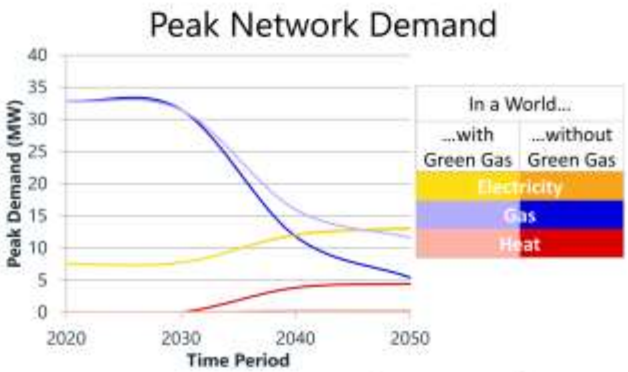


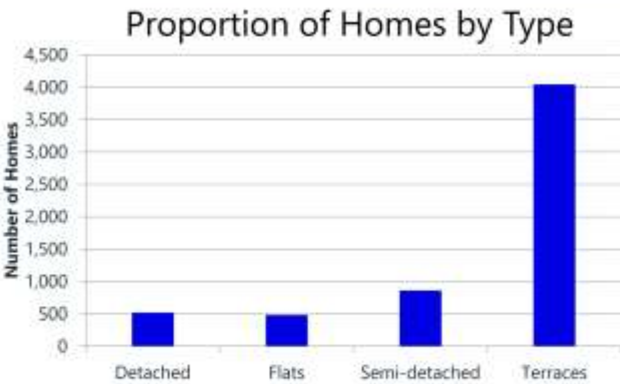
Analysis Area 3 Fact File

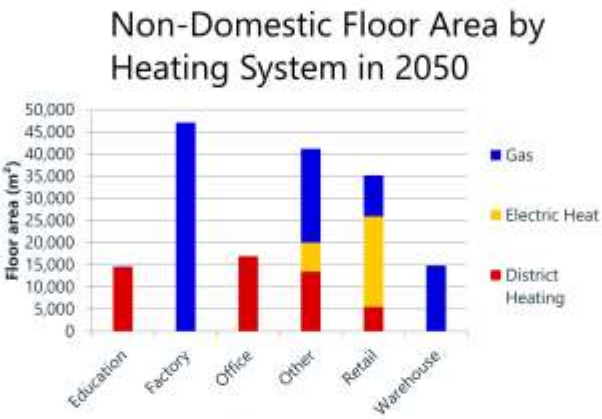


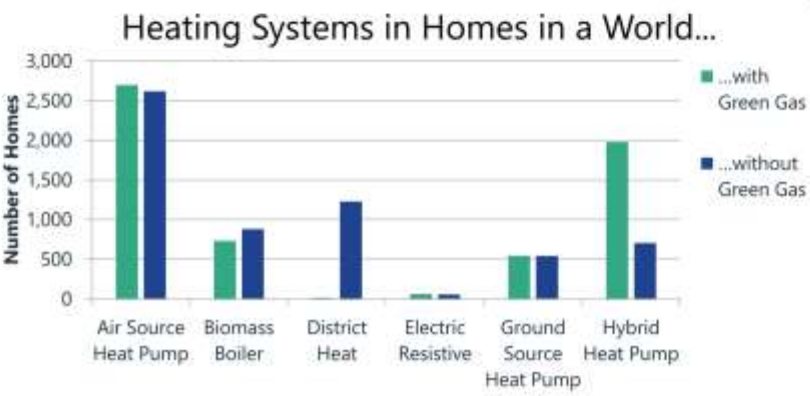
Located in the North East of BCBC, analysis area 3 contains the A4064 from Pontycymer through Pont-y-rhyl. The A4061 enters the analysis area at Nant-y-moel and Blackmill.





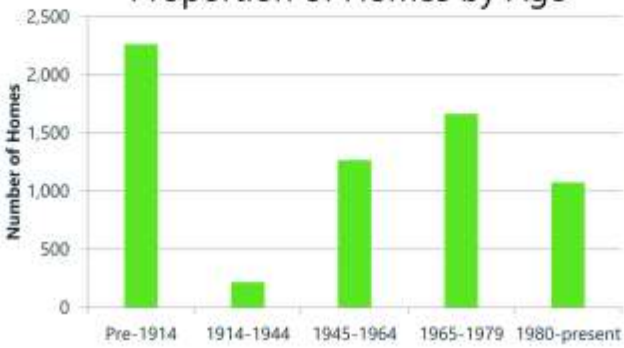


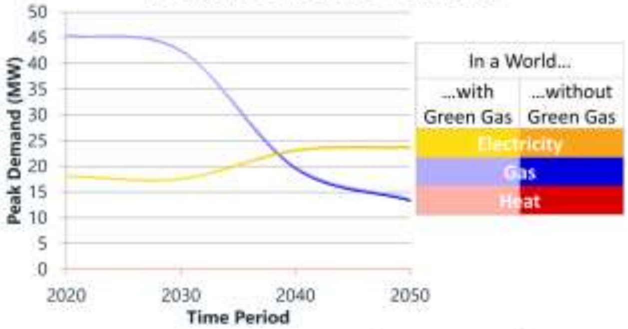


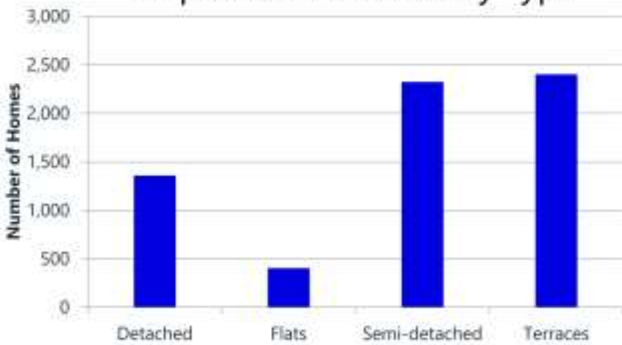


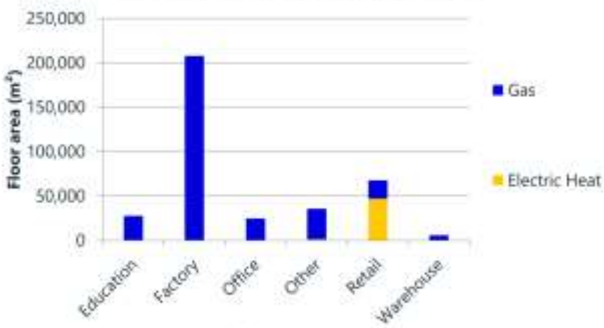
Analysis Area 4 Fact File

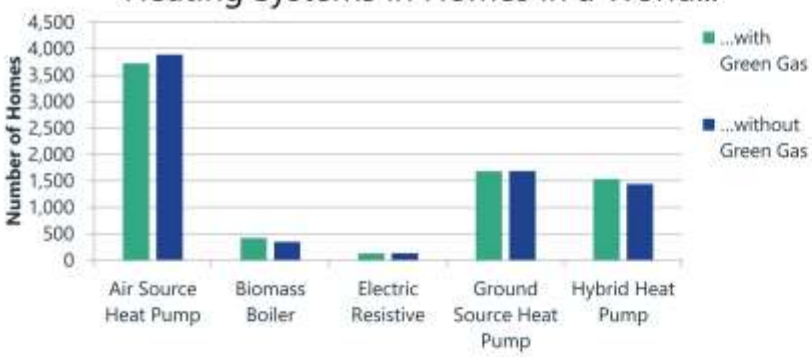
Located in the North of BCBC, analysis area 4 contains Garth, Llangynwyd, Coytrahen and Brynmenyn. To the East it stretches past Bettws, finishing just after Llangeinor.



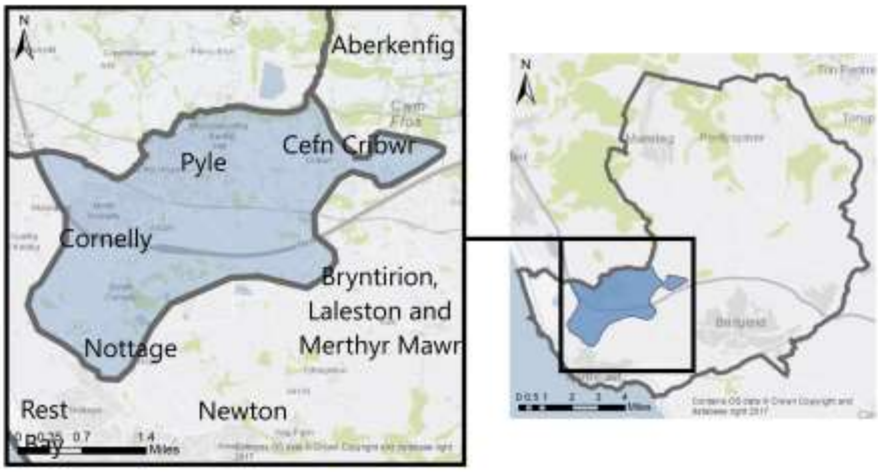




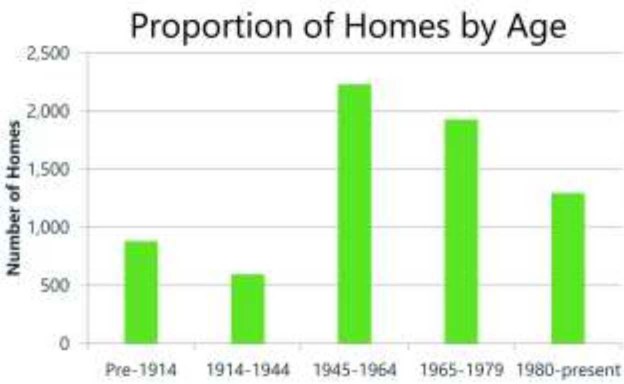


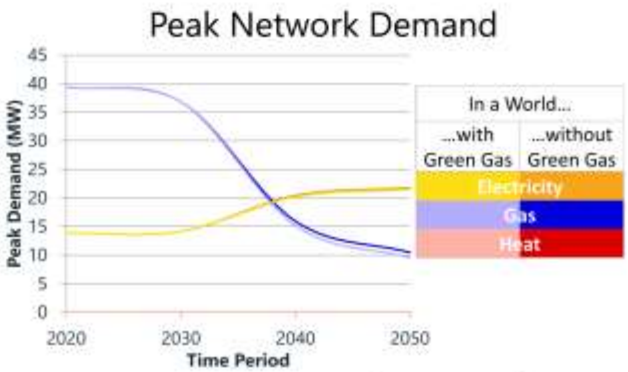


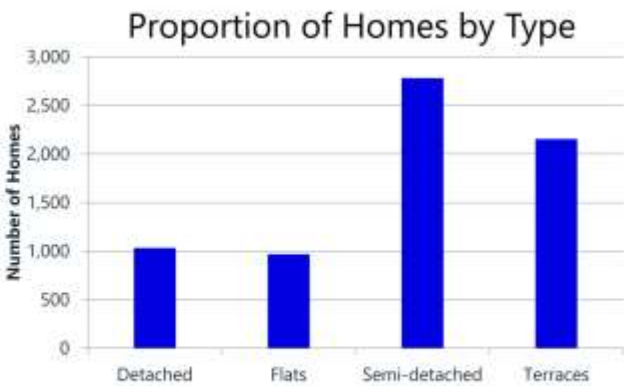
Analysis Area 5 Fact File

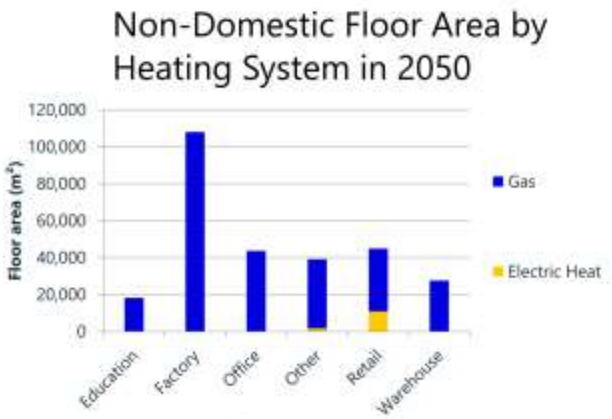


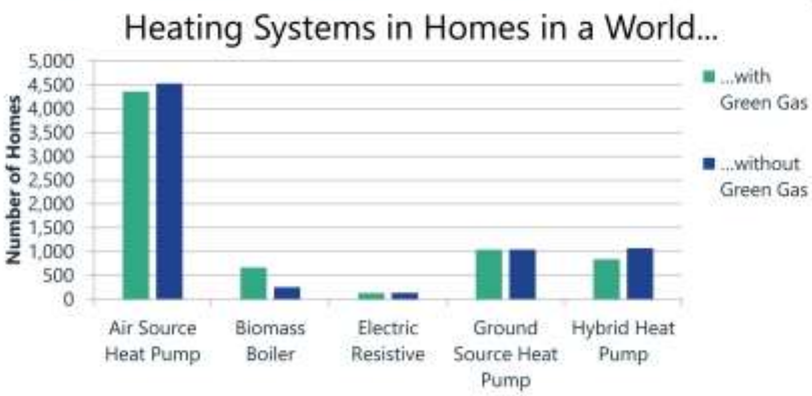
Located in the West of BCBC, analysis area 5 contains the entry point to BCBC via the A48. It contains Pyle and Kenfig Hill, and stretches as far as South Cornelly to the South. To the East it contains Cefn Cribwr and Cefn Cross.





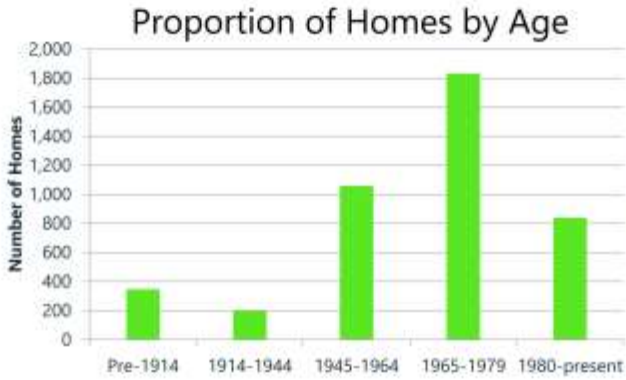


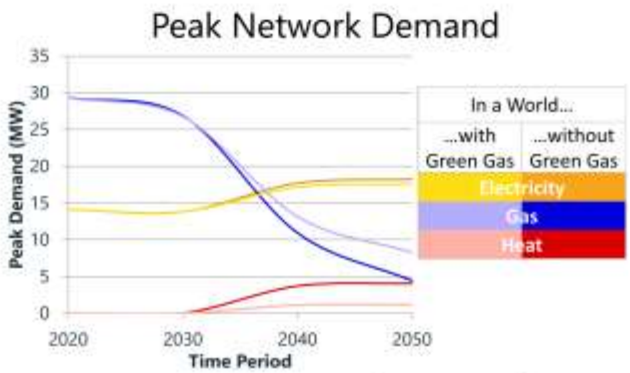


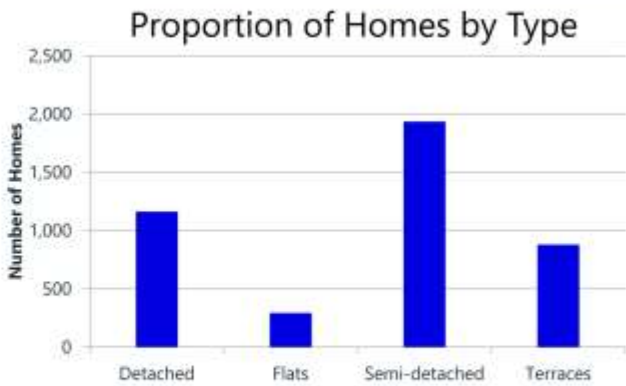


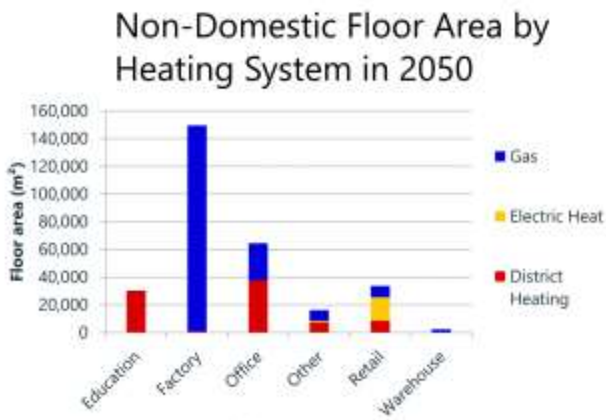
Analysis Area 6 Fact File

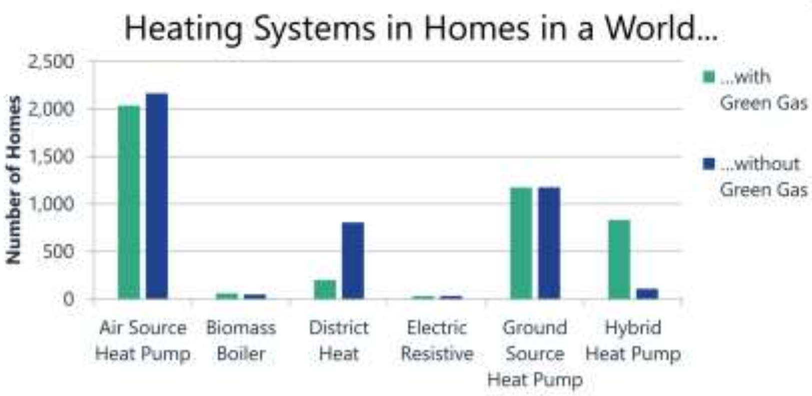
Analysis area 6 is located in the East of BCBC. Connected to analysis area 7 by the M4 at the Western boundary, analysis area 6 covers Pencoed in the South and Heol-yCyw to the North. The Northern boundary is located just above Glynoggwr.





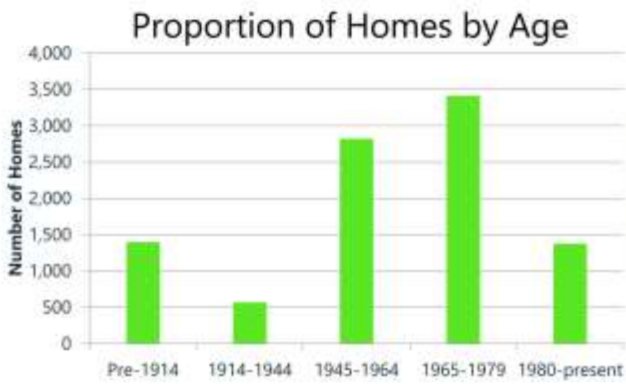


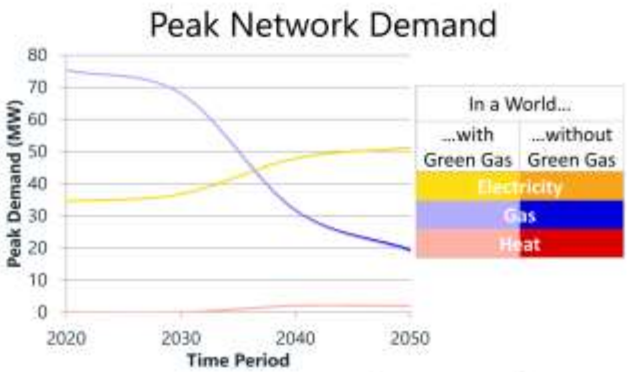


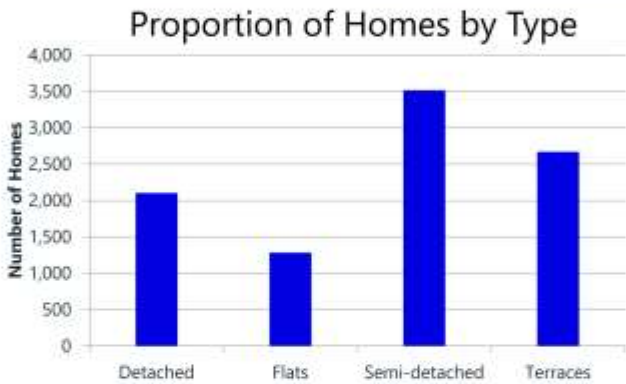


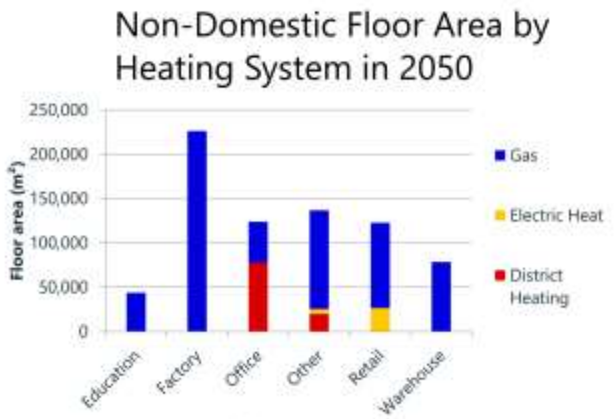
Analysis Area 7 Fact File

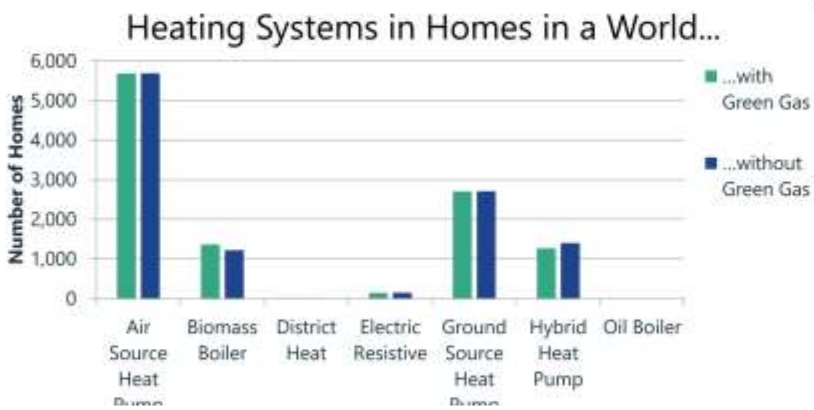
Located in central BCBC, analysis area 7 contains Sarn and Aberkenfig, stretching up to Tondu in the North. In the South its boundary is located past Coity, as far as Bridgend town.



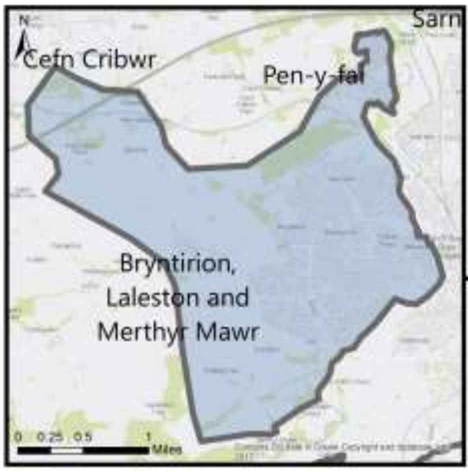




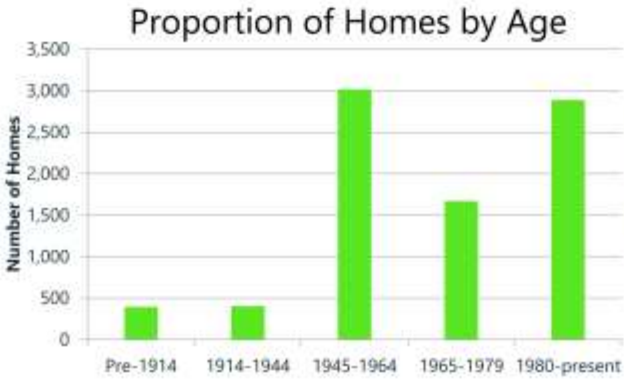


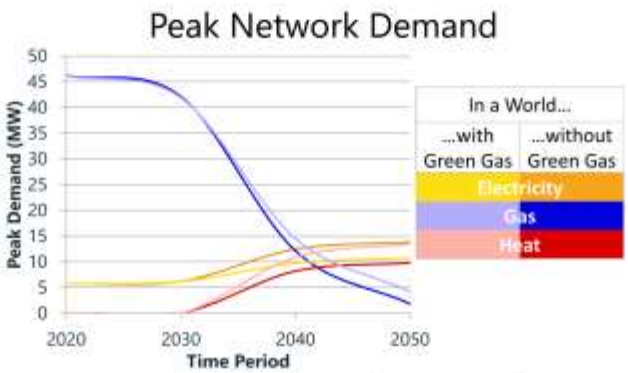


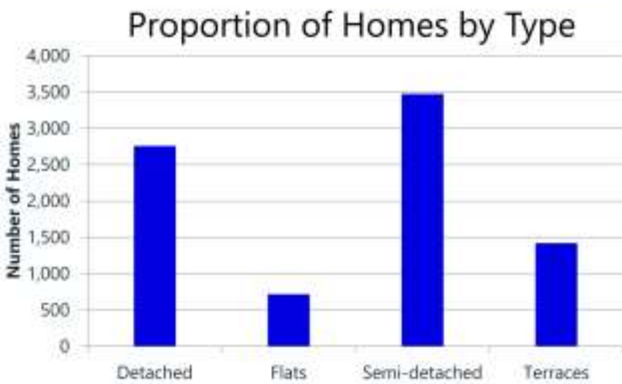
Analysis Area 8 Fact File

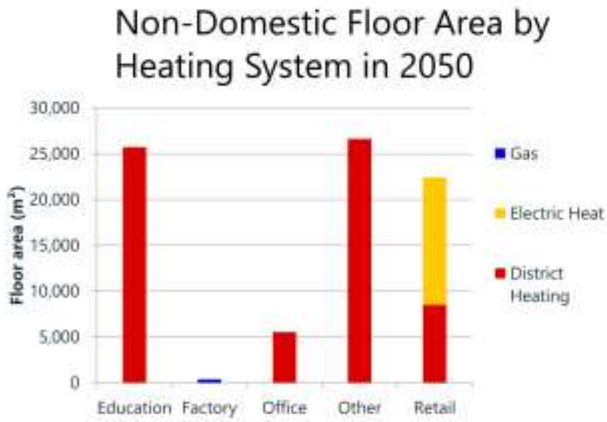


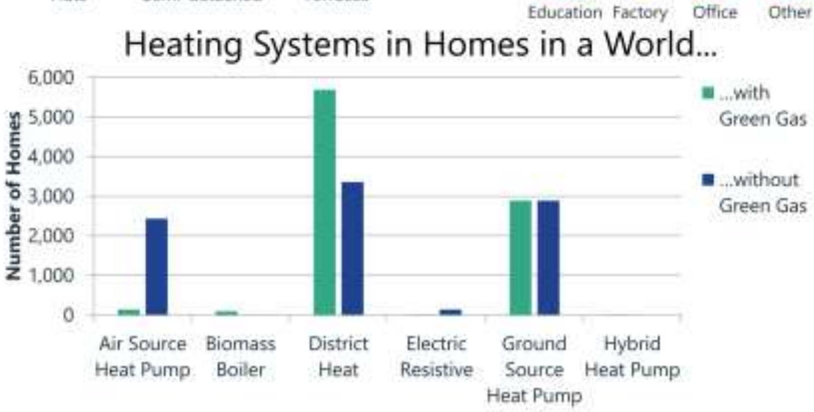
Located in central BCBC, analysis area 8 is connected to analysis area 12 by the A48 and A473. It stretches to Pen-y-fai to the North and Bridgend town to the East.



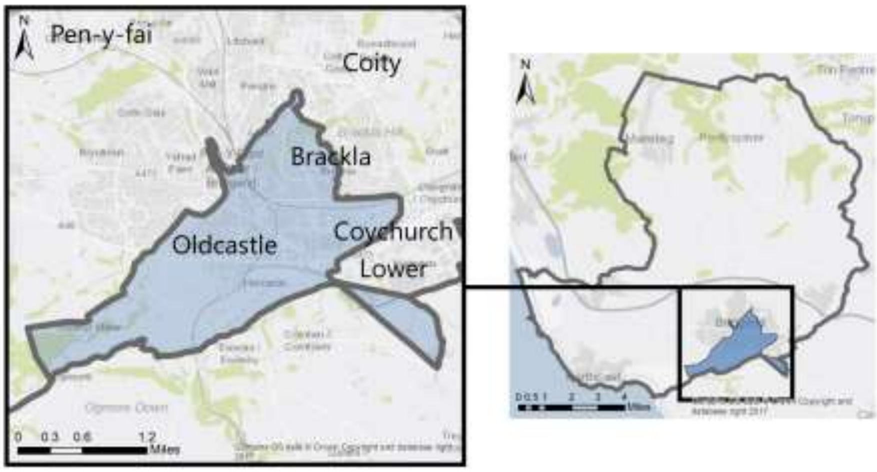




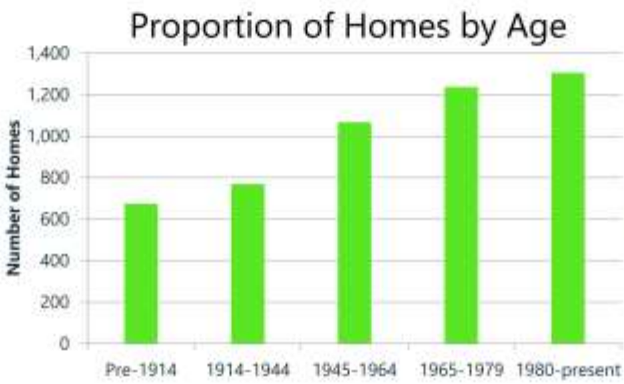


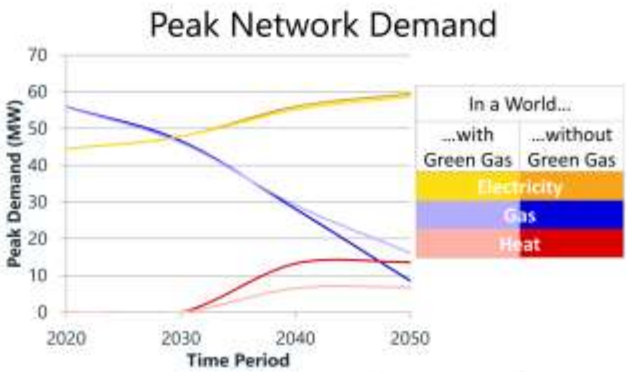


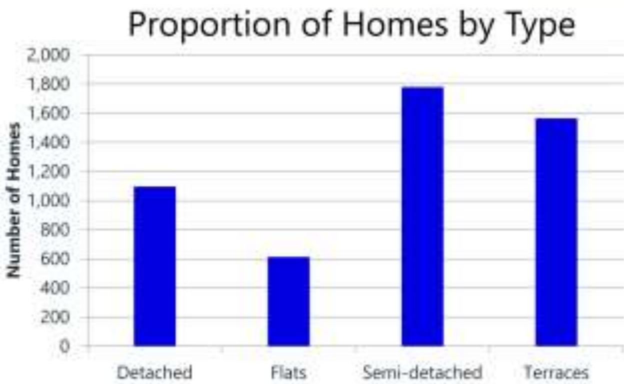
Analysis Area 9 Fact File

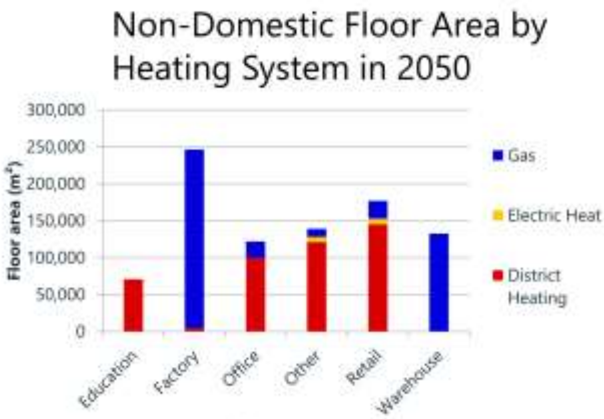


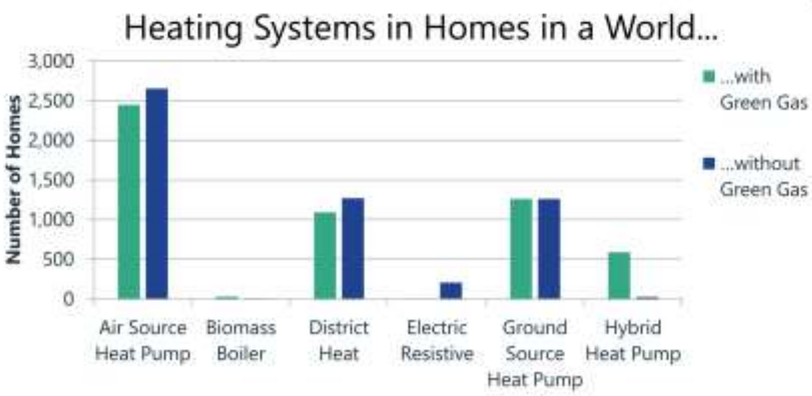
Located in the centre of BCBC, analysis area 9 runs from Merthyr, Mawr and Ogmore to Bridgend town. To the East it stretches as far as Brocastle.



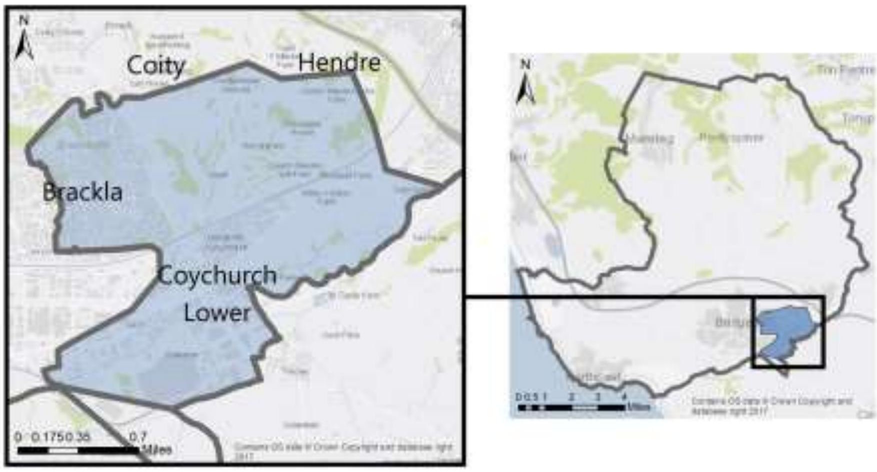




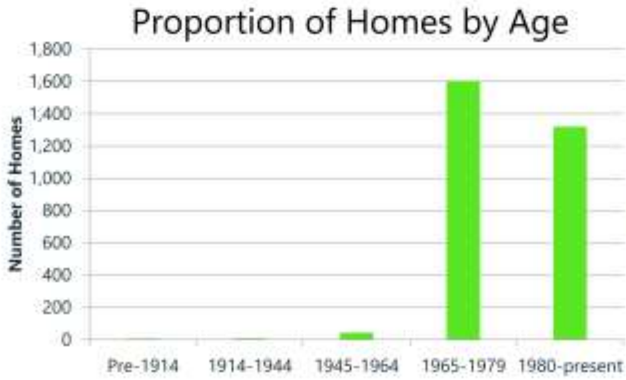


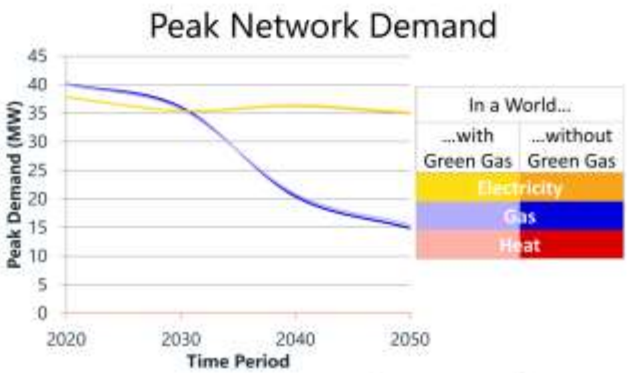


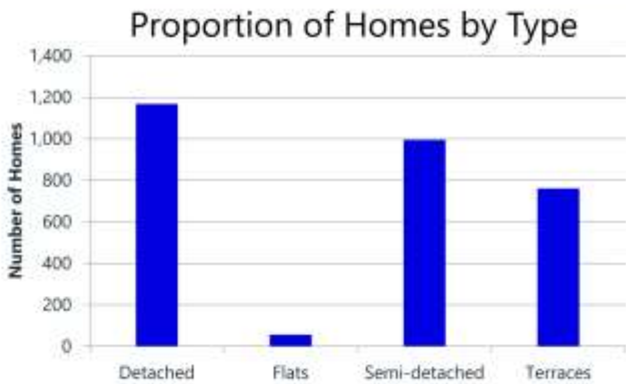
Analysis Area 10 Fact File

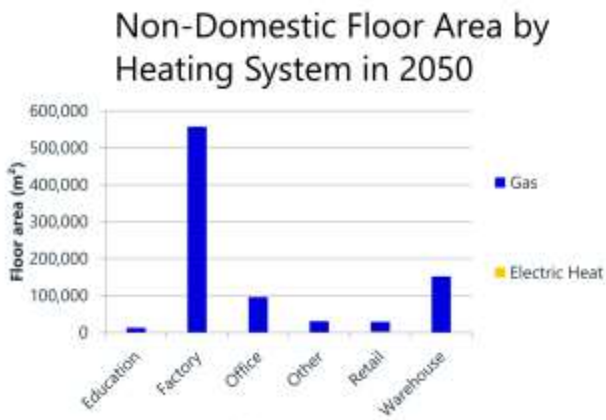


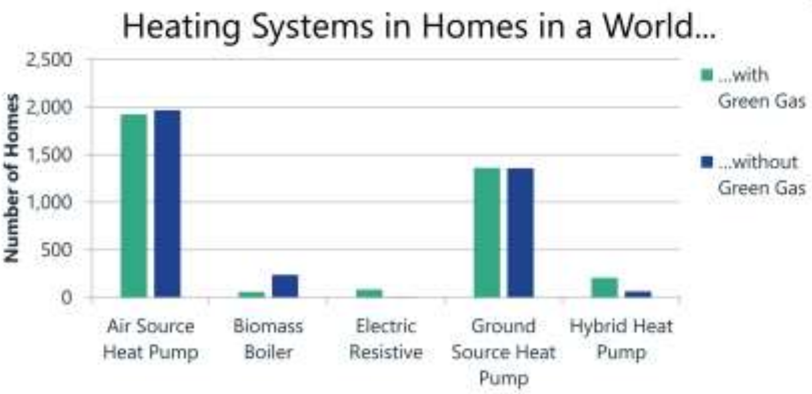
Located in the East of BCBC, analysis area 10 is connected to Bridgend town via the A473. It contains Bridgend Industrial Estate, Brackla and Coychurch.



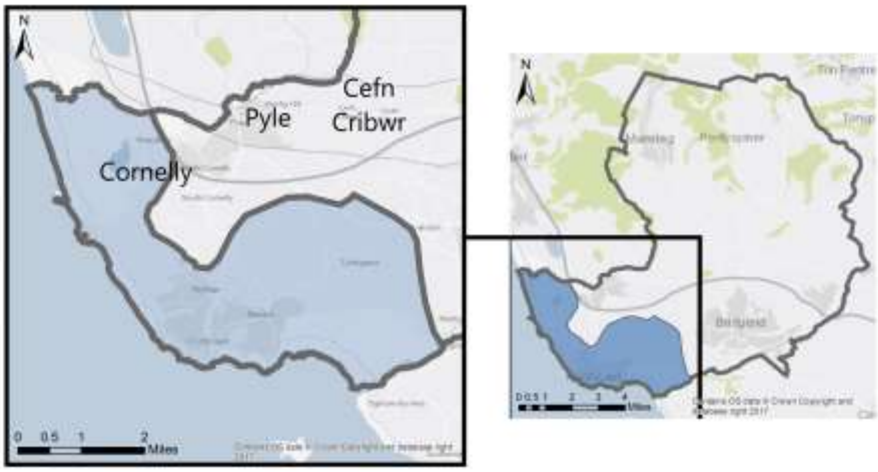




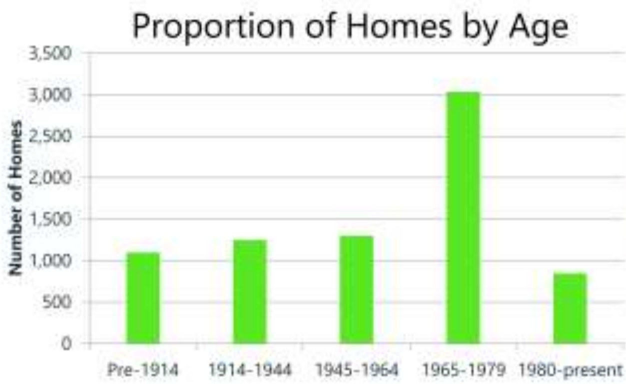


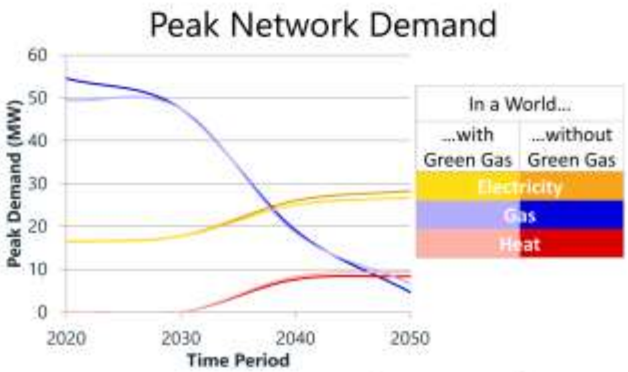


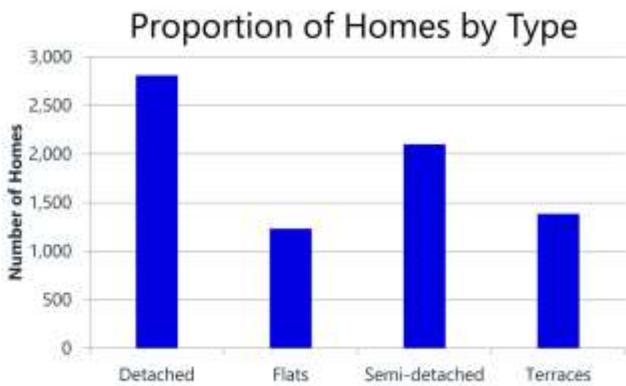
Analysis Area 12 Fact File

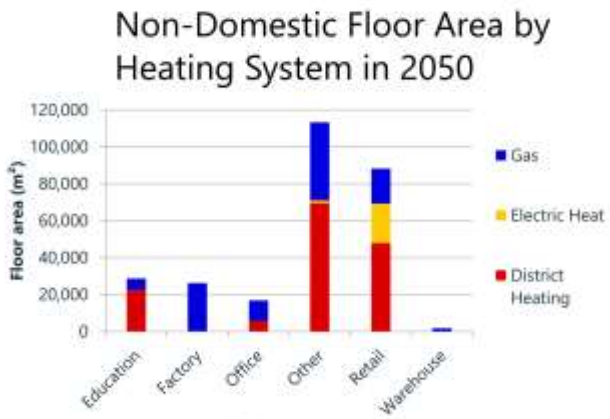


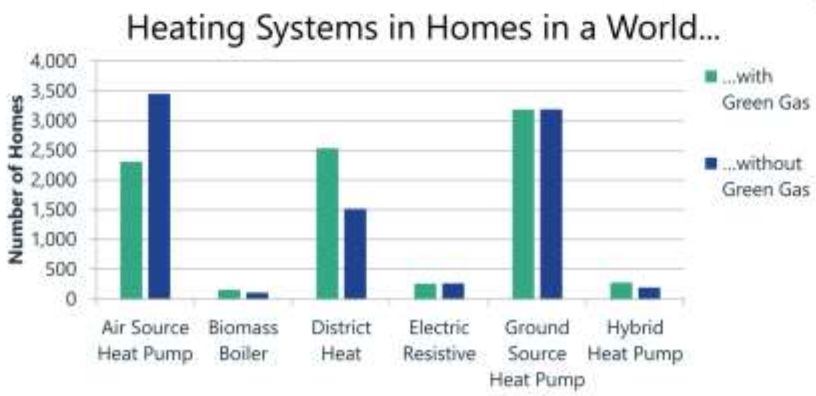
Located in the West of BCBC, analysis area 12 is separated from analysis area 5 by the M4. It emcompasses Maudlam and Kenfig, stretching to Nottage and Porthcawl in the South, and Tythegston to the East.











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Data has also been provided by Bridgend County Borough Council, Wales and West Utilities and Western Power Distribution to aid the representation of the Bridgend study area.

Document Control

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Author	Dr Natalie Lowery
Reviewer	Richard Halsey
Approver: (Approval Denoted by Signature)	Emma Harrison

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Revision History

Date	Version	Comments
09/03/2018	0.1	Draft
21/03/2018	0.2	Amendments post ESC review
19/04/2018	0.3	Amendments post KSG review
24/04/2018	1.0	Final (Post EH review)

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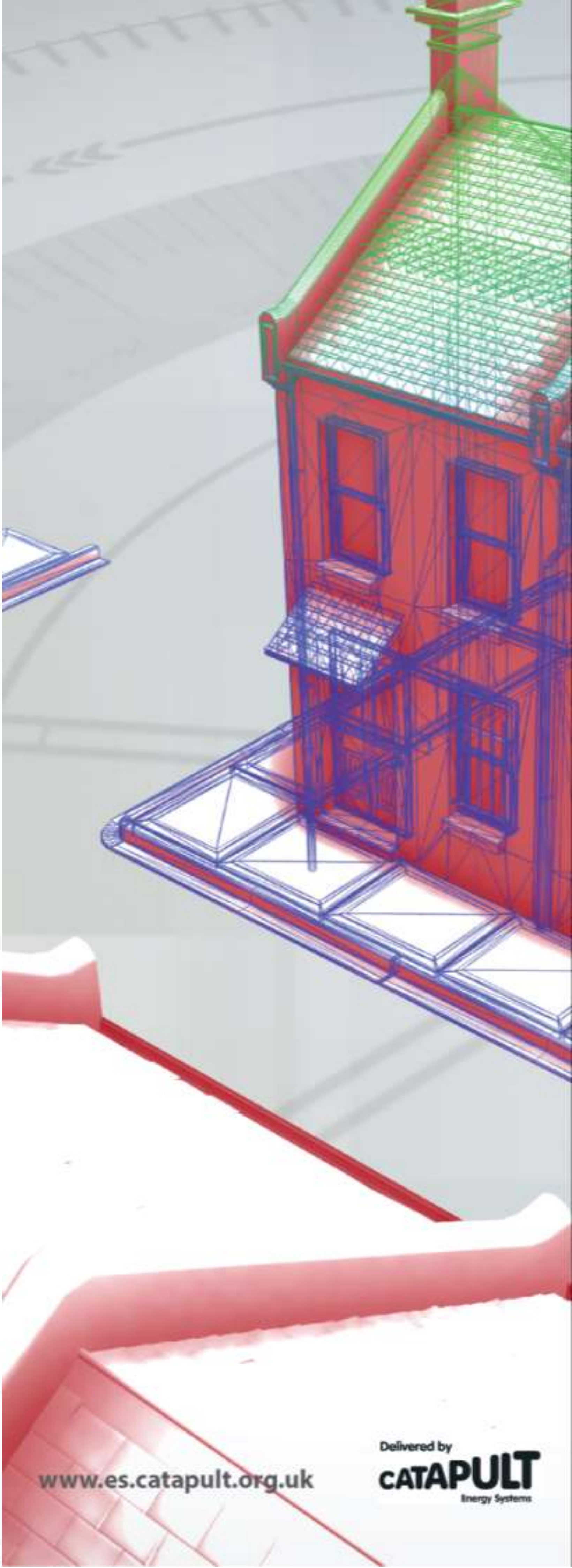
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