Programme Area: Smart Systems and Heat

Project: WP2 Newcastle Area Energy Strategy

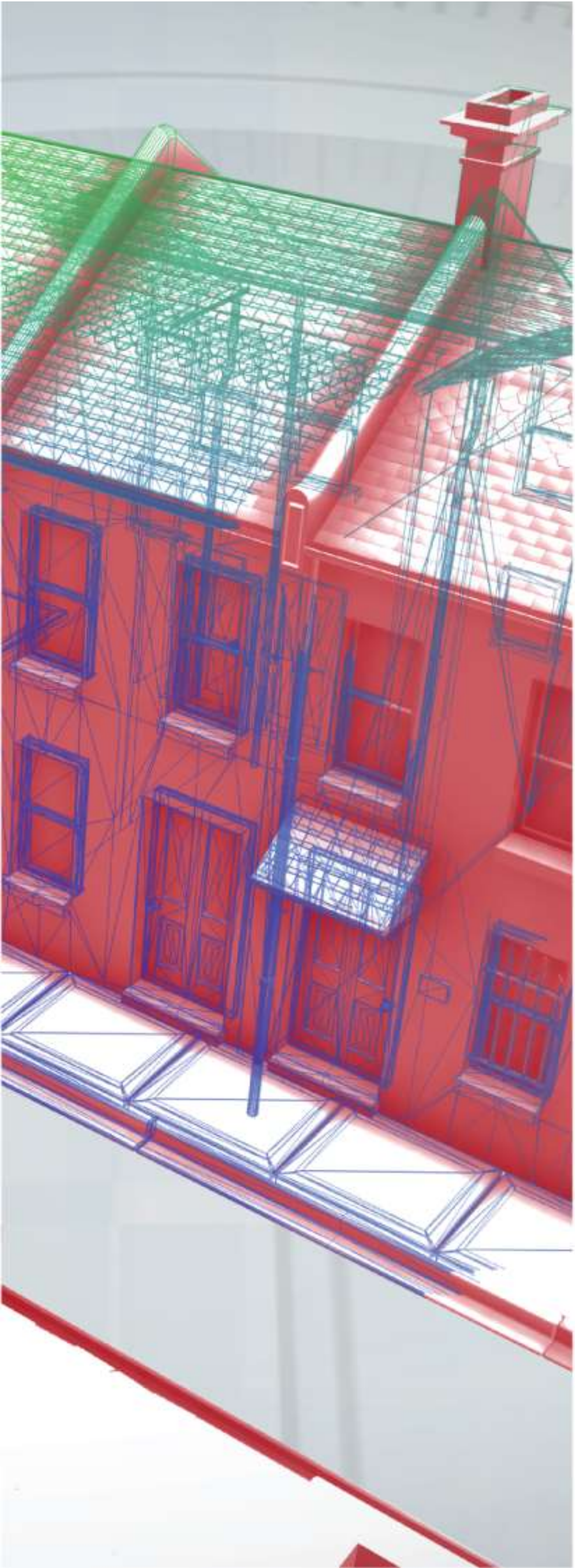
Title: Newcastle City Council Local Area Energy Planning Evidence Base

Abstract:

This document (The Evidence Base) presents the results of an EnergyPath Networks modelling study and underpins a higher-level Strategy. The Strategy provides a high-level outlook and timeline for technological and related changes necessary to achieve the decarbonisation of heating in Newcastle. The creation of the Evidence Base and the Strategy was motivated by the shared commitment to respond effectively to meet the requirements of international, European and national decarbonisation targets and the policy imperative to address climate change and transition to a low carbon economy.

Context:

The Energy Systems Catapult has worked collaboratively with Newcastle City Council, Northern PowerGrid, Northern Gas Networks and Newcastle University utilising its EnergyPath Networks modelling capability to assess the options for decarbonisation of the buildings within the City. This evidence base aims to provide a foundation for the Council and other key stakeholders, including existing network operators, 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 over the next decade.



Newcastle City Council

Local Area Energy Planning

Evidence Base

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Motivation

This Evidence Base is one of two related documents which together offer a new approach to local area energy planning in the UK. The **Evidence Base (this document)** presents the results of an *EnergyPath Networks*[1] modelling study and underpins a higher-level Strategy. The **Strategy,** which is published separately in draft, provides a high-level outlook and timeline for technological and related changes necessary to achieve the decarbonisation of heating in Newcastle. The creation of the Evidence Base and the Strategy was motivated by the shared commitment to respond effectively to meet the requirements of international, European and national decarbonisation targets and the policy imperative to address climate change and transition to a low carbon economy.

[1] http://www.eti.co.uk/programmes/smart-systems-heat/energypath

Contents

Executive Summary 5

1 Introduction 10
1.1 Context 10
1.2 Project Overview 10
1.3 Evidence Base Scope 11

2 The Energy System 15
2.1 Overview 15
2.2 UK Energy Generation 15
2.3 The UK Electricity Network 16
2.4 The UK Gas Network 19
2.5 The Local Energy System 21

3 EnergyPath Networks Modelling Approach 27
3.1 Overview 28
3.2 Data 31
3.3 Model Data Verification 32
3.4 Domestic Buildings 32
3.5 Non-Domestic Buildings 36
3.6 Energy Infrastructure 37
3.7 Spatial Analysis 38
3.8 Modelling Areas 39
3.9 Limitations and Uncertainties 41
3.10 Technologies 44
3.11 Carbon Emissions 48

4 Options and Choices for a Low Carbon Local Energy System 51
4.1 Local Area Representation 51
4.2 Base Run 51
4.3 Business as Usual 51
4.4 Sensitivity Testing 55
4.5 National Pathway Sensitivity 56
4.6 Energy Cost Sensitivity 61
4.7 Technology Cost Sensitivity 65
4.8 Heat Storage Times 71

4.9 Heat Storage Capacity 73
4.10 Advanced Retrofit 76
4.11 Energy from Waste 80
4.12 Forced Solar Electricity Generation 82
4.13 Restricted Biomass 84

5 Future Local Energy Scenarios and Network Choices 89
5.2 Cost Analysis 111
5.3 Local Constraints 118

6 Conclusions 120

Executive Summary

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 demand for energy and 60% in Newcastle[2].

A new approach to planning and delivering 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 in the city of Newcastle (The City). The UK has committed to a legally binding obligation to cut greenhouse gas emissions by 80% by 2050 (against 1990 levels). In addition, the Paris Climate Conference achieved a binding and universal agreement with the aim of keeping global warming below 2°C. Newcastle City Council has adopted a citywide Climate Change Strategy and Action Plan [3] and in March 2016 established a vision that the City will be Powered by 100% Clean Energy by 2050.

Cutting carbon emissions from buildings is recognised as more cost effective than achieving deep emissions reductions in other sectors such as transport. Reducing and managing energy demand from homes and buildings in Newcastle and transforming the City's energy system is essential to cost effectively meeting national and local carbon reduction targets[4].

As part of the Energy Technologies Institute's Smart Systems and Heat (SSH) programme, The Energy Systems Catapult has worked collaboratively with Newcastle City Council, Northern PowerGrid, Northern Gas Networks and Newcastle University utilising its EnergyPath Networks modelling capability[5] to assess the options for decarbonisation of the buildings within the City. This evidence base aims to provide a foundation for the Council and other key stakeholders, including existing network operators, 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 over the next decade.

This Evidence Base describes the detailed modelling and analysis of transition options and costs for the local energy system that has been undertaken to provide a foundation for Newcastle's Local Area Energy Strategy. The key findings are listed below.

[2] Total energy demand and associated carbon emissions comprises gas, electricity, oil and coal used in buildings for heating plus electrical energy used for lighting and appliances
[3] Newcastle's Citywide Climate Change Strategy and Action Plan
[4] Cutting carbon emissions in the buildings sector is considered more cost effective compared to most other sectors.
[5] See Section 3 for a description of EnergyPath Networks and www.eti.co.uk/programmes/smart-systems-heat/energypath

Using the Evidence Base

- Modelling using EnergyPath Networks has helped to identify particular transition options that occur consistently across a wide range of input assumptions. Some areas of the city are consistently selected for district heating or individual electric heat solutions whilst other areas show wide variability. In addition, the factors which have the greatest influence on these selections can be identified.
- This information can be used to inform the development of a Local Area Energy Strategy for Newcastle and to identify areas for action.

Newcastle's Energy Strategy

- We cannot have perfect foresight out to 2050. There is a range of potential future pathways for the transition of Newcastle's local energy system given the inherent uncertainty in planning for longer term.
- National choices and actions will influence local choices which will need to consider the balance between cost and risk. It is likely that the risks associated with some apparently low cost local solutions will be considered too great and that higher cost, lower risk choices will be preferred[6].
- With the options identified as currently available in Newcastle it is not possible to achieve complete decarbonisation of heat and so technology development is required to achieve Newcastle's long-term ambitions. This technology development will influence the City's future decarbonisation pathways and is required to allow lower risk choices to be made.
- Newcastle' strategy will need to be refined and developed as new technologies appear, current technologies develop and better information becomes available.
- There are a number of projects that appear to be low regret and should be progressed in the near term.

Economic Benefits

- Transition to a low carbon energy system in Newcastle could deliver net positive energy savings of c. 19 TWh compared to business-as-usual. However, when these are monetised, this results in a cost to society of £340 million (as gas heating is displaced by more expensive low carbon fuels).
- Across a range of scenarios, it is expected that between 9,000 and 21,000 homes could receive a reduction in the cost of delivering energy to their homes - this should be reflected

[6] An example is extensive use of biomass due to the high level of uncertainty around the future cost and availability of biomass. The analysis suggests that biomass boilers would be suitable for many homes in Newcastle but this exposes residents to a high risk of high future energy costs.

in their fuel bills. Across all scenarios, these homes are concentrated in the following wards: Benwell and Scotswood, Wingrove, Westgate, Elswick, North Jesmond, South Jesmond, Ouseburn and Byker - these correlate with areas with high levels of fuel poverty. However, it is unlikely that energy savings (where they apply) from the transition will be sufficient to significantly reduce levels of Fuel Poverty - other measures may be required to close the gap.

- On average, more than 5.5 million tonnes of CO_2 are saved as a result of the transition – this equates to a benefit of more than £350 million when valued with a carbon price[7].
- An estimated 5,500 jobs could be created between 2030 and 2050 when most buildings are expected to start transitioning to low carbon heating systems. This is predicted to fall to a baseline of approximately 4,000 jobs by 2050 which, are expected to extend beyond this point. These are additional jobs primarily from retrofitting domestic buildings and from installation of new energy networks.

Carbon Emissions

- To deliver Newcastle's ambition will require the complete decarbonisation of homes and buildings by 2050. Business-as-usual without any local carbon target will not drive the change needed to buildings and local energy infrastructure. Newcastle needs an ambitious local carbon target to cost-effectively deliver its ambition by 2050.
- Achieving the City's vision and climate change goals will require decarbonisation of national electricity supply. This falls outside Newcastle's local policy control. In addition, co-ordinated planning and action will be required to achieve significant changes to homes and energy infrastructure.
- To achieve its ambitious renewable energy target Newcastle City Council will need to develop a strategy to decarbonise the non-domestic buildings in the City.

Cost

- The total cost of Newcastle's energy system to 2050 under business-as-usual is estimated at £10.4 billion[8]. The additional cost of transition to a low carbon energy system supporting Newcastle's ambition between now and 2050 is estimated to be between £0.7 billion and £2.4 billion depending on the pathway choices and is expected to be more than £1 billion.
- Analysis has found that changes intended to save cost in one part of the energy system typically shift the cost to another part of the system where it increases[9].

[7] Carbon prices are from the latest Interdepartmental Analysts Group guidance and either "traded" for electricity to reflect the presence of a carbon market in the form of the EU ETS, or valued using a "non-traded" price for all other fuels. www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

[8] These costs include network reinforcement, new build and operation, changes to individual homes (including heating system changes and fabric retrofit) and the cost of the energy consumed. Costs are discounted to 2015 values.

[9] As an example restricting the times of day when heat storage can be charged to save network reinforcement costs leads to a £40 million increase in total cost as more expensive heating systems are required (higher power, or larger storage).

Gas and Electricity Networks

- Gas is almost completely eliminated from domestic buildings at a 90% local carbon reduction target for buildings in Newcastle.
- Around 60% of predicted electricity network reinforcement is required to support an expected increase in demand from non-domestic buildings.

Heat Networks

- District heating is likely to play an increasing role in delivering cost effective low carbon heat to homes and buildings.
- Existing and planned heat networks provide a base for further expansion. In Newcastle, these could provide an infrastructure 'seed' for cost effective future expansion of district heating within the City to support long term decarbonisation of homes and buildings.
- Decentralised energy in the form of gas-fired CHP could play an important part of a future energy system and reduce reliance on imported energy to the City. There is an economic case for local electricity generation through gas-fired Combined Heat and Power (CHP) plants in the near term. In the longer term this plant may still be valuable on the coldest winter days to provide both additional heat for heat networks and electricity to power homes with individual electrically powered heating systems.
- Sources of low carbon heat within Newcastle for use in heat networks need to be identified to support decarbonisation ambitions.

Heating Systems

- The lifespan of domestic heating systems means that most homes are unlikely to have systems replaced more than twice between now and 2050. This gives two opportunities for change, although this could be influenced by new business models such as *Heat as a Service* (HaaS)[10] being introduced.
- A wide range of heating system options is required to be able to make the deepest carbon reductions. District heating and individual electric solutions, including heat pumps, are likely to play a significant part in delivering low carbon heat to buildings in Newcastle. Different heating technologies are likely to be more cost effective in different housing types and geographical areas of the City. In addition, the relative future costs of fuels and heating systems influence which options are likely to be preferable.

[10] www.eti.co.uk/insights/domestic-energy-services

- The poor thermal performance of some of the housing stock means that currently there are limited low carbon heating system options that can meet their peak demand. A trade off will need to be made between improving the thermal performance of these buildings in order to allow alternative heating systems to be used and fitting a more powerful heating system that might provide a cheaper overall solution but result in higher carbon emissions.

Fabric Retrofit

- Retrofit of thermal efficiency measures is better suited to some housing types and areas of the City than others.
- Retrofit of thermal efficiency measure to reduce energy demand in homes will make up part of the solution but there are few cost-effective options available for a large proportion of buildings given the measures already implemented by the City Council and others.
- Lower cost items such as topping up loft insulation, filling the last 'easy-to-fill' cavity walls and fitting double glazing where properties still have single glazing should be prioritised. Whole house retrofit[11] is very expensive and is unlikely to deliver cost-effective carbon savings to justify the work at current energy prices although it may deliver wider social benefits such as reducing fuel poverty and improved comfort.

[11] This might include a series of measures such as solid wall and floor insulation as well as items such as triple glazing or the EnergieSprong approach of 'wrapping' an existing building in new wall and roof panels in order to improve thermal efficiency.

1 Introduction

1.1 Context

Newcastle City Council is committed to be a leader in energy systems change and the process of decarbonisation as set out in its Climate Change Strategy and Action Plan and Energy Masterplan. Newcastle City Council is one of three UK local authorities participating in a pilot to develop and test a new approach to local area energy planning based on a whole-system modelling methodology to meet its ambition to power the City with 100% clean energy by 2050.

This Local Area Energy Strategy (LAES) 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 sound evidence base.

The output from the study consists of two documents:

- An Evidence Base (this document). The Evidence Base provides the technical basis and area-specific evidence base to support the development of the Strategy summarising the EnergyPath Networks based analysis and supporting information.
- A Strategy document which builds on the Evidence Base and includes the other essential interdependent economic and social factors that are central to the Strategy’s development, such as consumer markets, commercial readiness and policy & regulatory aspects. The Strategy contains an implementation plan, supported by a roadmap, outlining an approach to plan for and deliver a resilient and low carbon energy system.

1.2 Project Overview

The project to develop a Local Area Energy Strategy for Newcastle was commissioned and funded by the Energy Technologies Institute (ETI) as part of the Smart Systems and Heat Programme and has been undertaken through a collaboration between Newcastle City Council (NCC), Northern Power Grid, Northern Gas Networks, Newcastle University (the Key Project Stakeholders) and the Energy Systems Catapult, utilising its EPN modelling capability. It aims to provide a foundation for the Council and other key stakeholders, including existing network operators, 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.

Newcastle-upon-Tyne is the eighth largest city in England. The modelling of the local energy system has considered a total of 146,100 existing buildings within Newcastle, made up of circa 127,300 domestic and 18,800 non-domestic buildings. The information has been sourced from *OS Addressbase* data and updated so that the strategy also considers additional planned new development building that is essential for Newcastle’s growth.

1.3 Evidence Base Scope

The scope to produce the evidence base is detailed in Table 1-1 below.

Table 1-1: Project Scope

Item	Scope Description
1	The project team agreed that within the EnergyPath Networks Project "Study Area", the representation of the existing energy networks, local building stock, etc. and the options for network/building stock transformations, are of sufficient completeness for the scope of the study and stakeholder needs.
2	Required data sets that exploit the full capacity of the model have been identified and sourced. This information was then analysed and where necessary required pre-processing was performed, this allows the data to be efficiently uploaded into the model.
3	The EnergyPath Networks Project Team agreed with the Key Project Stakeholders that the modelling approach, which relates to form, quality, representation and the level of analysis, was of sufficient completeness for the needs of the study as well as the Key Project Stakeholders.
4	Following consensus with the key stakeholders on the local area representation, a first run of the EnergyPath Networks model was produced to create a 'Base Run', this identifies potential scenarios and decarbonisation options for the study area for further analysis. The outputs were then shared and discussed with the Key Project Stakeholder Group to obtain comments/consensus regarding the next stages of modelling/assessment.
5	A series of "Sensitivity" tests on the Base Run were performed, such as assessing energy, technology cost and energy use sensitivity to facilitate discussion and mutual understanding across the Key Stakeholder Group.
6	An accompanying evaluation (through a supporting separate document) of the updated modelling outputs has been produced to inform the development of the Strategy; assessing Economic and Social Benefits as well as providing an initial overview of the impact the outputs could have on Policy, Regulation and investor confidence.
7	A series of final "iterations" to refine the modelling outputs were then conducted, so that key learning points from previous analysis can be incorporated into the models "Final Runs".
8	Following the "sign off" of the final modelling outputs, this document (the Evidence Base) and the supporting Strategy document have been created to record the whole project process in an agreed format for sharing to a wider group of stakeholders and interested parties.

1.3.1 Key Scope Parameters

The development of the Evidence Base and Strategy is based upon the consideration of low carbon heating options for Newcastle 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.
- Non-domestic buildings are considered, to understand the energy use associated with these buildings and the impact this may have on energy infrastructure only, as this could affect the options available to the domestic sector. NCC will need to increase its understanding of Newcastle's non-domestic buildings (as recommended in Strategy) to develop a robust evidence base so that the strategy can be developed further.
- Transport and associated emissions are not assessed; however expected uptake of electric vehicles has been included based in consultation with NCC so that the impact of electric vehicles on the electricity network is assessed within the model.
- The Evidence Base does not consider the following options to decarbonise heat:
    a. Building retrofit following the Energiesprong[12] philosophy on a building-by-building basis, as there was no data available at the time of the project to identify suitable buildings in Newcastle. The maximum level retrofit considered was solid or cavity wall insulation with loft insulation and triple glazing (referred to as insulation package option 1or 2 in section 5.1.4).
    b. Hydrogen for heating and or the repurposing of the gas grid for hydrogen, as well as the introduction of green gas to the existing gas network[13]. This was due to lack of suitable data being available at the time of the project modelling work.
- The model focuses on identifying the options with the lowest cost to society to reduce emissions. As such it doesn't focus on options to reduce fuel poverty as this would involve a different set of priorities (and potentially lead to higher total costs).

[12] This is a retrofit based on wrapping the whole house in a more energy efficient shell. See www.energiesprong.uk
[13] These options are discussed in the accompanying Strategy document.

1.3.2 Evidence Base Process

The Evidence Base is developed using EnergyPath Networks, a modelling framework which has been designed in partnership with local authorities to develop cost-effective local energy system options for the UK (see Section 3). EnergyPath Networks:

- Has a view of the national energy system from generation to end use, considering multiple energy vectors.
- Is based on developing a detailed spatial representation of a local area with the ability to understand the spatial relationship between the buildings and networks that serve them, so that decarbonisation options can be analysed at a detailed and localised level.
- Considers the local area both now and in the future (to 2050) in terms of building stock, energy demands and energy networks.
- Use of an optimisation process to compare a large number of combinations of options (>1m), enabling comprehensive sensitivity analysis, to inform multi-objective system decisions.
- Allows stakeholders to define drivers or constraints relevant to the local area.
- Supports proactive planning and investment by giving confidence between now and 2050 e.g. which potential technologies, where and when?
- Aids consensus building with stakeholders and (in the future) local communities.
- Identifies the least cost decarbonisation measures that we can have confidence in progressing in the near term through Deployment projects, along with identifying where further evidence is required (through Development & Demonstration, Data Gathering & Systems Analysis and Research projects) so that we can begin to plan for the medium to long term

The process of using EnergyPath Networks and producing the Strategy is shown below, see Figure 1-1.

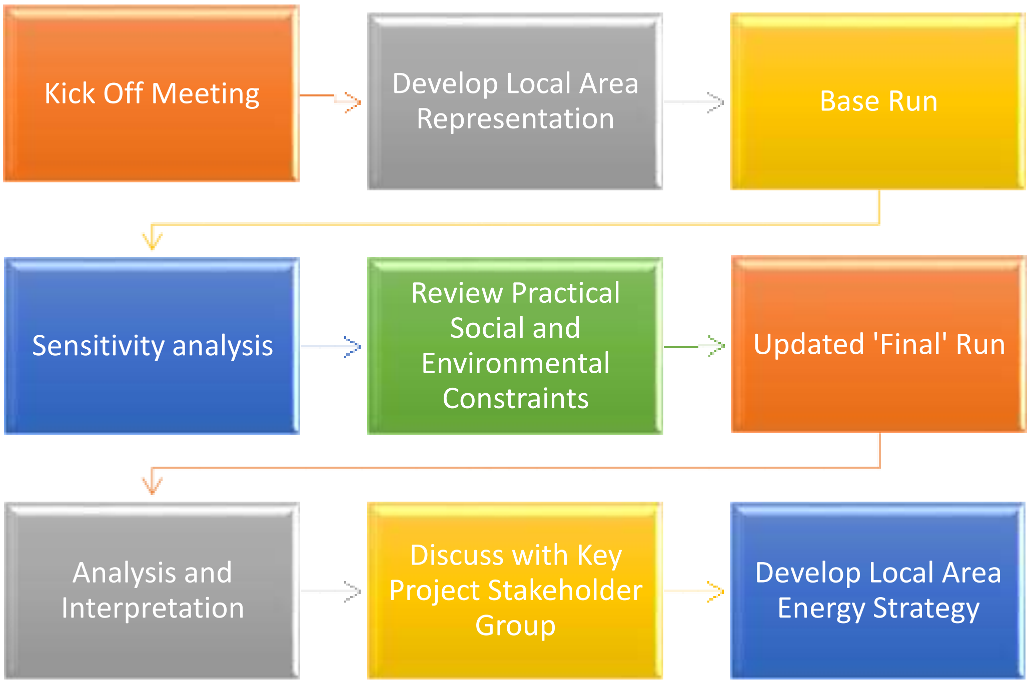

Figure 1-1 Project Process

2 The Energy System

This Chapter discusses Newcastle's electricity and gas networks, together with any known or planned district heat networks. These systems are an integral component of informing the development of the LAES. Many of the decarbonisation options being considered will have an impact on these systems. For example, if a decarbonisation option is based on the use of electricity, analysis would be needed to determine the impact of the corresponding additional electrical demand on the electricity network.

2.1 Overview

The transition of the UK energy system to low carbon is a major economic and practical challenge, affecting consumers, current and future energy suppliers and network operators. Electricity and gas distribution network operators will be required to deliver lower carbon supplies to homes and buildings and either be upgraded or replaced by alternative network solutions before 2050.

2.2 UK Energy Generation

The UK currently has a number of different forms of electricity generation using different fuel sources and technologies which give the current level of security of supply and affordability. Fossil fuels are used to generate approximately 52% of the UK's electricity generation. They include natural gas (42%), coal (9%), and oil (1%) based on DECC 2016 figures (full figures for 2017 were not available at the time of writing). Nuclear power generation accounts for 21% of UK electricity and is generated from fifteen nuclear power reactors, but this is planned to be halved by 2025 as reactors reach end-of-life.

Renewable Energy

Renewable energy is generally defined as energy that is generated from resources which are naturally replenished at a faster rate than they are consumed. Sources include sunlight (solar), wind, tidal, waves, geothermal and biomass. The contribution from renewables to the UK's final energy consumption increased from ~2% in 1990 to 8% in 2015. There was also a significant year on year increase in renewable electricity (up 29%) between 2014 and 2015 (BEIS, 2016) and renewable heating, although renewable transport contributions fell slightly in 2015. Figure 2-1 below shows the use of renewable energy for heat, electricity and transport.

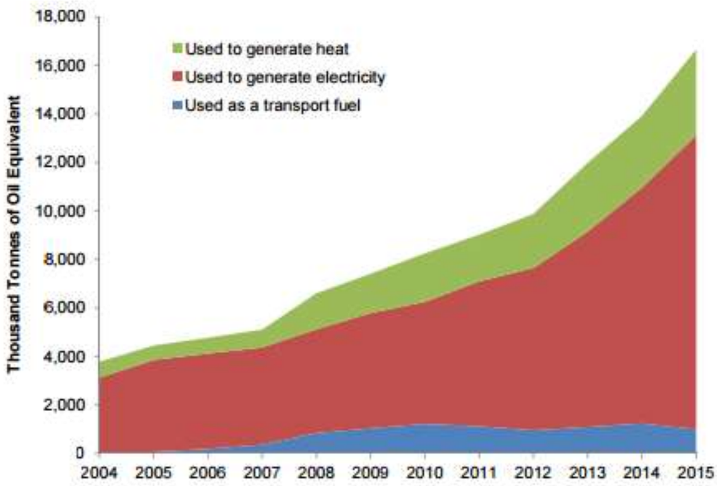

Figure 2-1 Trends in the Use of Renewable Energy[14]

The UK electricity network is connected to systems in France, the Netherlands and Ireland via interconnectors. The UK uses these to import or export electricity when it is most economical. In 2015, the UK was a net importer from France and the Netherlands with net imports of 13.8 TWh and 8.0 TWh respectively. Total net exports to Ireland amounted to 0.9 TWh.

2.3 The UK Electricity Network

2.3.1 Transmission Network

There are four high voltage transmission networks in the UK enabling the bulk transfer of high voltage electricity from power stations to the regions. They are divided into the four regions shown in the national electricity transmission Map (see Figure 2-2 below), the assets for each region are also detailed in Table 2-1 below. The Moyle interconnection which links the electricity grids of Northern Ireland and Scotland through submarine cables is owned and operated by Mutual Energy.

[14] Department of Energy & Climate Change – UK Energy Statistics Q1 2016

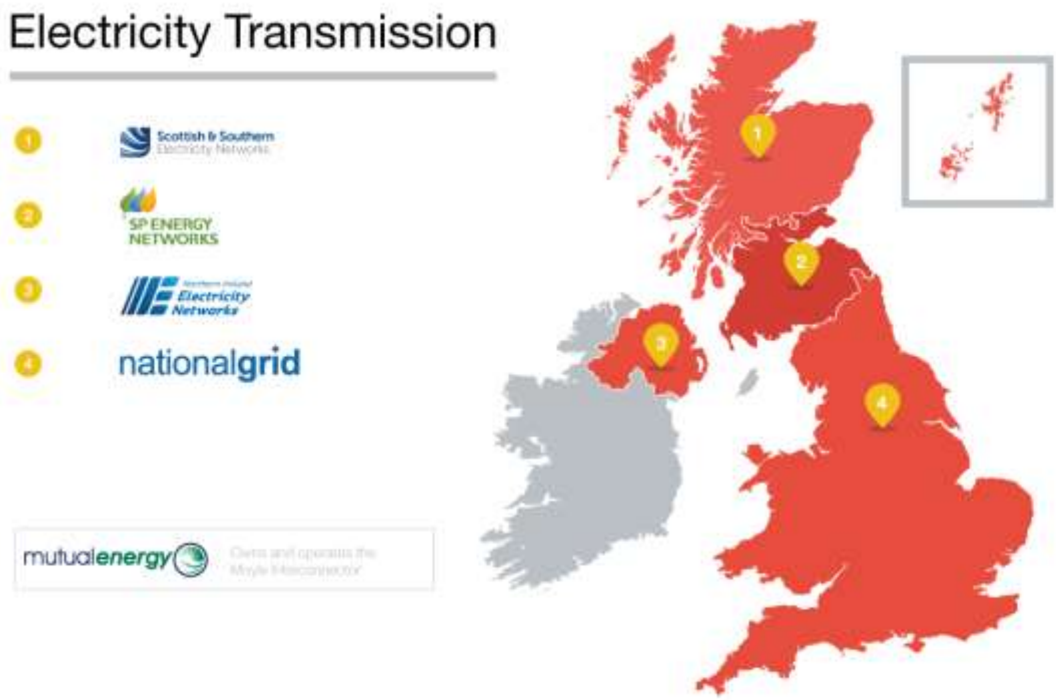

Figure 2-2 UK Electricity Transmission (©Energy Networks Association)

Table 2-1 UK Electricity Transmission Data (ND = No data)

Network operator	Region	Overhead line (km)	Underground cable (km)	HV substations
National Grid	England and Wales	7,200	1,500	338
SP Transmission PLC - SP Energy Networks	Central and Southern Scotland	4,000	320	32
Northern Ireland Electricity	Northern Ireland	22,000	ND	ND
Scottish Hydro Electric SHE Transmission PLC	North of Scotland	5,000	ND	ND

2.3.2 Distribution Networks

The electricity distribution networks are regional grids that transport the electricity branch from the transmission networks to deliver power for industrial, commercial and domestic users. The regional Distribution Network Operators (DNOs) are shown in the Figure 2-3, together with those of independent distribution network operators. There are ten Electricity Distribution Networks throughout the UK with corresponding asset information presented in Table 2-2 UK Electricity Distribution (ND = No data). Some local electricity distribution networks are managed by Independent Distribution Network Operators (IDNOs), for example GTC, and directly or indirectly connected to the DNO networks.

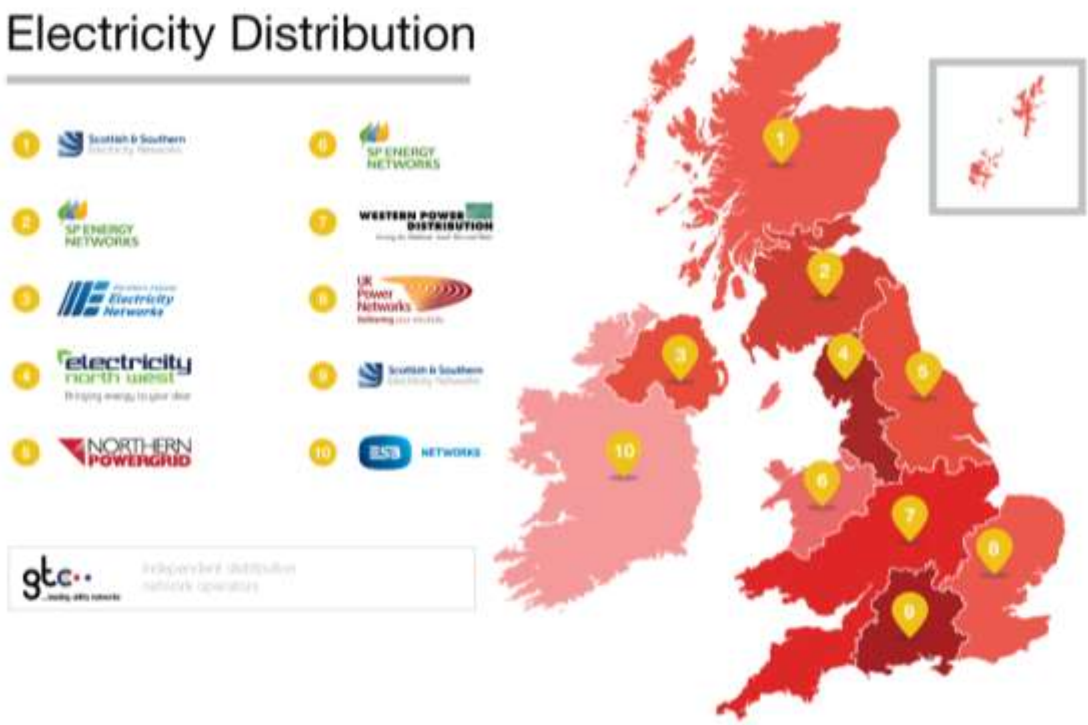

Figure 2-3 UK Electricity Distribution (©Energy Networks Association)

Table 2-2 UK Electricity Distribution (ND = No data)

Network operator	Region	overhead line (km)	Under-ground cable(km)	HV substations
Electricity North West	North West	13,000	44,000	ND
Northern Ireland Electricity Networks	Northern Ireland	47,000		300
Northern Powergrid	Northeast, Yorkshire and North Lincolnshire	94,000		60,000
SP Energy Networks:	North Wales, Scottish Borders and Dumfries & Galloway	40,000	65,000	30,000
Scottish and Southern Energy (SSE) Power Distribution	North of Scotland and Central Southern England	130,000		106,000
UK Power Networks:	London, the South East and East of England	4,000	138,000	100,000
Western Power Distribution	Midlands, South Wales and the South West.	91,000	132,000	185,700

2.4 The UK Gas Network

2.4.1 Gas Transmission

The UK's Gas system extends to approximately 280,000 kilometers and it is managed by National Grid (England, Wales & Scotland) and Mutual Energy (Northern Ireland). The network comprises high (12,000km), medium (35,000km) and low (233,000km) pressure networks.

The national grid's high-pressure gas network extends to approximately 7,660 kilometres (4,760 miles) with 24 strategically located compressor stations and is the nation's only transmission system, being a regulated monopoly. In 2015 / 2016, the network transported more than 80 billion cubic metres of gas which generated greenhouse gas emissions of 7.3 million metric tonnes carbon dioxide equivalent (CDE).

The National Grid PLC's annual report[15] (2015 / 2016) includes a key performance indicator (KPI) target to reduce greenhouse gas emissions by 45% by 2020 and 80% by 2050, compared with a 1990 emissions figure of 19.6 million tonnes. GTC are also identified as a nationwide Independent Gas Transporter (IGT).

There are eight gas distribution networks (GDN) in the UK, as illustrated in the figure below, with corresponding asset information provided in Table 2-3. Newcastle's gas distribution network is operated by Northern Gas Networks.

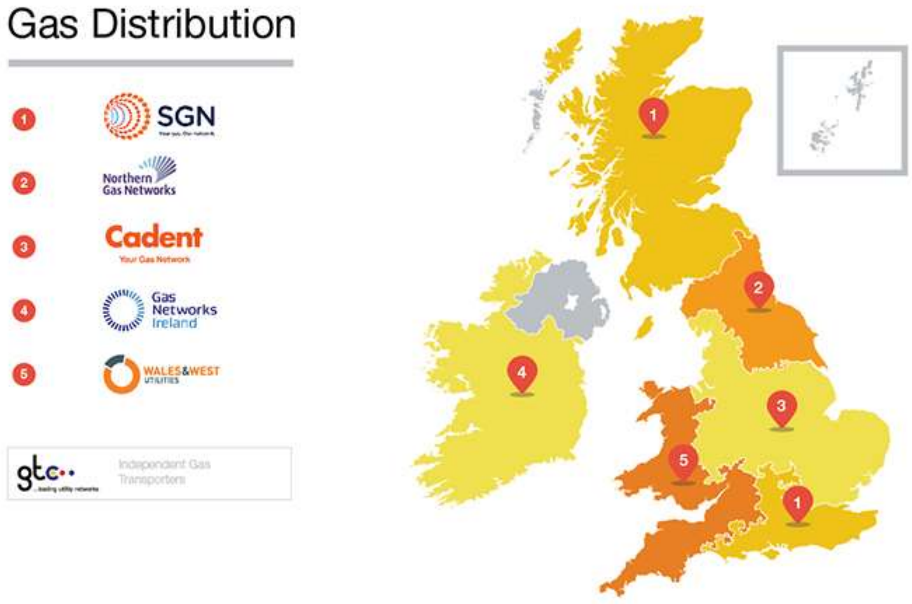

Figure 2-4 UK Gas Distribution (©Energy Networks Association)

[15] The National Grid PLC Annual Report -2015 / 2016

Table 2-3 UK Gas Distribution

Network	Network extent (km)
National Grid:	131,000
Northern Gas Networks	37,000
SGN	74,000
Wales & West Utilities	35,000

2.5 The Local Energy System

This section summarises the current Local Energy System as represented within EnergyPath Networks.

2.5.1 Local Electricity Distribution Network

Northern Powergrid's network distributes power to some eight million people and 3.9 million homes and businesses throughout the North East of England, Yorkshire and North Lincolnshire. Of these 127,000 domestic buildings and 19,000 non-domestic buildings are in Newcastle. The network comprises 94,000 km of overhead power lines and underground cables and 60,000 substations. Figure 2-5 shows the 17 Northern Powergrid's High Voltage (HV) substations that have been assessed. Figure 2-6 shows the 769 Low Voltage (LV) secondary substations modelled within EnergyPath Networks[16]. The location of the High Voltage substations is important to the EnergyPath Networks analysis, as described in Section 3.8 Modelling Areas.

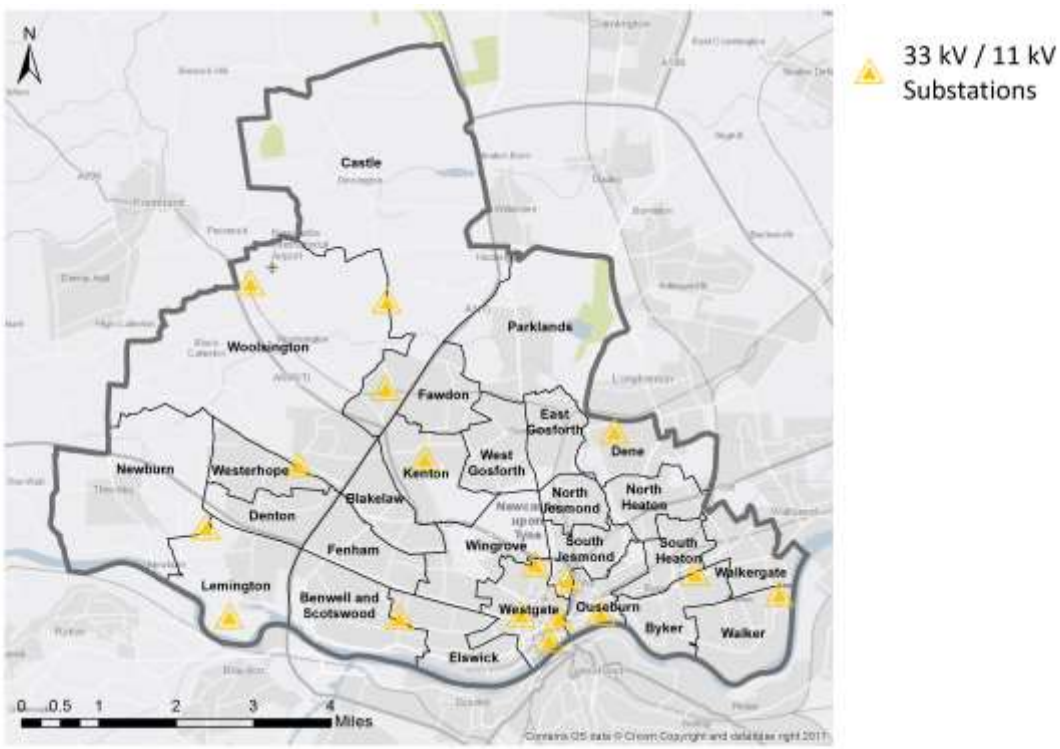

Figure 2-5 Northern Powergrid's HV Substations in Newcastle

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

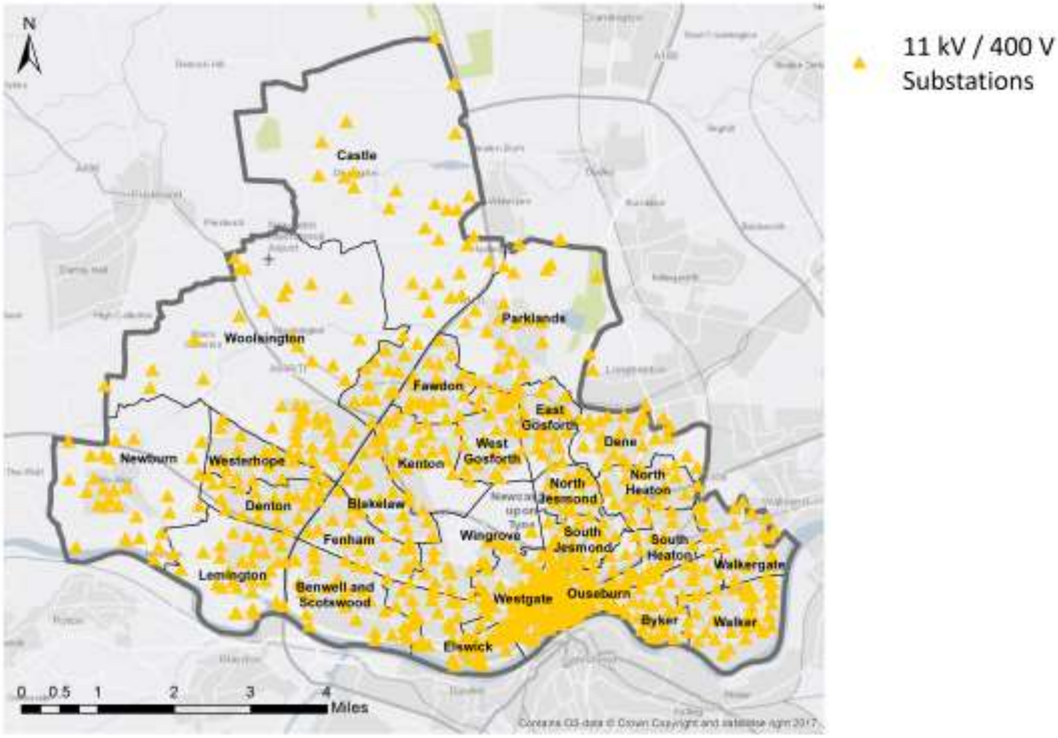

Figure 2-6 Northern Powergrid's LV Secondary Substations in Newcastle

2.5.2 Local Gas Network

The Northern Gas Network currently distributes gas to 5.5 million people and 2.7 million homes throughout the North East, Northern Cumbria and much of Yorkshire and North Lincolnshire. In Newcastle 117,000 homes are supplied. The gas network consists of more than 37,000 km of pipelines.

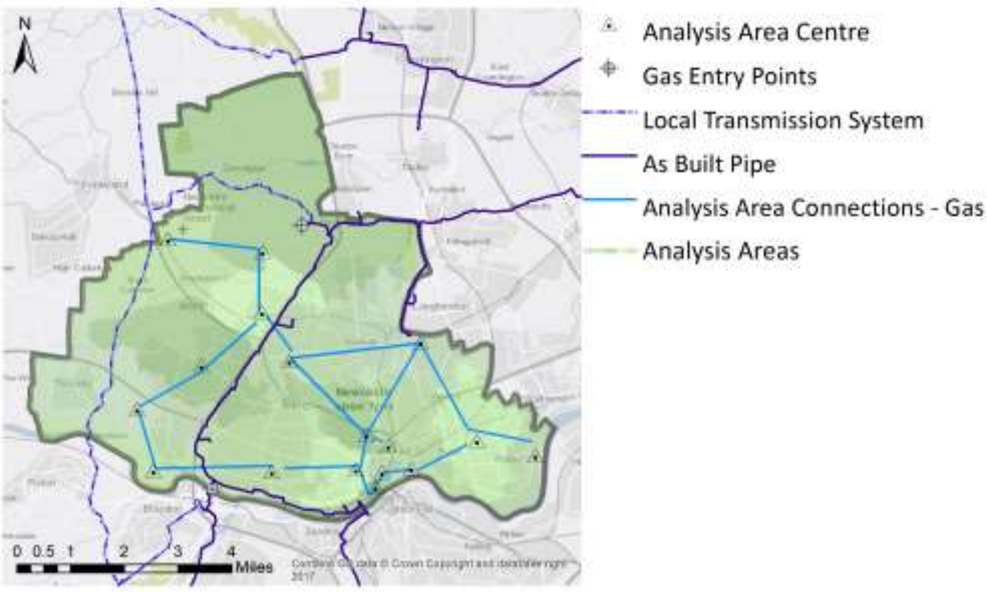

Figure 2-7 Gas Network Representation as Modelled in EnergyPath Networks

A gas network which is sized to meet current demand levels is simulated in EnergyPath Networks, shown in Figure 2-7. There is an underlying assumption within the EPN modelling that the present-day capacity of the network is large enough to meet all future demand[17]. In the Newcastle EnergyPath Network analysis, gas network components can be decommissioned or extended to cover off-gas areas.

2.5.3 Local District Heat Network

Newcastle already has established district heat networks. There are currently four energy centres at Scotswood, Riverside Dene, Byker and Royal Victoria Infirmary as shown in Figure 2-. Newcastle therefore has an advantage in transitioning to district heating (where appropriate) as the technology and its deployment is familiar.

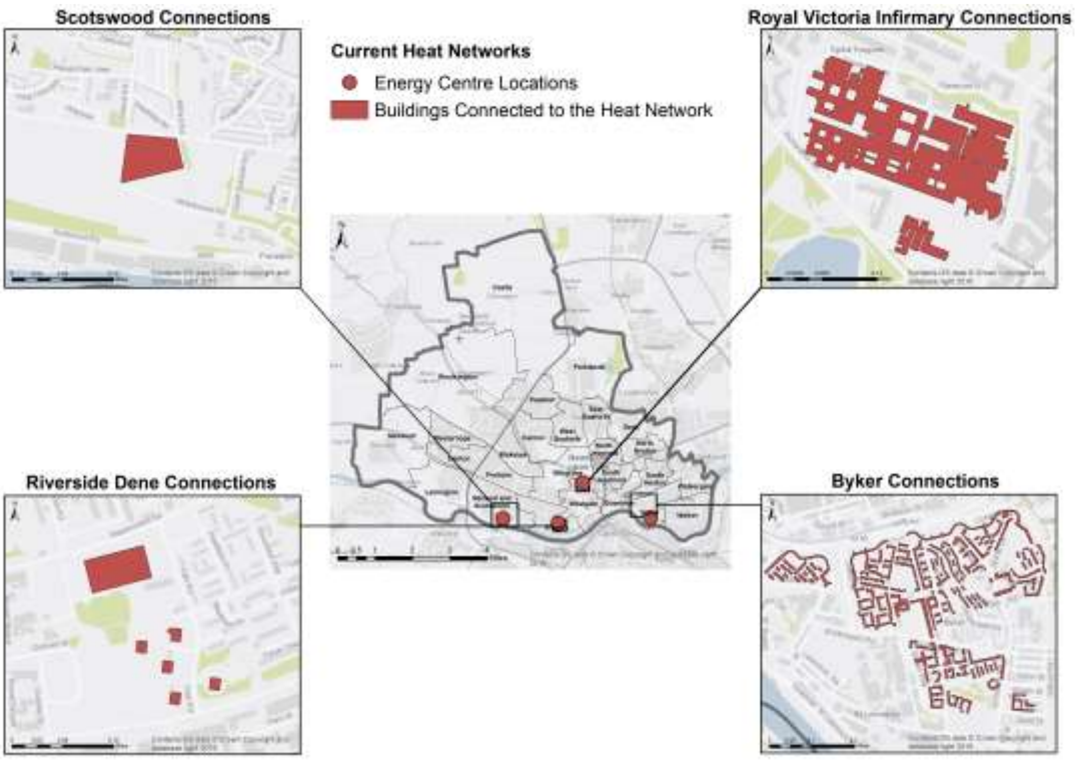

Figure 2-8 Newcastle's Existing District Heat Network (DHN).

[17] Based on using natural gas.

2.5.4 Planned Growth

Understanding future growth in Newcastle is important as it will lead to increasing energy demand arising from heating and electricity use in new homes and buildings. Figure 2-9 below illustrates Newcastle's proposed domestic new build locations that have been assessed within EnergyPath Networks. Table 2-4 below provides a breakdown of the proposed domestic new build's that have been assessed. As a proportion of the total assumed 2020 Business-as-usual energy demand assessed within EnergyPath Networks, the additional estimated domestic demand is not significant in the case of gas demand (circa 3%) and electricity demand (circa 2.5%). However approximately 24% of assumed heat demand (heat network) is attributed to Newcastle's proposed new homes, the locations modelled to connect to heat networks are shown in Figure 2-10.

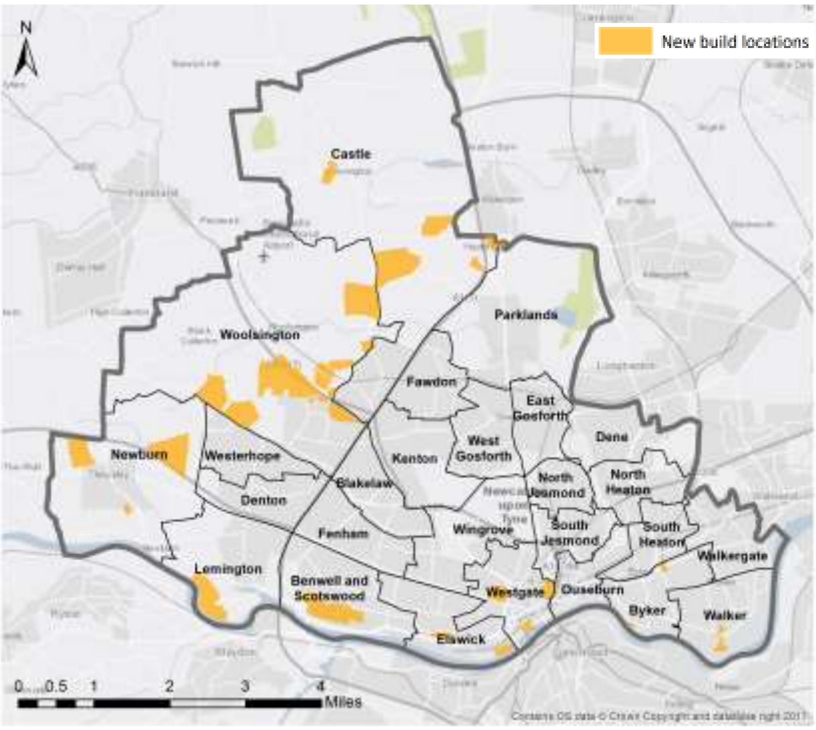

Figure 2-9 Newcastle's Proposed New Build Locations

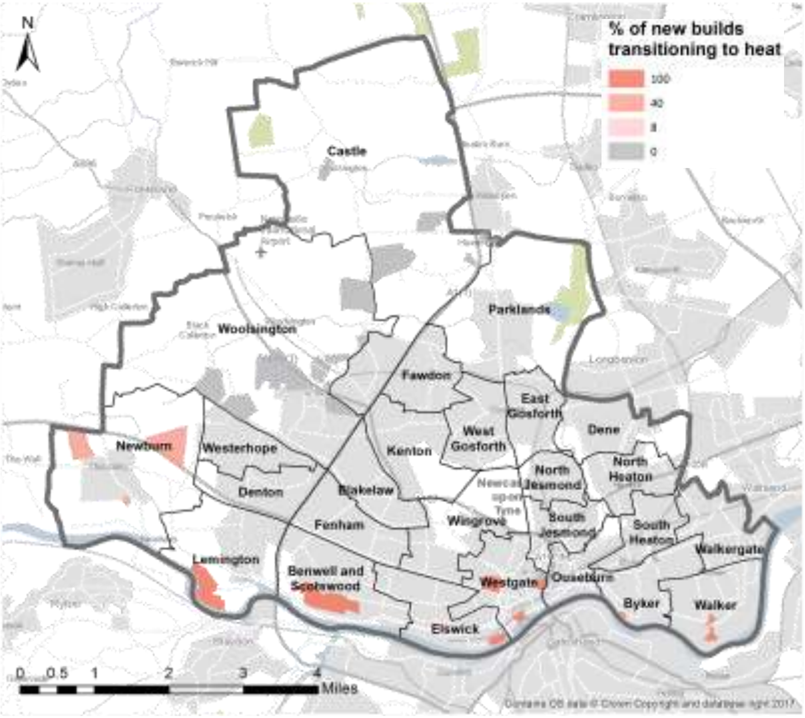

Figure 2-10 New Build Location Modelled to Connect to Heat Networks

Newcastle'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. Whilst new developments will use less energy than a similar existing building, their inclusion within 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 new buildings are assumed to still be built with carbon intensive heating systems), however building fabric improvement would not be a focus for these buildings.

Table 2-4 Breakdown of Proposed Domestic New-Build Homes

	Studio Flat	1 Bed Flat	2 Bed Flat	3 Bed Flat	Bed House	3 Bed House (Medium)	3 Bed House (Large)	4 Bed House	2 Bed Bung-alow	Total	Build Period
Benwell & Scotswood	0	28	96	0	254	41	690	184	7	**1300**	2015 – 2030
Byker	0	20	40	6	16	74	18	18	8	**200**	2018 – 2026
Dinnington	2	19	38	6	35	63	50	31	6	**250**	2017 – 2022
Elswick	6	59	114	13	40	76	16	16	16	**356**	2021 - 2026
Hazlerigg/ Wideopen	5	37	75	13	70	125	100	63	12	**500**	2018 – 2029
Kingston Park/ Kenton Bank Foot	8	60	120	20	112	200	160	100	20	**800**	2017 – 2028
New Biggin Hall	3	22	45	8	42	75	60	38	7	**300**	2017 – 2025
Newcastle Great Park	6	45	140	15	191	308	277	233	15	**1230**	2019 – 2029
Throckley	5	41	82	14	77	138	110	69	14	**550**	2017 – 2030
Walker	0	14	55	0	115	221	190	84	37	**716**	2015 – 2030
Newburn	0	0	50	0	50	175	50	150	25	**500**	2024 – 2030
Upper Callerton	12	90	180	30	168	300	240	150	30	**1200**	2018 – 2030
Middle Callerton	10	75	150	25	140	250	200	125	25	**1000**	2017 – 2030
Lower Callerton	8	60	120	20	112	200	160	100	20	**800**	2017 – 2030
Science Central	0	67	106	34	43	100	0	0	0	**350**	2015 – 2024
East Pilgrim Street	8	57	114	19	107	191	152	95	19	**762**	2020 – 2029
Stephenson Quarter	28	210	450	75	0	0	0	0	0	**763**	2015 - 2029
Overall Proportions	**0.9%**	**7.8%**	**17.0%**	**2.6%**	**13.6%**	**21.9%**	**21.4%**	**12.6%**	**2.2%**		

3 EnergyPath Networks Modelling Approach

This Chapter describes the EnergyPath Networks modelling approach used to inform the investigation of future local energy scenarios and develop a Local Area Energy Strategy for Newcastle. It explains the level of data and inputs that are created on a building-by-building level of data granularity, along with the process EnergyPath Networks uses to assess the data through its Decision Module. The Decision Module compares decarbonisation option combinations (scenarios) and selects the set that meets the set CO_2 emissions target at minimum total cost.

EnergyPath Networks runs multiple scenarios and involves detailed sensitivity analysis, generating repeated decarbonisation themes that are prevalent across all scenarios. The same solutions are either highlighted as the lowest cost decarbonisation measure, or there is enough confidence to determine that the theme should be investigated through further development & demonstration, data gathering & systems analysis and research activities. This results in the identification of decarbonisation themes that are discussed further in the accompanying Strategy.

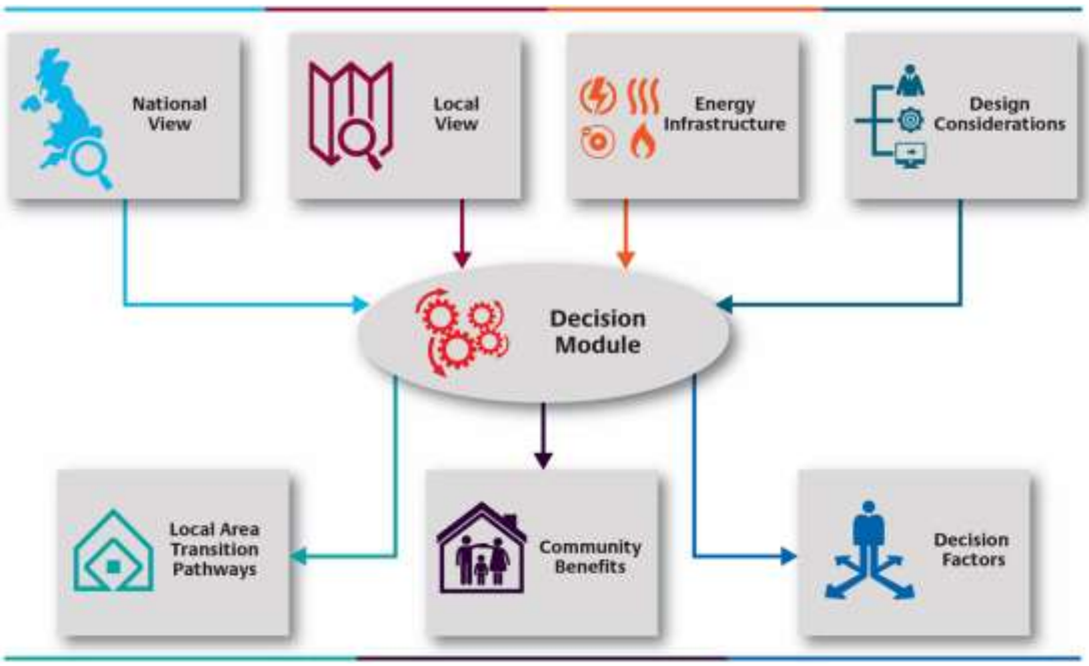

Figure 3-1 Overview of EnergyPath Networks

Background information for the low and zero carbon technology options assessed within EnergyPath Networks is provided in Appendix A.

3.1 Overview

EnergyPath Networks is a whole system optimisation analysis framework. It uses optimisation techniques and a decision module to compare a large number of combinations of options (tens 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. They include:

- Integration and trade-off between gas, heat and power energy vectors.
- Integration through the energy supply chain from building, upgrading or decommissioning assets (production, conversion 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.
- Creation of specific local energy transition options for potential progression, whilst providing a view out to 2050 to ensure long-term resilience in near-term decisions and hence mitigate the risks of stranded assets.
- Spatial granularity up to a few thousand dwellings level (potentially finer where required).
- Temporal resolution to decades up to 2050.

Figure 3-2 to Figure 3-5 below illustrate national, local, energy infrastructure and design considerations assessed for various configurations in the EnergyPath Networks analysis.

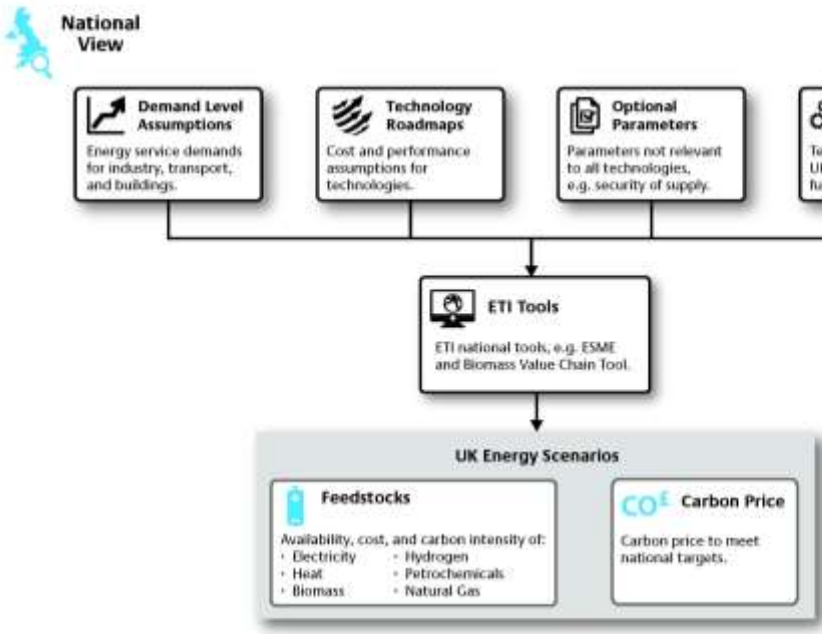

Figure 3-2 National Considerations

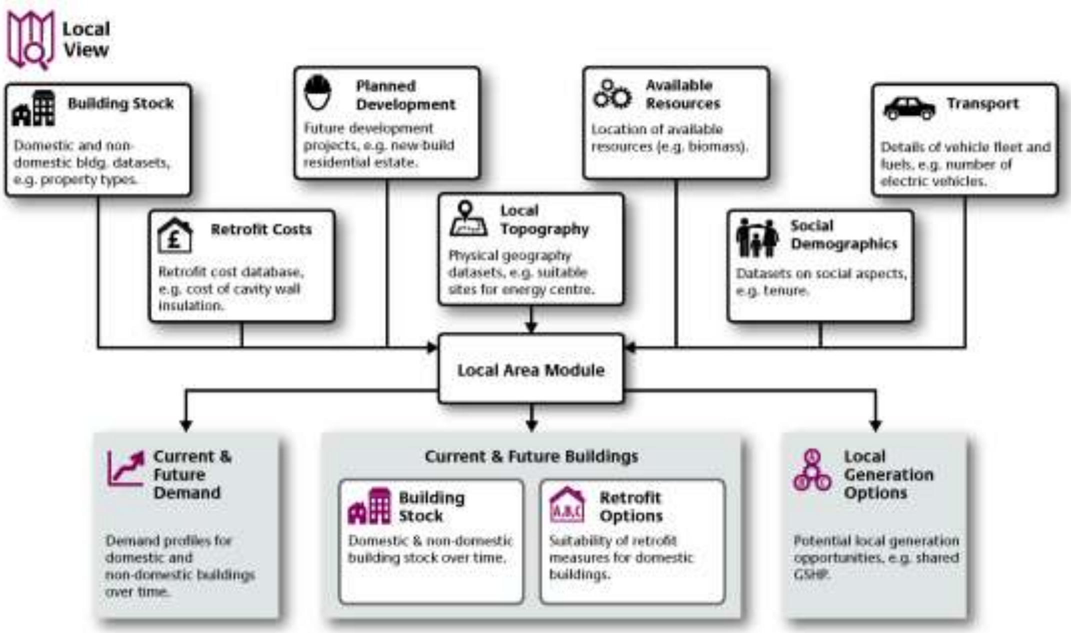

Figure 3-3 Local Considerations

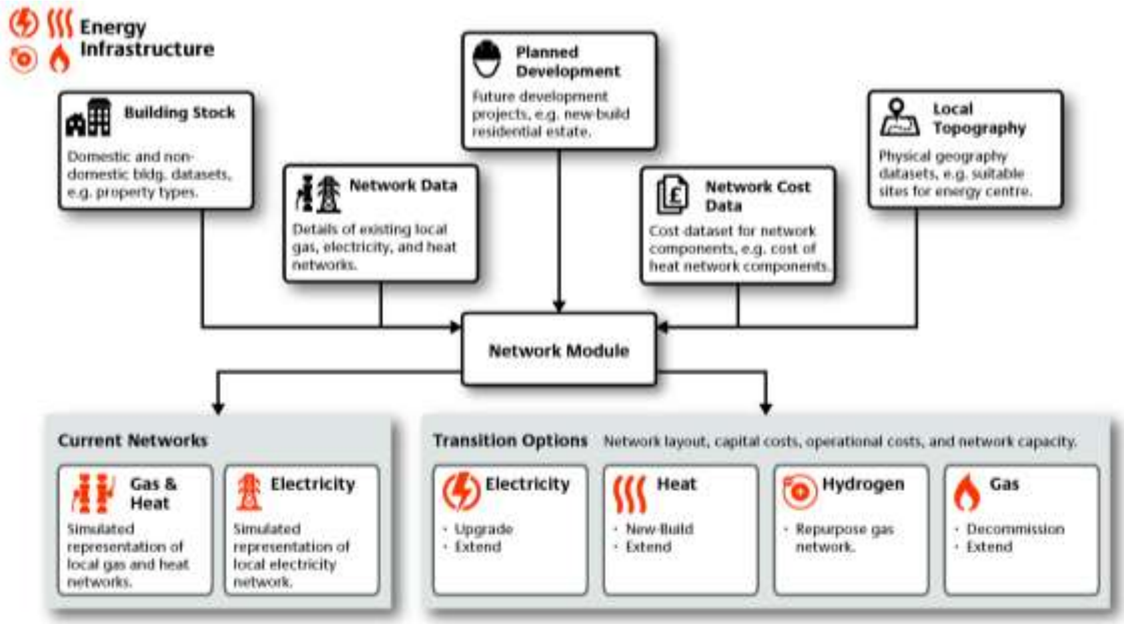

Figure 3-4 Energy Infrastructure Considerations

Figure 3-5 Design Considerations

3.2 Data

EnergyPath Networks requires input data for the local buildings and energy networks assessed within the study area. Primary sources of data on building types, condition and thermal properties are shown in Table 3.1. Primary sources of gas and electricity network data, such as network configuration, topography and heat networks, are shown in Table 3.2. The data are used subject to copyright and licence conditions listed in Appendix B.

Table 3-1 Primary Data Sources used in EnergyPath Networks Study of Newcastle - Buildings

Building Data		
Item	**Primary Data Sets**	**Year Published**
Domestic building archetype	Geo Information building classification - Ordnance Survey address base	2015
Domestic building thermal properties	Buildings Research Establishment: Standard Assessment Procedure calculator	SAP 2012
Domestic building current condition	English Housing Survey - Local Authority Data	2012
Domestic appliance use profiles	DECC household electricity survey	2013
Domestic retrofit costs	Energy Technologies Institute data	2012
Domestic heating system prices	DECC inputs into domestic RHI	2012
EV charging profiles	National Travel Survey analysis	Analysis 2015. Based on 2003 – 2010 data
Non-domestic building use class	Valuation office agency Ordnance Survey Geo Information building classification	2010 2016 2015
Non-domestic building energy profile	UCL CARB2 data CIBSE energy benchmarks	2012 2008

Table 3-2 Primary Data Sources used in EnergyPath Networks Study of Newcastle – Networks

Network Data	
Item	Primary Data Sets
Electricity network: current configuration	Distribution Network Operator (Northern Powergrid)
Gas network current configuration	Gas Network Operator (Northern Gas Networks). – Xoserve
Topography – building locations, building heights and existing road network	Ordnance Survey
Heat networks	Newcastle City Council
Electricity network costs	Distribution Network Operator (Northern Powergrid)
Electricity network technical parameters	Distribution Network Operator (Northern Powergrid)

Gas network costs	Energy Technologies Institute infrastructure database
Heat network costs	Energy Technologies Institute infrastructure database. ARUP
Heat Network technical parameters	ARUP
Energy Centre costs	Energy Technologies Institute data
Energy Centre technical parameters	Energy Technologies Institute data

3.3 Model Data Verification

Newcastle was originally a Roman settlement and retains much of its medieval street pattern. The energy networks and other infrastructure reflect this layout and a large-scale upgrade of this infrastructure will be challenging, as would be the case in any city where areas are already congested with existing infrastructure and utilities. This increases the cost and complexity of providing new infrastructure.

EnergyPath Networks relies on good data and information on the built environment and existing energy systems and infrastructure to help produce a realistic model which reflects existing energy systems, energy use and physical constraints for technology deployment. To verify physical asset data, engineering consultants ARUP (Ove Arup and Partners) were commissioned to consider specific areas/decarbonisation options and assess their feasibility as potential transition options, focusing on:

- Consideration of options including heat pump retrofit, hot water storage solutions and building fabric retrofit
- Consideration of area-wide development of district heat networks and energy centres
- Assessing district heat network routing and connection feasibility to areas of existing terraced housing
- Assessing district heat network routing feasibility specifically to areas of existing social housing
- Identification of general constraints associated with the provision of Ground Source Heat Pumps (GSHPs), heat networks and biomass boilers to different housing archetypes

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

3.4 Domestic Buildings

Domestic and non-domestic buildings are handled 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 rate of heat loss 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 3.3. The new-build category is based on the minimum efficiency level required by current building regulations. There are ten modelled property types, shown in Table 3-4. This allows more than 50 different age and property type combinations which are used to define the thermal characteristics of existing and planned domestic buildings.

Table 3-3 Domestic Building Age Bands

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

Table 3-4 Domestic Building Types

Property Type
Converted Flat: - Mid Floor / End Terrace
Converted flat: - Mid Floor / Mid Terrace
Converted Flat: - Ground / Top Floor / End Terrace
Converted Flat: - Ground / Top Floor / Mid Terrace
Detached
End Terrace
Mid Terrace
Purpose-Built Flat: - Mid Floor
Purpose-Built Flat: - Ground / Top Floor
Semi-detached

3.4.1 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.

Data from the English Housing Survey is used to modify these basic construction standards based on knowledge of the level of retrofit which has typically been applied to different property types. For example, if 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 will be categorised as having this measure applied. A similar process is used to define whether buildings have single or double-glazing and the level of loft insulation present. Rather than using assumptions in all cases, information supplied by Newcastle City Council on measures which have been applied to specific buildings under various energy efficiency schemes has been prioritised where available.

The Retrofit measures considered in the study are shown in Table 3-5.

Table 3-5 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[18]
New build upgrade to High Thermal Efficiency
Reduced infiltration 1 (Draught proofing)
Reduced infiltration 2 (Whole dwelling)
Triple glazing

Additional information regarding the housing stock assessed in EPN is provided in Appendix C.

3.4.2 Current Heating Systems

The definition of current heating systems is handled in a similar way to the definition of the building fabric. Xoserve data was used to identify which buildings are not connected to the gas grid. English Housing Survey data was then used to define heating systems based on the most likely heating system combinations within each archetype group. Data from Newcastle City Council was added where the actual heating system in individual buildings is known. Once the current thermal efficiency of a building had been defined the Ordnance Survey *MasterMap* data

[18] 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

was then 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[19]. SAP calculations have been used to calculate the overall heat loss rate and thermal mass of every domestic building in the study area. It is also possible to define all possible future pathways for each building. These pathways include potential to install different 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.

3.4.3 Future Heating Systems

Possible current and future heating system combinations are shown in Table 3-6. 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 – typically either not present or a hot water tank.

Table 3-6 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
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	None	None

[19] 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)

Ground Source Heat Pump	None	200 litre water tank
Ground Source Heat Pump	None	400 litre water tank
District Heat Network	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

Once future pathway scenarios have been defined for different buildings a series of mathematical models of them are built which include both the current and possible future levels of retrofit and heating system combinations. For each pathway scenario assessed the energy demand can be calculated for heat (from heat networks), gas and electricity as required to meet a pre-defined target temperature profile.

3.5 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 its thermal performance. Due to these limitations, an energy benchmarking[20] approach is used to establish the energy demand of the non-domestic stock using established benchmarks. 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 9 different characteristic days shown in Table 3-7, each of which has a unique energy demand profile to simulate a range of seasonal weather conditions. Benchmarks are defined for current and future use to represent changing energy use over time.

Table 3-7 Characteristic Heat Days

Characteristic Heat Day
Autumn Weekday
Autumn Weekend
Peak Winter
Spring Weekday
Spring Weekend
Summer Weekday

20

Summer Weekend
Winter Weekday
Winter Weekend

The building footprint floor area for each building is calculated from the *OS MasterMap*. The building height from the same source is 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 demand is calculated for each of the characteristic days.

3.6 Energy 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 city, 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 steady-state load flow modelling of networks to establish current and future capacities. The cost of operating and maintaining the networks vary with network capacity and is modelled similarly.

The EnergyPath Networks method does not replace the detailed 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 estimated costs of these impacts can then be calculated and the effects of different options on different networks can be compared.

Northern Powergrid provided data for the current electricity network. The primary data used was the locations and nameplate capacities of the HV (11-33kV) and LV (400V to 11kV) substations. This information was used to synthesise the electricity network by connecting HV to LV substations and LV substations to buildings based on the shortest distances along the road network. Network feeder capacities were then calculated based on the current load on each feeder and a headroom allowance. In addition, the average cost of replacing network assets was also provided by Northern Powergrid and used to establish the cost of reinforcing different parts of the network to different capacities.

Data from Xoserve was used to establish which buildings in the study area are currently connected to the gas grid. Xoserve provide services to the gas industry including management of gas supplier switching and transportation transactional services. The *Xoserve* data was supplemented by information from Northern Gas Networks, 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 position may change if the gas network is used to provide hydrogen in the future.

Newcastle City Council provided details of current heat networks in Byker, Riverside Dene and Scotswood. This included both the heat generation technologies used in the energy centres and details of which buildings are connected to each energy centre. Information was also provided on new heat networks planned for the city at Science Central, the Civic Quarter and the Scotswood extension. This included both the planned heat provision technologies and the buildings which are intended to be connected to each network. Within the EnergyPath Networks model current networks were defined as existing assets and the proposed build of future networks were also defined so that all the planned buildings were connected to the appropriate heat network in 2020.

In addition, the cost of building new heat networks to different capacities in other parts of Newcastle and extending the planned and existing networks to connect more buildings were estimated.

3.7 Spatial Analysis

Through the use of 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 Energy Infrastructure, 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 loads scenarios in different parts of the city and the energy flows between those locations. In addition, an understanding of network lengths and required capacities can be established.

3.8 Modelling Areas

Due to the number of buildings and the complexity of the energy networks within the study area it is not possible to analyse all the options for each building individually when making decisions about future options. The study area is divided into a number of clusters or modelling areas. These modelling areas are defined by the area served by the actual High Voltage substations illustrated in Section 2.5.

These modelling areas are necessary conceptually within the EnergyPath Networks model but do not correspond directly to local districts, wards or neighbourhoods recognised by the Council. Figure 3-6 shows the relationship between ward boundaries[21] and modelling areas.

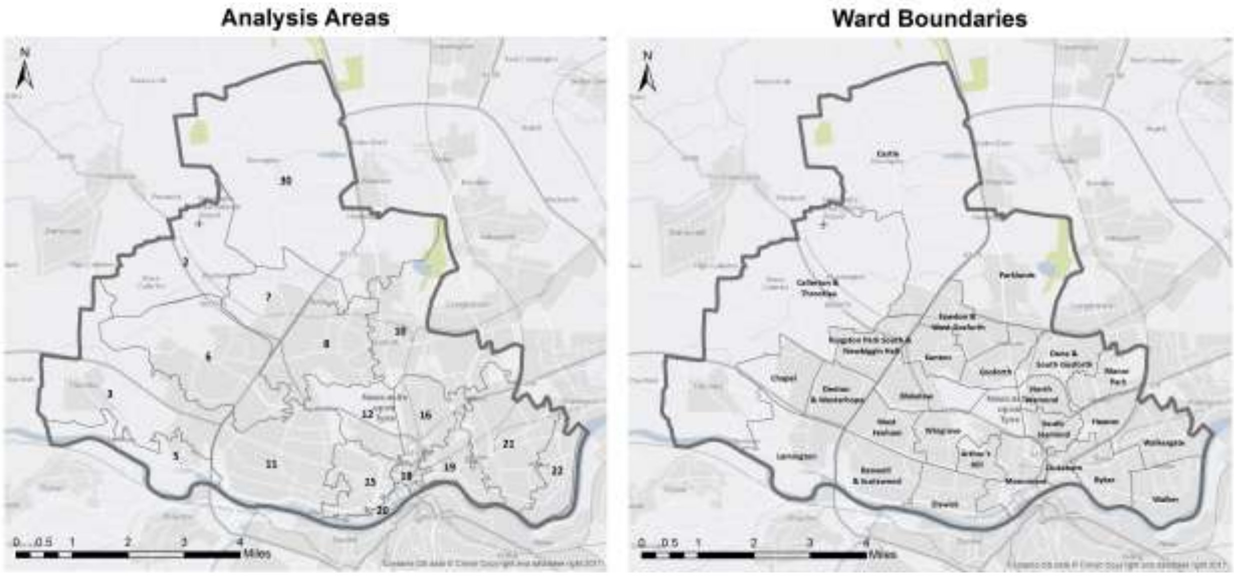

Figure 3-6 EnergyPath Networks Analysis Areas and Newcastle City Council Ward Boundaries (from 2018)

The Need for Aggregation

Within each modelling area, different components of the system are aggregated. For example, scenario combinations regarding retrofit and heating systems for buildings with similar thermal performance and retrofit costs will be made collectively for each area. Similar buildings within an individual study 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 the study 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.

[21] The Ward Boundaries replicate the updated boundaries proposed by the Electoral Review 2016. If accepted, the new electoral arrangements will come into force at the next scheduled elections for Newcastle upon Tyne in 2018.

Boundaries of Study Area

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 city and the entire electricity network downstream of each substation to give the analysis areas discussed above. Once these study areas had been defined energy network links between them were defined. This allows transmission of heat and gas across the study area boundaries

3.8.1 Design Considerations

Within EnergyPath Networks only feasible technical solutions are considered e.g. those listed in Section 3.4.3 including DHN, GS/AS heat pumps, electric resistive, hybrid boilers, domestic storage. Options which are not feasible are excluded, for example, fitting a ground source heat pump and 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 practical in a real-world environment. For example, the selection of ground source heat pumps into areas of dense terraced housing is excluded. A lack of space means that cheaper ground loop systems cannot be fitted whilst there is insufficient access for the equipment required to create 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 requirement for additional top-up heat from an alternative source.

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 re-purposed for other uses which householders find more valuable, maybe as additional storage, or to increase the size of a room.

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; the table in Section 3.4.3 details the maximum size of hot water tank that has been assessed. As such, system options with large accompanying hot water tanks would not be suitable for flats.

In an alternative situation, a Local Council, or Housing Association (a Registered Provider of Social Housing), might be planning a wide scale home improvement programme in a particular area of a city with the objective of tackling fuel poverty. This retrofit programme should be included in the EnergyPath Networks analysis.

It is possible to force or constrain different technology options in EnergyPath Networks for particular building types and geographic areas to reflect these technical, commercial, social and consumer choice considerations; this approach has been used in the analysis where relevant.

3.9 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 in order to limit the complexity of the EnergyPath Networks analysis in order to keep the scale of the analysis being performed at a level that allows for practical analysis.

3.9.1 Fixed Input Parameters

Some parameters are considered as fixed inputs within EnergyPath Networks. They are treated as constant loads, or conforming to a fixed load profile on the energy networks and options to vary them are excluded from the decision module. The following energy demands are modelled as fixed inputs:

- Domestic lighting and appliance demands are based on data from DECC's household electricity survey which gives these demands for different house types.
- Electric vehicle charging profiles are based upon assumed take-up rates[22] 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.
- Current and future non-domestic building demands are calculated based on building use and established energy benchmarks.

3.9.2 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 typically

[22] Analysis has been based on an assumed electric vehicle take-up rate of 65% of homes owning electric vehicles by 2050, as agreed with Newcastle City Council, with charging profiles included based upon this assumed rate and car journeys extracted from the Department for Transport's National

used is based upon the temperature profile 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 particular 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.

Within the Decision Module it is not currently possible to include options for connection of non-domestic buildings to heat networks. Once areas of the city have been identified for heat network development the user can specify which non-domestic buildings should connect to the networks and the dates of connection. For this assessment (in certain scenarios) public sector buildings with notable heat demands were selected to connect to heat networks, where a heat network has been modelled to develop. This limitation may result in decreased deployment of heat networks within EnergyPath Networks because the total potential heat load is not considered within the decision process.

3.9.3 Network Modelling

The network modelling approach is based on the assumption that development of future energy systems should be driven by consumer requirements 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 the influence of some aspects of using demand side response to reduce network loads during times of peak demand.

Electricity and Heat Networks are synthesised where full network connection and capacity data is not available. This means that decisions concerning network reinforcement may be inaccurate where network operators do not provide connection 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 in order to understand the influence of different options on network costs. It is not intended to replace full network modelling conducted by network operators.

The EPN model does not account for electrical reinforcement between the transmission network and 33kV. In addition, it can only consider gas grid commissioning at an analysis area level. This requires an option to have no gas demand in the whole area which is not achievable in the model due to residual non-domestic demand for space and process heat which does not have alternative pathways. Hence it is unable to assess partial decommissioning within an analysis area.

3.9.4 Technology Cost and Performance

EnergyPath Networks attempts to establish the future energy system which will have the lowest cost to society. Critically it assumes that the mechanisms which enable and encourage its implementation will then be developed (as discussed in the LAES). As well as technical parameters, the selected option is determined by the costs associated with different technology options. It is important that cost[23] 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 particular technology when deployed at scale. As an example, cost data sets associated with the domestic renewable heat incentive were used to produce the cost information 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 information might be commercially sensitive, for example CHP plants and heat networks, in which case alternative data sources were 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.

3.9.5 Stakeholder Inputs

The EnergyPath Networks model has been developed in partnership with a project stakeholder group, to benefit from their specific expertise, including Newcastle City Council, Northern Powergrid and Northern Gas Networks, and (more recently) Newcastle University. This group has been involved throughout the process and has been given the opportunity to review:

- The underlying cost data and input assumptions.

[23] Cost is defined as the assumed actual cost of the item, rather than price, as price can be variable dependent on mark up or discounts applied by various providers.

- The modelling process used.
- Setting of the carbon target.
- Outputs from the original Base Run and the sensitivity analyses.
- Decisions based on those outputs that have been used to define inputs for subsequent runs.
- The final Local Area Energy Strategy.

In addition, engineering consultants ARUP[24] 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:

- Definition of the range of pipe sizes that are used to create heat networks and the associated costs of installation.
- Analysis of outputs across wide areas of the city 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.
- Detailed analysis of domestic individual building pathway options to check for technical and practical feasibility and to confirm that estimates of current and future energy use are appropriate.

3.10 Technologies

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

3.10.1 Primary Heating Systems

Different heating systems have been considered within the analysis including current systems and possible future options. Table 3-6 Heating System Combinations (see Section 3.4.3) 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**, the main source of heat for domestic premises in the UK.

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

- **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 the 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** 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 air source heat pump 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.
    - 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 they are not a fully low carbon heat solution in EnergyPath.
- **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 Heat Networks** provide 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 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 provide heat on to lower carbon alternatives such as a large-scale ground source heat pump or a biomass boiler.

3.10.2 Building Retrofit Options

Domestic buildings in the UK have been constructed to a wide variety of building regulations depending on the time when they were constructed. Many older buildings have low levels of insulation and require significantly 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, cavity wall insulation and triple glazing retrofit options are modelled within the EnergyPath Networks model.

3.10.3 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. Where there is no solar generation, hot water is heated using gas or electricity.

3.10.4 Energy Centre Technologies

District heat networks provide 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** 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 Combined Heat and Power** 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 Combined Heat and Power** 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.

3.10.5 Energy Storage

Energy (Heat) storage was considered at two scales:

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

In both cases, it was 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. This frees up useful additional space in the property valued by customers. These consumer preferences are captured in the EnergyPath Networks decision process.

3.11 Carbon Emissions

Calculation of carbon emissions and setting of future targets is complex. This section does not provide full details on the subject but gives a high-level view of the approach used for this study, noting that the Council provides a detailed forecast of emissions in its Climate Change Strategy.

Newcastle City Council has committed to become a 100% Clean Energy City by 2050[25,26] for which emissions associated with buildings need to be as close to zero as possible. The following sources of emissions were included in the EnergyPath Networks model:

- Domestic buildings
- Industrial and commercial emissions (i.e. those related to buildings).

Transport emissions were excluded from the analysis.

The analysis does not include options for non-domestic buildings to change their heating system. Non-domestic energy consumptions were defined by input parameters. Emissions reductions from these buildings were represented by the input parameters and were 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.
- Connection of some buildings to heat networks which convert to low carbon heat sources. The buildings which are forced to connect to heat networks in the model fall into two categories:
    - Those which have been previously identified by Newcastle City Council as expected to connect to heat networks.

[25] Newcastle City Council. Declaration of the Vision
[26] http://democracy.newcastle.gov.uk/ieListDocuments.aspx?CId=857&MId=6011&Ver=4

- Other buildings which are owned and operated by Newcastle City Council within areas where large scale heat networks are to be deployed; and which the council might reasonably be expected to connect to emerging heat networks.

3.11.1 Decision Module

EnergyPath Networks has been used to support the development a Local Area Energy Strategy to help 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* 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 and based on the expected lifetimes of the heating systems). 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[27]. In addition, seventeen different heating system options can be combined with each level of retrofit. Exceptions will be if a new heating system technology is unable to provide sufficient power to meet heat demand in a building with low thermal efficiency that is not subject to retrofit. These combinations mean that some buildings in Newcastle have as many as 257 different future pathways which must be considered

[27] 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).

Buildings are aggregated into ten groups which have similar thermal performance and the study area is divided into sixteen sub-areas, as defined by the High Voltage network as per Figure 2-3 UK Electricity Distribution (©Energy Networks Association)and Figure 3-6 EnergyPath Networks Analysis Areas and Newcastle City Council Ward Boundaries. This generates 16,320 options for domestic buildings (102 building pathways for each of 10 building groupings and 16 analysis areas). New-build, reinforcement and decommissioning of energy networks, and different heat network technologies further increase the number of options in EnergyPath Networks.

4 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 Newcastle, followed by introducing the Base Run created by EnergyPath Networks. The Sensitivity Analysis that was applied to the Base Run to inform the development of Newcastle'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 scenario that has been developed to represent a local do-nothing situation.

4.1 Local Area Representation

A representation of Newcastle's existing local area system has been developed and imported into EnergyPath Networks based on the process described in Chapter 3. It is based on the OS map for the study area and provides the starting point on which to conduct the analysis and investigate possible future local energy scenarios and network choices.

4.2 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 an initial lowest cost transition pathway is produced for discussion with the Key Stakeholder Group which can be used for sensitivity testing. This pathway is checked to ensure that it is broadly feasible and adjusted based on local stakeholder feedback. 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 knowledge and local applicability. The Base Run is also used to identify any gaps in the data or local area representation that need to be updated.

4.3 Business as Usual

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 local decarbonisation measures are implemented. This comparison provides an indication of the benefits of the proposed changes and their associated costs.

Under a business as usual scenario a local area carbon target for the period to 2050 was set to be unchanged from the emissions in 2014. However, the EnergyPath Networks analysis assumes that decarbonisation of electricity generation will occur in parallel being subject to national greenhouse gas emissions reduction targets. This is shown in Figure 4-1. In-scope emissions (see section 3.11) in 2050 are predicted to be 28% of 1990 levels.

When a local carbon target is set, the model outcome results in nearly all properties transitioning away from gas boilers. In contrast, with no local carbon target, most stay on gas boilers because this is generally the lowest cost option. The limited reduction in domestic emissions that occurs is due to some switching of buildings to heat networks and fabric retrofit being undertaken to approximately 8,500 buildings.

Without a local carbon target, the number of properties connected to district heat networks increases from approximately 3,600 in 2014 to circa 11,000, compared to potential scenario with a total of 79,000 when a local carbon target is set. This suggests that some retrofit and connection of some domestic buildings to heat networks are cost-effective options regardless of any emissions reduction requirement, particularly as improving energy efficiency also reduces individual building's energy use.

Increased heat network deployment without a carbon target is likely to be due to economies of scale and improved network utilisation which can reduce the cost of delivered heat to individual customers.

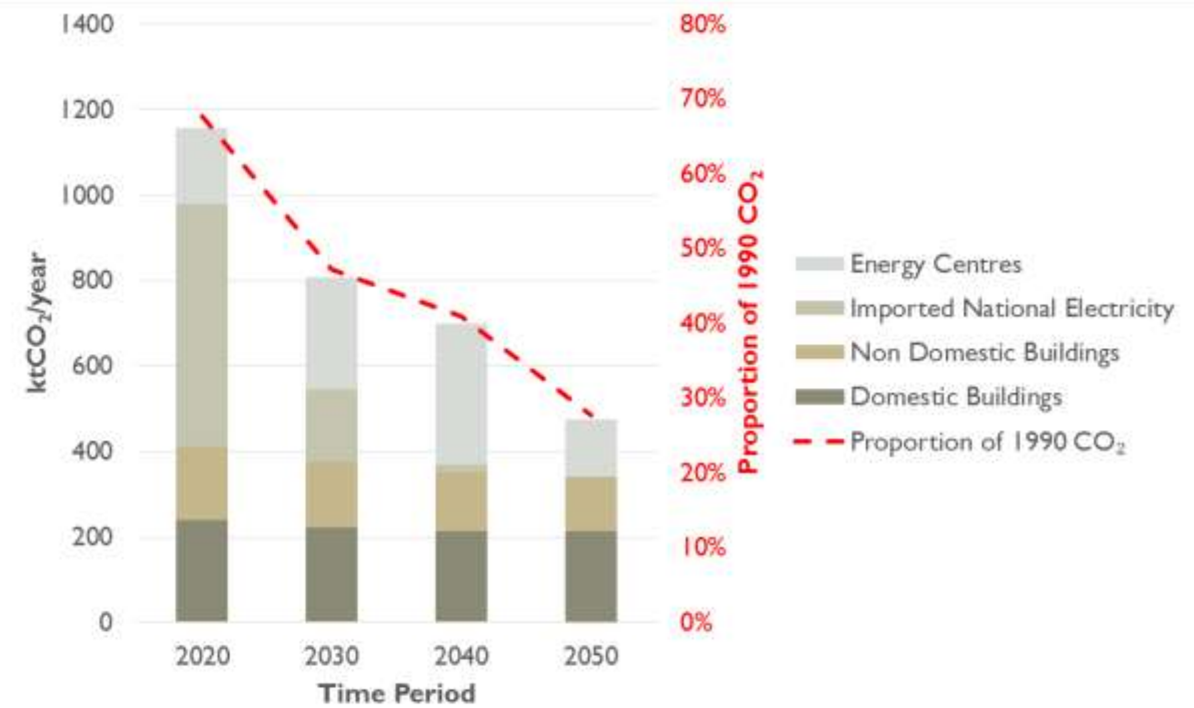


Figure 4-1 Carbon Emissions Projection for the Business as Usual Case

When a local carbon target is set the sources of heat for heat networks are switched from gas powered options to large scale electric heat pumps in order to meet the projected demand in a low carbon way. In contrast, with no local carbon target, gas technologies remain the predominant technology for heat delivery to heat networks. These include combined heat and power units which are used for electricity generation with a significant proportion of the heat produced not initially being utilised, where the model is working on the assumption of the plant operating on an electrically led basis to maximise the economic benefit. The target indicates that the costs of imported low carbon electricity are likely to be higher than locally generated electricity produced using gas-powered technologies. Even with a local carbon target installed gas fired combined heat and power systems are operated to generate electricity and some of the generated heat is not utilised. This indicates that local, community energy schemes are likely to be of value at a wide range of local carbon emission scenarios.

Figure 4-2 and Figure 4-3 show electricity and heat production from energy centres with and without a local carbon target. They indicate that electricity dominates heat production if a business as usual (no carbon target) is maintained (Figure 4-2), and a large uptake in the quantity of heat used once a local carbon target is imposed (Figure 4-3).

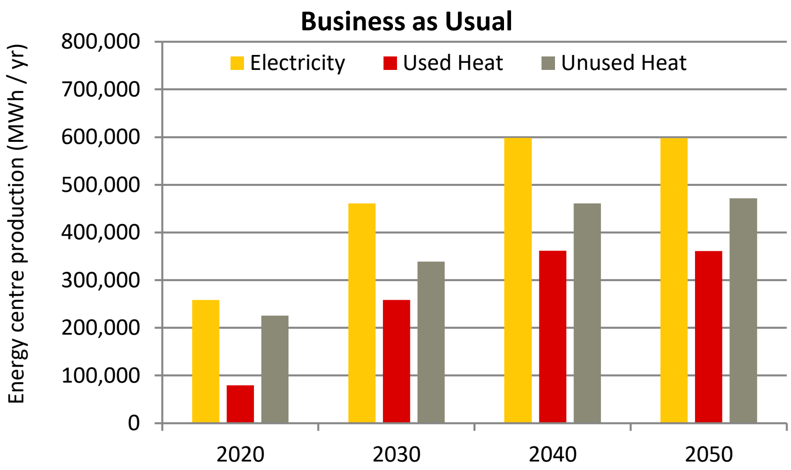


Figure 4-2 Electricity & Heat Production from Energy Centres with no Local Carbon Target

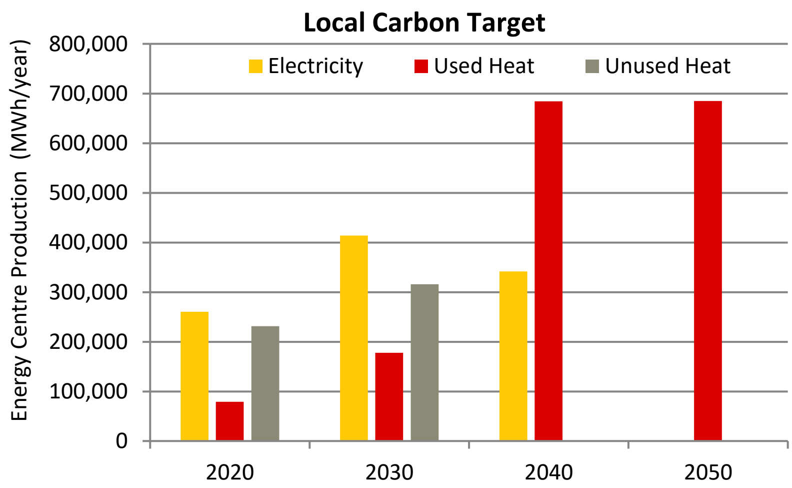


Figure 4-3 Electricity & Heat Production from Energy Centres with a Local Carbon Target

EnergyPath Networks outputs show that increased electricity network capacity is likely to be required in Newcastle regardless of any local carbon target. Without a local carbon target, total network capacity (11kV and 400V) is predicted to require around 20% more capacity by 2050. This is mainly due to increased loads from the non-domestic sector. With a local carbon target capacity in these parts of the network is predicted to require a further 10% more capacity to account for the switch of domestic buildings to electric heating systems and the use of large scale heat pumps in energy centres.

Key Points from the Business as Usual Scenario

- A significant reduction in local carbon emissions could be achieved without the requirement to set a local carbon target if national government achieves its goals and successfully decarbonises national electricity generation. However, this would not enable Newcastle's 100% clean energy ambition.
- Gas boilers can be expected to remain the predominant heating system in domestic buildings if there is no requirement to reduce local carbon emissions.
- Expansion of the existing and planned heat networks and some level of building fabric retrofit appear to have an economic case regardless of a requirement to reduce carbon emissions from buildings.
- Local electricity generation could have a place in Newcastle's energy system whether or not a local carbon target is set.
- Electricity network reinforcement is likely to be required in Newcastle to support increasing demand from non-domestic buildings regardless of whether heat supply to domestic buildings is electrified.
- The total additional cost (over this BAU scenario) between 2015 and 2050 is estimated to be around £1.2-£1.4b when compared to the two scenarios to achieve a 91% emission reduction discussed in the LAES. Noting that not all costs would be met by Newcastle's population.

4.4 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 Newcastle 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 following areas:

- National (Decarbonisation) Pathways
- Energy Cost
- Technology Cost
- Heat Storage Times (Availability)
- Heat Storage Capacity
- Advanced Retrofit
- Energy from Waste
- Forced Solar Electricity Generation
- Restricted Biomass

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 Final Run model.

4.5 National Pathway Sensitivity

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 co-ordination. 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 Newcastle.

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[28]. Using this model, the ETI have looked at two different future scenarios for the UK energy system, Clockwork and Patchwork[29], which have been used as national pathway scenarios for assessment in EnergyPath Networks in the Newcastle study.

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 city level. Cities and regions compete for central support to meet energy needs tailored to local conditions.

The primary differences between these two scenarios, as illustrated in Figure 4-4 in terms of their influence on the inputs to EnergyPath Networks are:

- Nationally generated electricity has a higher carbon content in Patchwork, especially in 2020.
- National electricity prices are lower in 2020 and higher in 2040 and 2050 in the Patchwork scenario.
- Biomass prices are lower in 2050 in Patchwork.

The Patchwork scenario results also show:

- More biomass boiler installations from 2035 onwards.
- More low temperature Air Source Heat Pumps (ASHP) in the 2020 and 2030 time periods but less in the later time periods.
- Fewer Ground Source Heat Pumps (GSHP) in the 2040 and 2050 time periods.

This is driven by the electricity and biomass prices in the Patchwork scenario. Higher electricity prices in later time periods lead to non-electric heating systems being installed in preference to

[28] See http://www.eti.co.uk/modelling-low-carbon-energy-system-designs-with-the-eti-esme-model/
[29] 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/)

heat pumps. The price of biomass is significantly less in the Patchwork scenario in 2050, which drives extra biomass boiler installations.

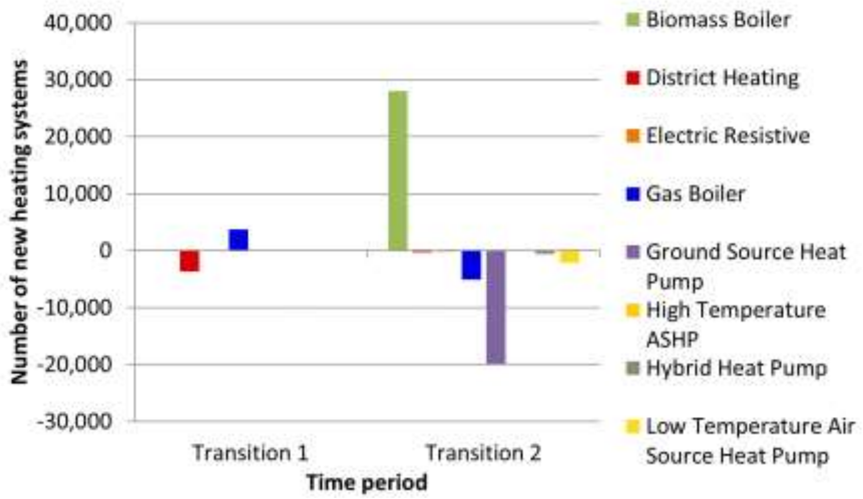


Figure 4-4 Difference in the Numbers of Heating Systems Installed between the Clockwork & Patchwork Scenarios (positive numbers show increased deployment under Patchwork)

Different heating systems deployed under the separate scenarios when combined with increased solar photovoltaic deployment in the Patchwork scenario lead to different requirements for network reinforcement as shown in Figure 4-5.

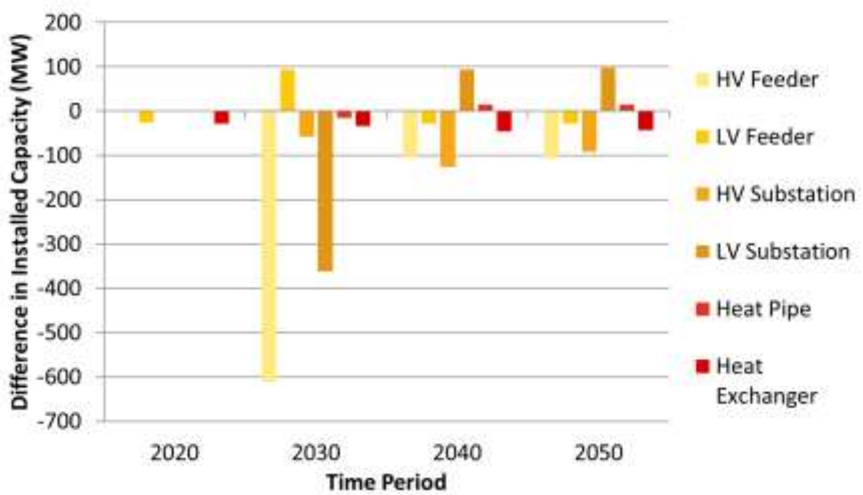


Figure 4-5 Difference in Energy Network Installed Capacity Between the Clockwork & Patchwork Scenarios (positive numbers show increased deployment under Patchwork)

Within the Clockwork scenario there is no deployment of solar photovoltaic installations as it is not cost effective. This is due to a lower electricity import cost since national decarbonisation is more gradual as a result of national long-term planning. In the Patchwork scenario, some solar photovoltaic is installed from 2030 onwards as shown in Figure 4-6. The total area installed of approximately 210,000m^2 is less than the maximum potential area identified by Newcastle City Council of around 350,000m^2. This option generates around 6,700 GWh per year by 2050.

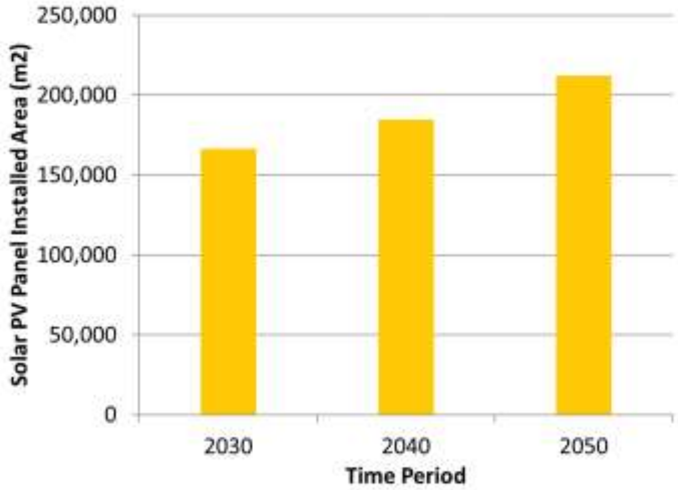


Figure 4-6 Difference in Installed Solar PV Area (m2) Between Clockwork & Patchwork Scenarios (positive numbers show increased deployment in patchwork)

The largest difference in installed capacity is for LV substation and HV feeder upgrades over the planning period (2014-2050), although this could be dependent on the development of power storage and the impact this could have on the electricity network. These upgrades are generally avoided in the Patchwork scenario compared with Clockwork, particularly in 2030, although more HV feeders are upgraded in the Patchwork scenario in the 2040-time period. This is attributed to the following factors:

- The difference in the cost and/or carbon content of electricity is influencing the scale of electricity demand and so the network upgrade required.
- A cheaper biomass price means that less electricity network reinforcement needs to take place – apart from in 2040 where biomass is more expensive in the Patchwork scenario. This could be why we see a shift in HV feeder upgrade in 2040.

There is a small amount of gas grid extension in the Patchwork scenario which is not seen in the Clockwork scenario connecting around 170 additional buildings to the gas grid in later years.

The relative contribution from various energy centre technologies to installed capacity is shown in Figure 4-7 and Figure 4-8. Under Clockwork (Figure 4-7) there is a clear decline in contribution from gas, CHP and gas turbines from 2030, the difference being taken up by heat pumps. The Patchwork scenario (Figure 4-8) shows an earlier uptake of heat pumps, increasing significantly over the planning period.

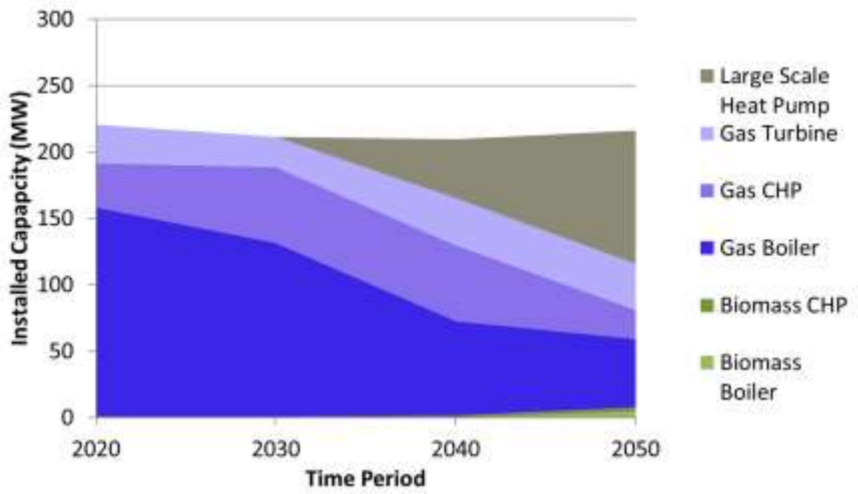


Figure 4-7 Energy Centre Installed Technology Capacities for Clockwork Scenario

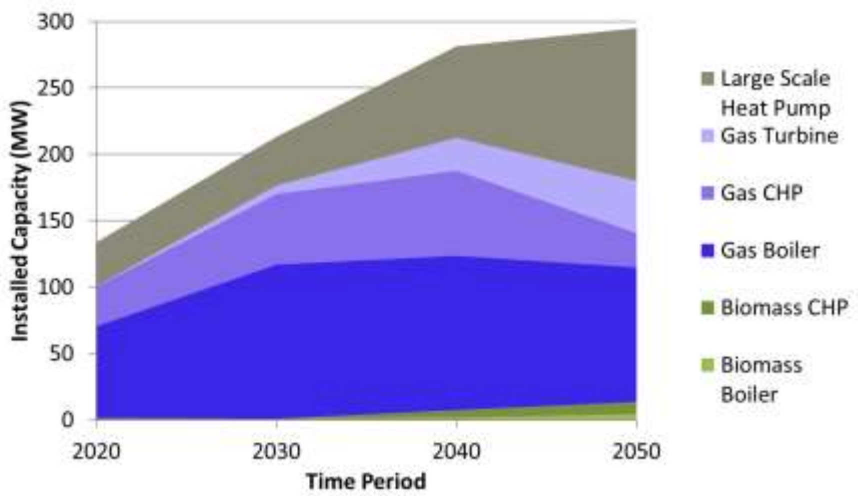


Figure 4-8 Energy Centre Installed Technology Capacities for Patchwork Scenario

More gas CHP is installed and operated in 2020 in Clockwork. In contrast large-scale heat pumps are installed in Patchwork as early as 2020. This is driven by the differences in the cost and carbon content inputs at the boundary of the national electricity grid. The extra CHP installed capacity in Clockwork is also used to generate more electricity in early years.

The relative demand for heat generation versus energy production is shown in Figure 4-9 and Figure 4-10 for the planning period. The figures compare energy production for Clockwork and Patchwork scenarios. Under Clockwork (Figure 4-9) there is a greater initial demand for both heat generation and electricity demand. Under Patchwork (Figure 4-10) initial demand is lower but ramps up steeply until peak demand in 2040. The profiles are thereafter similar with a decline in demand until 2050.

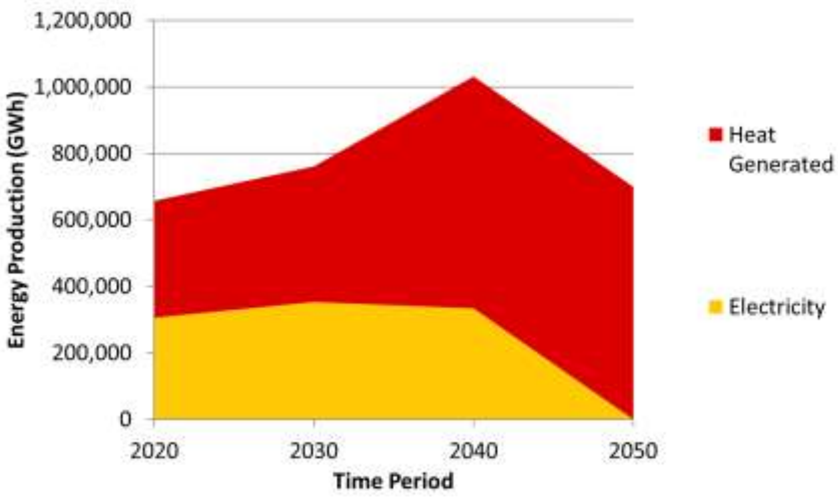


Figure 4-9 Energy Centre Energy Production for Clockwork Scenario

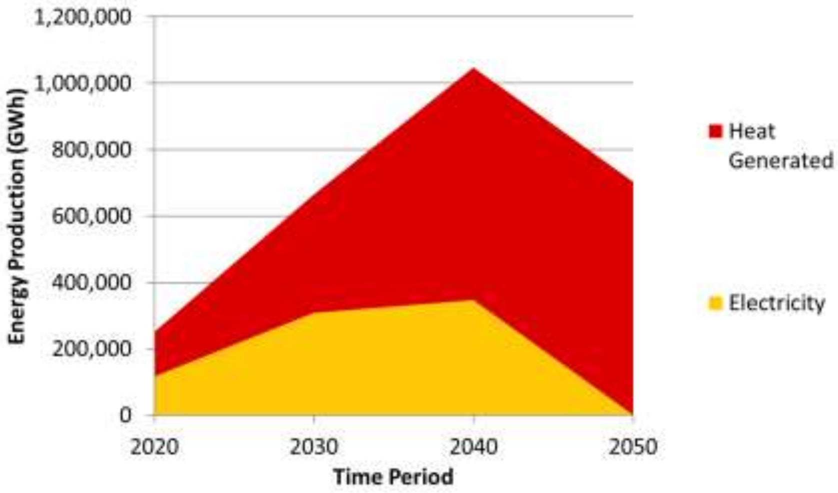


Figure 4-10 Energy Centre Energy Production for Patchwork Scenario

The total Newcastle City energy system cost from 2015 to 2050 for the Patchwork scenario is around £1.7b more than for the Clockwork scenario as shown in Figure 4-11. Most of the increase in cost is due to increased spending on electricity due to higher costs for imported electricity. This is a result of the less well co-ordinated UK energy system development within the Patchwork scenario leading to higher national electricity generation costs.

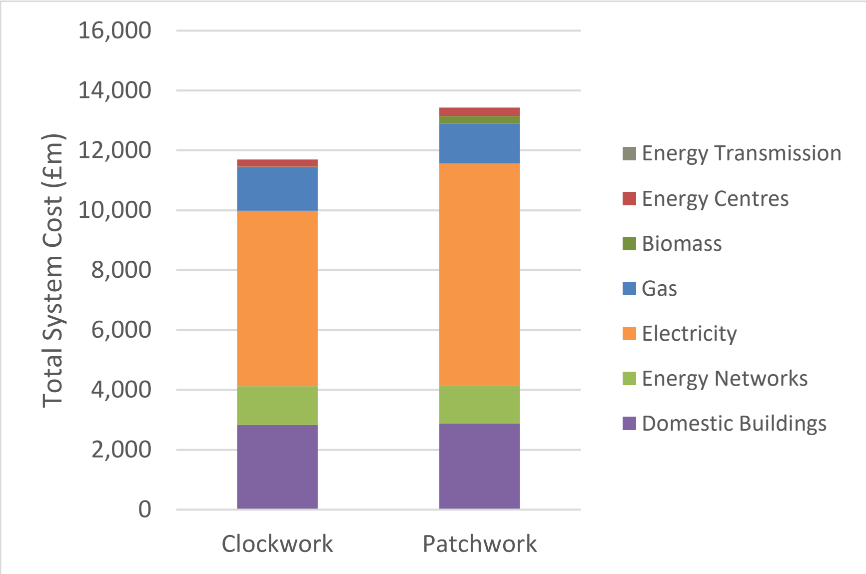


Figure 4-11: Total System Cost from 2015 - 2050 in 2015£

Key Points

- Around 28,000 more biomass boilers are chosen in preference to heat pumps due to higher electricity costs in the Patchwork scenario.
- The move away from gas boilers is slower in Patchwork. There are fewer gas boilers eventually.
- There is a gas network extension for around 170 properties in Patchwork.
- There is more solar PV deployed in Patchwork.
- More gas CHP is installed and run in 2020 in Clockwork. In contrast large scale heat pumps are installed in Patchwork as early as 2020. This is driven by the differences in the cost and carbon content of electricity at the boundary, although it is recognised that this type of system is generally untested in the UK.

Stakeholder Group Decision

After discussion within the stakeholder group it was agreed that the Patchwork scenario would be used as the basis for future post sensitivity analyses as it was felt this better represented the likely future national energy system to inform future local energy scenarios and Strategy development.

4.6 Energy Cost Sensitivity

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, listed in Table 4-1.

Table 2-1 The Energy Cost Scenarios Modelled in EnergyPath Networks

Scenario	Vector	Unit Costs
Baseline	All	Modelled future energy costs from ESME clockwork
Electricity Price Index 0.75	Electricity	-25% reduction in all electricity prices from baseline
Electricity Price Index 1.25	Electricity	25% increase in all electricity prices from baseline
Electricity Price Index 1.50	Electricity	50% increase in all electricity prices from baseline
Electricity Price Index 1.75	Electricity	75% increase in all electricity prices from baseline
Biomass Low Price	Biomass	2050 Biomass price reduced to £49 to follow 2020 – 2040 trend. (Baseline price for 2050 is £355)
Biomass Mid Price	Biomass	2050 Biomass price set to £201
Gas Price Index 0.75	Gas	-25% reduction in all gas prices from baseline
Gas Price Index 1.25	Gas	25% increase in all gas prices from baseline

Electricity costs

Changes in the electricity price have a modest impact on the modelling outcomes but a large impact on the total cost paid. Within the range of the prices modelled, the total cost changes by approximately half of the percentage change in electricity price, for example a 50% increase in electricity price increases the total cost by 25%. As the electricity price increases up to a 50% increase, approximately 10,000 houses in 2050 switch from heat pumps to district heat networks. This occurs by growing heat networks in two areas, rather than starting any new heat networks in other areas. Although this switch to heat networks reduces domestic electricity demand, the energy centre electricity demand increases to generate the heat, meaning the total drop in electricity demand is lower. As electricity prices increase from +50% to +75% there is no further increase in district heat networks. Instead deployment of heat pumps continues to fall whilst the number of biomass boilers start to increase.

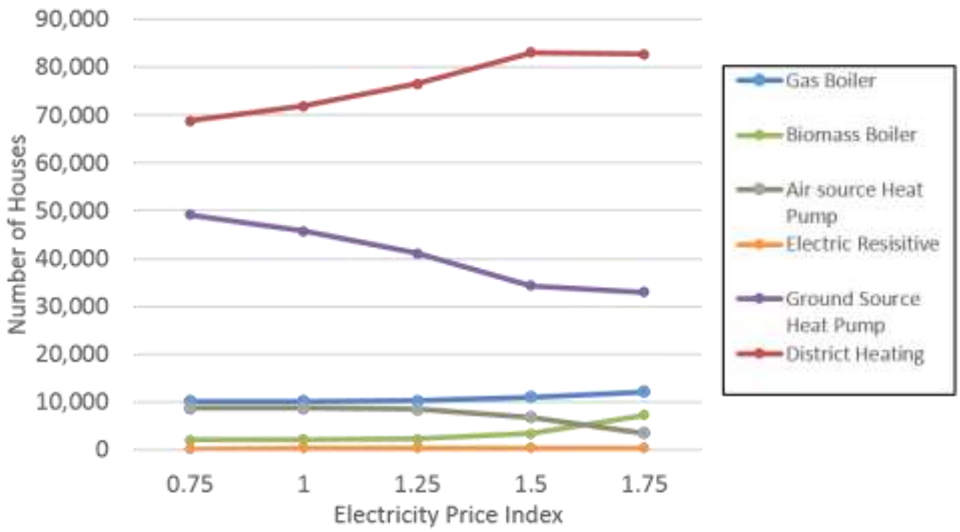


Figure 4-12 Influence of Electricity Price on the Numbers of Different Heating Systems Deployed

Figure 4-12 shows Influence of electricity price on the numbers of different heating systems deployed. As electricity prices increase, the output of energy centre heat pumps also increases as domestic heating systems are switched from electric heating systems to district heat. Demand for electricity falls as prices increase, however the overall fall is proportionally less than the fall in domestic demand as the use in energy centres increases.

Gas costs

Changes in the gas price +/- 25 % have a limited impact on the total cost paid (approx. 3%), and zero impact on the preferred decarbonisation method selected by the model, i.e. there are no changes in domestic transitions or in the use of gas in energy centres. This is due to the requirement to reduce carbon emissions driving gas demand rather than the cost of the gas. Changes in gas price have little impact on the use of gas based energy centre production.

Biomass costs

Figure 4-13 shows the influence of biomass price on the number of different heating systems deployed by the model. Changes in the 2050 biomass price[30] have a large impact on the form of the optimal transition, but a very limited impact on the total cost paid. If the 2050 biomass price increases in line with the 2020-2040 trend, then biomass boilers would be the most common domestic heating system. Even with a low biomass price and 55,000 homes with biomass boilers, only 27% of the available biomass (based on Newcastle City Council figures) is being used. This suggests that biomass availability will not be a constraint on uptake.

[30] Biomass price includes all cost aspects.

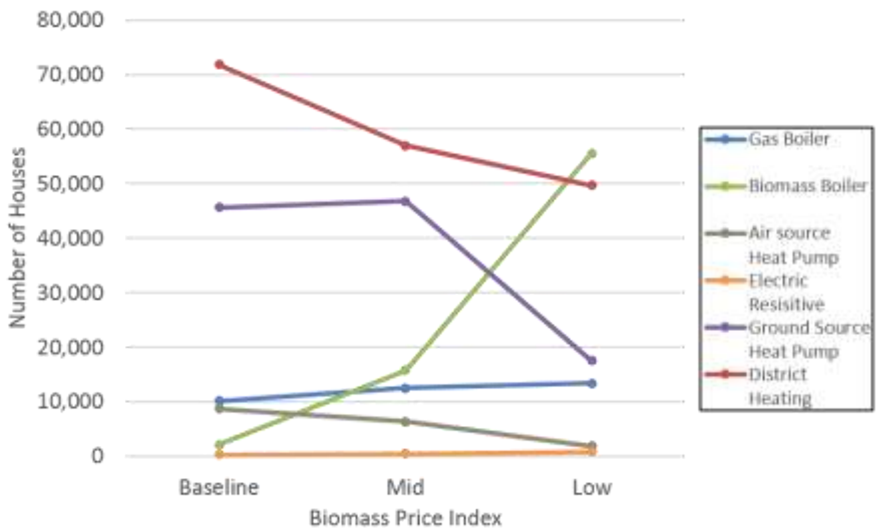


Figure 4-13 Influence of Biomass Price on the Number of Different Heating Systems Deployed

The influence of energy prices being different 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 4-2. 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 prices are planned for but the electricity price is actually 75% of that expected, then £3.8m extra will be spent to achieve the transition between 2015 and 2050. Generally, basing assumptions on a lower price gives a higher risk than assuming a higher price, i.e. if you assume for a low price but prices are high you overpay by more than if you had assumed for a high price and prices were low.

Table 4-2 Influence on System Cost of Outcomes that are Different to Planned

		Price Scenario Experienced								
	Difference to Optimal Cost (£m)	Baseline	Electricity Price x 0.75	Electricity Price x 1.25	Electricity Price x 1.50	Electricity Price x 1.75	Gas Price x 0.75	Gas Price x 1.25	Biomass Low Price	Biomass Mid Price
Plan Adopted	Baseline		3.8	3.3	16.1	36.9	0.0	0.2	87.3	16.0
	Electricity Price x 0.75	15.3		37.8	69.7	109.7	21.9	9.0	104.0	32.1
	Electricity Price x 1.25	4.8	16.7		4.7	17.4	4.3	5.6	91.0	20.3
	Electricity Price x 1.50	18.0	38.8	4.2		3.8	17.2	19.0	96.2	29.5
	Electricity Price x 1.75	35.0	62.7	14.3	3.1		34.0	36.1	89.6	34.7
	Gas Price x 0.75	0.0	3.9	3.2	15.9	36.7		0.2	87.3	16.0
	Gas Price x 1.25	0.2	3.2	4.2	17.7	39.3	0.5		87.4	16.2
	Biomass Price Reduction in 2050	281.7	334.9	235.7	199.1	170.6	281.2	282.5		113.3
	Biomass Mid Price in 2050	29.0	40.8	24.3	29.1	41.9	28.9	29.3	26.2	

Key Points

- Changes in the 2050 biomass price have large impacts on the modelled decarbonisation scenarios, but very small impacts on the total cost paid.
- +/- 25 % changes in the gas price have small impacts on the total cost paid (approx. 3%), but no impact on the form of the modelled decarbonisation scenarios.
- Changes in the electricity price have modest impacts on the modelled decarbonisation scenarios, but large impacts on the total cost paid.
- Planning for cheaper than baseline energy prices has higher risks than planning for greater than baseline prices.

Stakeholder Group Decision

After discussion the Stakeholder group did not request any changes from the baseline energy costs for future modelling runs.

4.7 Technology Cost Sensitivity

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 de-carbonise the buildings in Newcastle.

For each of the technologies considered within EnergyPath Networks a range of cost values were defined based on available data. The average range across all the simulated parameters was 27%, with some parameters varying by over 130%. 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, acknowledging that we cannot predict precisely 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 particular 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.

Types of cost that were included in this analysis were:

- Domestic Heating System Capital Cost
- Domestic Building Storage Capital Cost
- Domestic Heat Control Capital Cost

- Domestic Building Retrofit Capital Cost
- Energy Network Capital Cost for Gas, Heat and Electricity
- Energy Centre Technology Capital Cost

4.7.1 Key Points

Whilst results varied across the modelling simulations, across most of Newcastle there were no dramatic changes in the basic form of the modelling outcomes. A district heat network is the most common method of providing heat to domestic buildings with electric heat pumps as the second most common solution.

In all cases around 9,500 gas boilers remained in buildings in 2050 although the precise locations of these buildings did change between runs. The number of buildings with any particular heating system varied by around 10% either side of the average value whilst the number of buildings with fabric retrofit changed by about 5%.

This limited change in outputs could be due to:

- Very robust solutions such that the least whole system cost scenario to achieve the carbon reduction target is not significantly affected by costs changing with expected ranges.
- Insufficient simulations being conducted to allow the full range of all the parameters to be explored. An analysis of the ranges of each parameter used in the analysis suggests that the full range has been explored for each parameter.
- Allowed parameter ranges being too restricted. Whilst no one can accurately predict the future, most of the technologies involved in the analysis have achieved reasonable levels of development and have been deployed in large numbers on a global scale. On this basis it is unlikely that many of the costs will change by large amounts. If any particular technology's cost does change by a large amount, then the trends identified below are still expected to be valid.

Across the whole city the selected domestic heating type/solution is very stable in some areas whilst other areas have significant levels of change as shown in Figure 14.4.

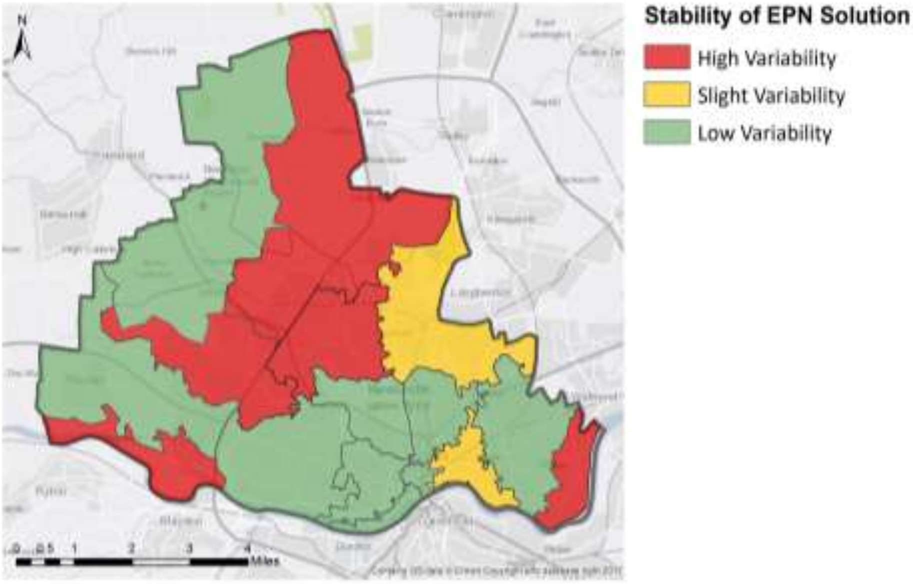


Figure 4-14 Local Authority Analysis Areas where the heating system solution is stable and those where there is High Variability across all simulations

4.7.2 Heating System Cost Sensitivity

Results across the full range of simulations were analysed to establish which costs influence the deployment levels of particular technologies. Listed below are the technology costs which have the greatest influence on the numbers of different heating systems deployed. It can be seen that in some cases, the cost of a technology has a significant influence on its deployment but for other technologies this is not the case. For example, decreasing the cost of biomass boilers results in increased numbers but the deployment of low temperature air source heat pumps is not strongly influenced by their cost because other costs are more influential. These differences are the result of performing the analysis at a “whole system” level rather than analysing each technology option in isolation.

With the exception of gas boiler hybrids all heating systems that use heat pumps are installed with heat storage. Except for ground source heat pumps, the number of heat pump based systems deployed is not influenced by the cost of heat storage.

The number of gas boilers increases when:

  - Air source heat pump costs increase
  - Biomass boiler costs decrease.

- The number of biomass boilers increases when:
  - Biomass boiler costs decrease
  - Air source heat pump costs increase
  - The cost of building heat networks increases

- High temperature air source heat pump numbers increase when:
    - Heating control prices decrease
    - The cost of building heat networks increases
    - The cost of installing heat interface units for heat network connections into houses increases
    - Air source heat pump costs decrease.
- The number of low temperature air source heat pumps increase when:
    - Heating control prices increase
    - Air source heat pump costs decrease.
- Low temperature air source heat pump/gas boiler hybrid numbers increase when:
    - Air source heat pump costs decrease
    - The cost of building heat networks increases.
- The number of electric resistive storage heating systems is not significantly influenced by technology costs. Other electric heating systems provide greater efficiency and so are preferred in the model.
- The number of ground source heat pumps increases when:
    - Their costs are low
    - The costs of heat storage in buildings is low
    - The cost of building heat networks increases
    - The cost of installing heat interface units for heat network connections into houses increases. This is only in the situation where the ground source heat pump is installed with low levels of heat storage. The deployment of ground source heat pump based systems with large heat storage tanks is not influenced by this factor.

The cost of building heat networks has a significant influence on which heating systems are selected. In contrast the costs of electricity network reinforcement and gas network extension does not influence the heating systems selected in Newcastle.

4.7.3 Energy Network Capacity Cost Sensitivity

The level of use of a particular heat solution influences the capacity of particular energy networks that are required. As electric solutions become more prevalent in a modelled scenario, then electricity network capacity has to increase to support the increased demand. Similarly, as more buildings are connected to heat networks in the city the total heat network capacity must increase. This means that there is a close correlation 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.
- 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.

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.

4.7.4 Retrofit Installation

The number of buildings modelled for improvements to thermal efficiency depends primarily on the cost of cavity wall insulation (the most common thermal efficiency improvement selected). This is driven by the differing levels of thermal performance of the buildings without insulation. When retrofit costs are high it is only economically viable to insulate the worst performing buildings. As the costs of retrofit decrease, it is economically sensible to improve the thermal performance of another tranche of buildings which are slightly less inefficient. Whilst there is variation in the numbers of buildings to which retrofit is applied, the timing also changes such that when costs are lower buildings are selected for retrofit earlier than when costs are higher.

It might be expected that improving the thermal efficiency of buildings would allow for a wider choice of heating systems to be used. However, the areas of the city which have the highest variability in the number of buildings selected for improved thermal efficiency are those which have the least variability in heating system types selected. Whilst deep retrofit might open up more options for different heating systems EnergyPath Networks does not view this as a cost optimal solution. It is also not clear why a resident would choose to have the cost and inconvenience associated with retrofit if they still have to have that associated with a new heating system when the total cost is higher. They can be expected to naturally choose the option with lowest cost and least inconvenience.

4.7.5 Heating Control Costs

There is a cost threshold below which advanced heating controls are deployed in EPN which is linked to the assumed energy savings that are achieved. As heating control costs increase more homes switch to a district heat network earlier and gas boilers that are replaced at end of life do not have advanced controls fitted.

The threshold is set so that if advanced heating controls cost less than £390 for an 11% reduction in energy consumption, then they are installed when gas boilers undergo a routine replacement at end of life. If their cost exceeds £500 for an 11% reduction in energy consumption, then advanced heating controls are not fitted at this time.

4.7.6 Energy Centre Technology Choices

As expected the installed capacity of heat generation technologies in energy centres increases as the demand for heat from networks increases. 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 requirement 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.

4.7.7 Total System Costs

The estimated total cost of the whole energy system in Newcastle to 2050 can be calculated from the modelling. Costs include capital costs, fuel costs and operation and maintenance costs. All future costs are discounted [31,32] to 2015 before being added up to get a total system cost. The most significant parameter in determining this total cost is the cost of building district heat networks. The costs for heat pumps and installing heat interface units for heat network connections into houses are also significant.

4.7.8 Technology Cost Sensitivity Key Points

- The lowest cost decarbonisation scenario for Newcastle's domestic buildings appears reasonably robust to changing future cost scenarios.
- A district heat network the most common method of providing heat to domestic buildings with electric heat pumps as the second most common solution. District heating is selected in preference to heat pumps for a number of reasons, of which the key are a lower total system

[31] 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).

[32] 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).

cost (including heating distribution system replacement) and as the existing and already planned heat networks which facilitate greater future uptake of the technology as the lowest cost option. In general, if the deployment of a district heat network increases then electric heat pump utilisation decreases.

- Although the lowest cost solution as a whole is fairly stable there is some spatial variation across Newcastle, with some areas having significant levels of change.
- The capacity of particular energy networks is influenced by the level of deployment of the heating solutions that use energy from those networks.
- The primary driver of heat network deployment is the cost of building those networks.
- Electricity network capacity varies much less than heat network capacity across the modelling runs as a certain level of electricity network reinforcement is always required to meet the anticipated increase in demand from the non-domestic sector.
- Total system cost is most strongly influenced by the cost of building heat networks.

4.8 Heat Storage Times

It is expected that electric heating will become more common as national electricity generation is decarbonised. As electricity demand increases there is an argument that there will be a future need to restrict energy demand at certain times. This is driven by a desire to reduce the level of electricity network reinforcement required to meet the new, higher peak demand. It is useful to be able to explore how the cost benefits of reducing electricity network reinforcement through demand reduction are balanced by increased costs in the wider energy system. The energy industry will need to develop solutions for managing peak demand that are acceptable to consumers.

Within EnergyPath Networks there is an option to include heat storage within individual buildings. By restricting the times at which this storage can be charged, referred to as load shifting, we can simulate the influence of introducing demand side response on the wider energy system. Two runs of EnergyPath Networks were compared. In the first run charging of domestic heat storage was available at all times. In the second storage charging was restricted during the morning and evening times of peak energy demand.

With the charge times of domestic building storage reduced, many heating systems could no longer meet target heat temperatures, particularly in larger buildings. This was true for all heating systems with small storage capacity. This had two influences:

- Reduced heating system options being available for many buildings.
- Increased heating system power being required to meet heat demand.

Load shifting will require larger heat storage capacity to be feasible in many buildings, if there is space to locate the store.

With a reduced set of heating system options available there was a shift to using larger storage with ground source heat pumps. There was also a higher uptake of hybrid heat pumps, biomass boilers and district heat networks. Hybrid systems are included in the electric category in Table 4-3, with 3,157 hybrid systems in the sensitivity run, meaning there is an increase in the number of properties that still require a gas connection.

Table 4-3 Change in Number of Households on each Fuel Type in 2050 between the Storage Mode Sensitivity and the Base Run (negative values are decreased households in the sensitivity).

Fuel Type	Change in Number of Households
Gas	-456
Electric	-9587
Biomass	8624
District Heat	241

The shift away from electric heating systems means that there is lower demand for electricity (around 80 GWh/year) and is the primary driver in a reduction in peak load of approximately 12 MW for the City. 9.5 MW of this reduction is on the Fosseway HV substation where there is the largest switch away from use of heat pumps. The result is a reduction in required electricity network capacity but this is balanced by a requirement for higher investments in (more expensive) heat networks. Network capacity changes are shown in Figure 4-15.

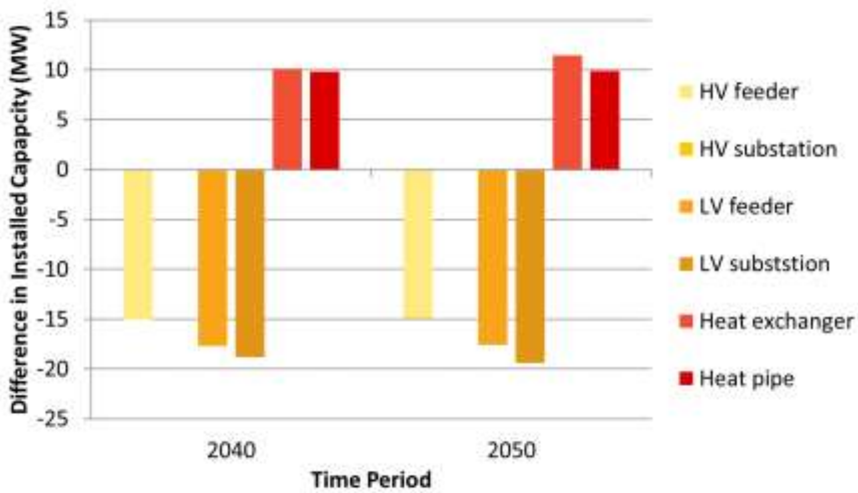


Figure 4-15 Difference in Energy Network Installed Capacity (Positive numbers show increased deployment with reduced storage charge times).

Overall the changes result in a higher total system cost from 2015 to 2050. The increase is estimated as £42 million, due to increased biomass consumption and domestic heating systems being more expensive.

Key Points

If the charge times for domestic heat storage are restricted:

- Many heating systems with small storage tanks cannot achieve target temperatures, particularly in larger buildings.
- More expensive heating systems are required to achieve target temperatures (higher power or larger storage).
- Increased deployment of biomass boilers.
- Increased deployment of Air Source Heat Pump (ASHP) – gas boiler hybrids.
- Ground Source Heat Pump (GSHP) switch to systems with larger storage.
- Some reduction in required electricity network capacity with an increase in heat network capacity.
- Changes in one of the part of the system to save money can lead to increased costs in other parts of the system.
- Total system cost increases by approximately £40m.

Stakeholder Group Decision

After discussion, the stakeholder group decided not to restrict heat storage use times for subsequent runs of EnergyPath Networks.

4.9 Heat Storage Capacity

The original EnergyPath Networks model runs included options for 1,000 litre hot water storage tanks. These are not considered to be a viable option for most houses for two reasons.

- Many households have removed their hot water tank and installed a combi-boiler. These consumers often place a high value on the space that has been made available by doing this and are unlikely to embrace heat solutions that require large amounts of domestic space to be sacrificed.
- Water tanks of this scale will weigh over 1 tonne when installed and so will not be practical in some houses due to structural concerns.

Large heat storage tanks were removed from the options available within the EnergyPath Networks decision module. This results in many heating system types no longer being available for all buildings. The largest change in modelled heating systems uptake is an increase in the use of biomass boilers, predominantly in Newburn and Castle which include rural areas. There is some increase in the use of hybrid heat pumps which are located in Jesmond, Heaton, Ouseburn and Byker to the east of the City centre. District heating is used to a higher level in East Gosforth and

Dene to the North East of the City centre. Table 4.4 shows the change in modelled heating systems in 2050 when large storage tanks are removed (positive values show an increase).

Table 4-4 Change in Deployed Heating Systems in 2050 when Large Storage Tanks are removed (Number of Homes)

Heating System	Change
Gas Boilers	231
Biomass	8374
High Temperature Air Source Heat Pump (ASHP)	-1933
Low Temperature Air Source Heat Pump (ASHP)	-5825
Hybrid Heat Pump	2263
Electric Resistive	0
Ground Source Heat Pump	-2132
District Heat Network	-978

These changes in heating systems result in changes in annual energy demand as shown in Figure 4-16. Gas consumption shows little change although more is now used in hybrid heat pumps rather than gas boilers.

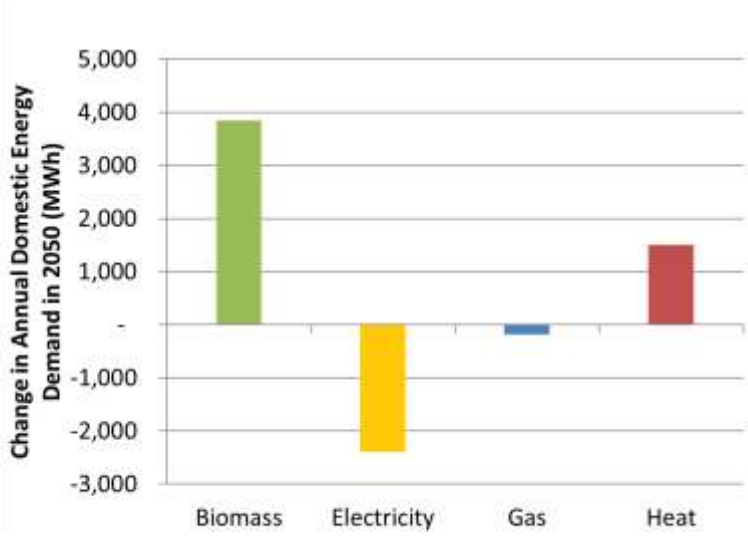


Figure 4-16 Change in Annual Domestic Energy Demand in 2050 (positive values show an increase when large storage tanks are removed).

The result of decreased reliance on electric heating systems and the switch to increased use of hybrid heat pumps means that less electricity network capacity is required. This is balanced, however, by a requirement for increased heat network capacity as shown in Figure 4-17. An increase in heat demand is seen, despite a reduction in the number of buildings connected to district heat due to the fact that a different, larger set of buildings are connected. Without large hot water tanks the options to heat larger buildings with electric heat pumps are reduced. These buildings are then more likely to connect to district heat. This is balanced in the optimiser by switching a larger number of smaller buildings from district heat to other solutions. Most of the reduced electricity network capacity required is associated with the network supplied by the Fosseway HV substation.

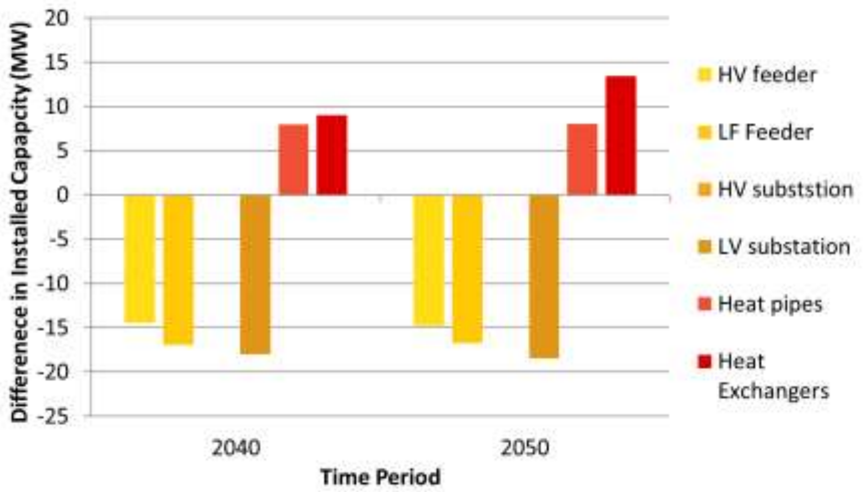


Figure 4-17 Change in Installed Network Capacity in 2040 & 2050 (positive values show an increase when large storage tanks are removed).

Cost increases are broken down in Figure 4-18. Total system cost from 2015 to 2050 increases by £55m (0.5%) when the large storage tanks are removed.

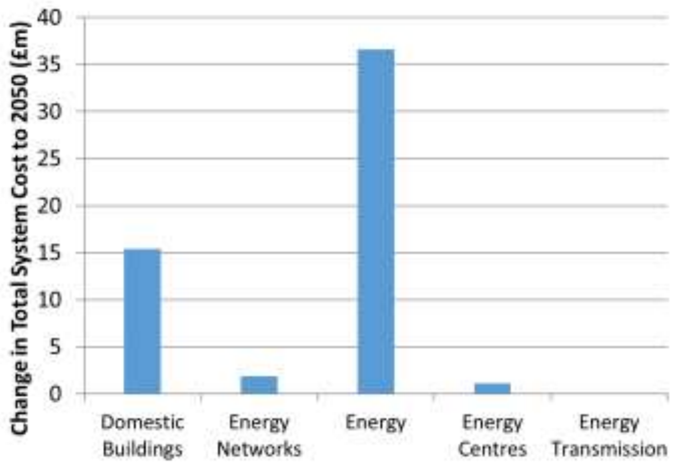


Figure 4-18 Change in Total System Costs to 2050 with Large Storage Tanks Removed

Key Points

EnergyPath Networks modelling indicated that removal of the large heat storage options would result in:

- Increased use of biomass boilers.
- Increased use of Air Source Heat Pump (ASHP) – gas boiler hybrids.
- Some reduction in required electricity network capacity.

- Some increase in required heat network capacity.

Stakeholder Group Decision

After review the stakeholder group made the following recommendations:

- Remove very large storage tanks.
- Adjust smaller storage tank sizes to the smallest possible whilst allowing use in a reasonable number of different archetypes. These new sizes varied depending on the heating system see Table 4-3: New hot water tank sizes.
- Remove storage options from hybrid heat pumps.

Table 4-3: New hot water tank sizes

Heating System	Hot Water Tank Size (litres)
High Temperature ASHP	500
Low Temperature ASHP	500
Electric Resistive	300
Ground Source Heat Pump	200 or 400

4.10 Advanced Retrofit

Retrofit of buildings which involves more than cavity wall and loft insulation, referred to as advanced retrofit in this document, can be extremely expensive and is often difficult to justify in terms of the value of the energy saved when compared to the cost of the measures installed. It may however be socially valuable as it can have a significant influence on levels of fuel poverty. It is often the case that social housing providers will perform high levels of retrofit as it meets social objectives; it can be justified in terms of long term investment in and management of assets and there can be opportunities to access subsidies in order to reduce costs.

Newcastle City Council owns and Your Homes Newcastle (YHN) manages a significant number of properties within Newcastle that could be considered for advanced retrofit. It is not possible to force retrofit on to individual buildings within EnergyPath Networks. As an alternative, a package of retrofit measures was forced (meaning manually selected for uptake as the model would not choose the option as the lowest cost means of reducing carbon) upon a limited range of domestic archetypes in particular regions of the City where Newcastle City Council and Your Homes Newcastle hold a considerable amount of the building stock.

The advanced retrofit package contained external wall insulation, loft insulation and triple glazing and was applied across a range of building types and ages. The buildings selected were predominantly in Denton, Fawdon, Kenton, Ouseburn, Walker, Westerhope and West Gosforth wards. These areas were chosen due to a high density of social housing, noting that practicalities such as planning permission have not been considered[33]. The result will be that approximately 35,000 buildings will have the advanced retrofit package installed in the 2020's. This represents some 26% of the domestic building stock in Newcastle. Of these buildings 32% are owned and managed by Newcastle City Council and Your Homes Newcastle.

Cost per building

The total estimated cost of advanced retrofit on 35,000 buildings is approximately £900m. The average cost was £21,300 per building with a range from £11,500 to £41,500. The distribution of costs is shown in Figure 4-19 below. These costs are based on those currently being achieved in retrofit programmes.

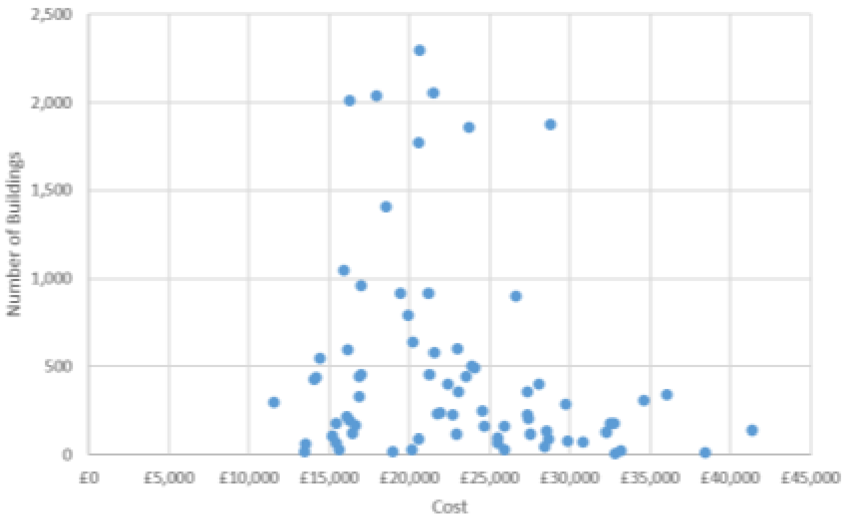


Figure 4-19 Distribution of Total Retrofit Cost per Building

Energy Saving per Building

The energy savings achieved in each building will depend on its thermal performance before the measures were applied. In some cases, this will be larger than in others. The method of applying advanced retrofit in the model will have resulted in buildings with cavity wall insulation receiving additional external wall insulation. The average gas saving (from building modelling) achieved was 1,600kWh / year or 16% of the demand prior to retrofit. Some buildings had considerably larger savings as seen in Figure 4-20.

A comparison of the cost of retrofit with the gas savings achieved shows that there is a wide variation in the distribution of annual gas savings per building after retrofit (

[33] It is noted that this is based on modelling outputs and full consideration would need to be given to all relevant regulations and requirements should such a scenario be considered further.

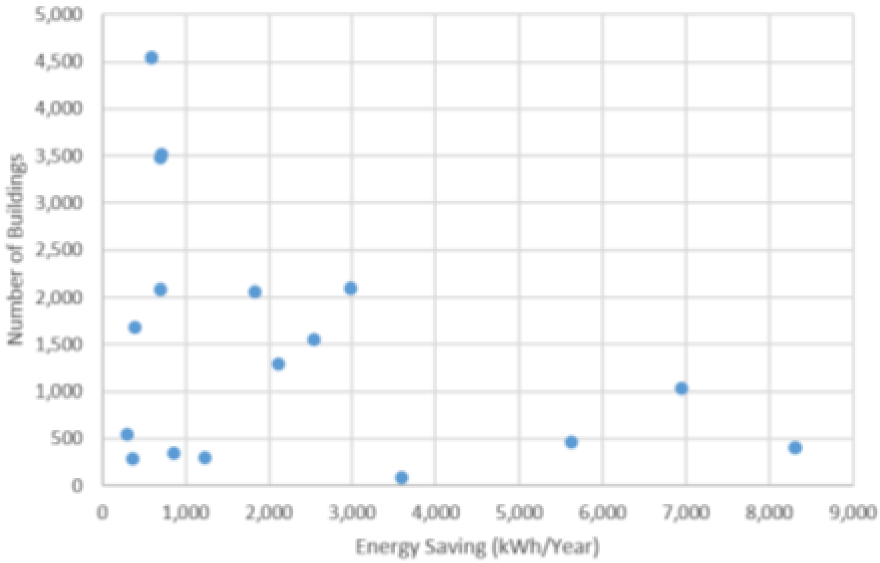


Figure 4-20) and between cost of retrofit and gas saving (Figure 4-21). Within this sensitivity the deployment of retrofit onto different buildings was forced regardless of the benefits that were likely to accrue. This demonstrates that a wholesale approach to building retrofit is not appropriate and that individual property level assessment is required to ensure that it is only conducted where the benefits outweigh the associated costs.

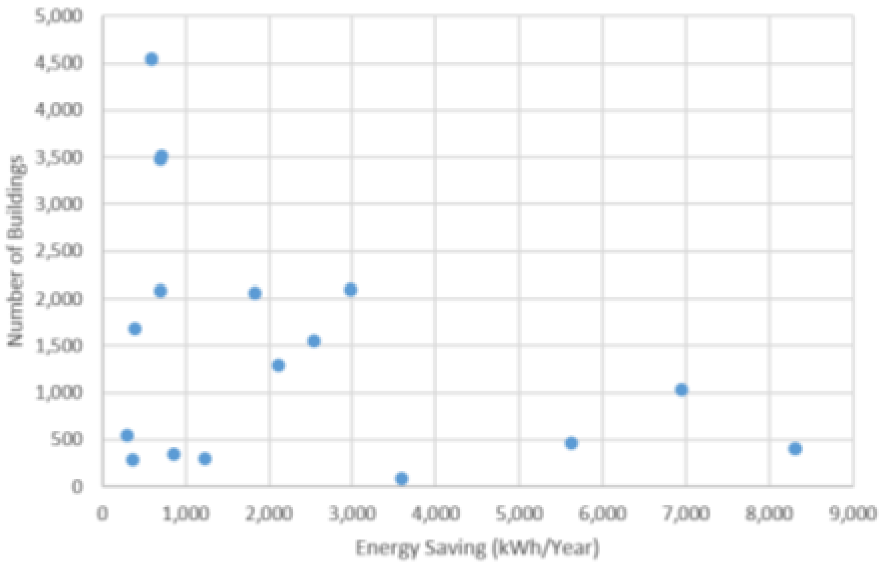


Figure 4-20 Distribution of Annual Gas Savings per Building after Retrofit

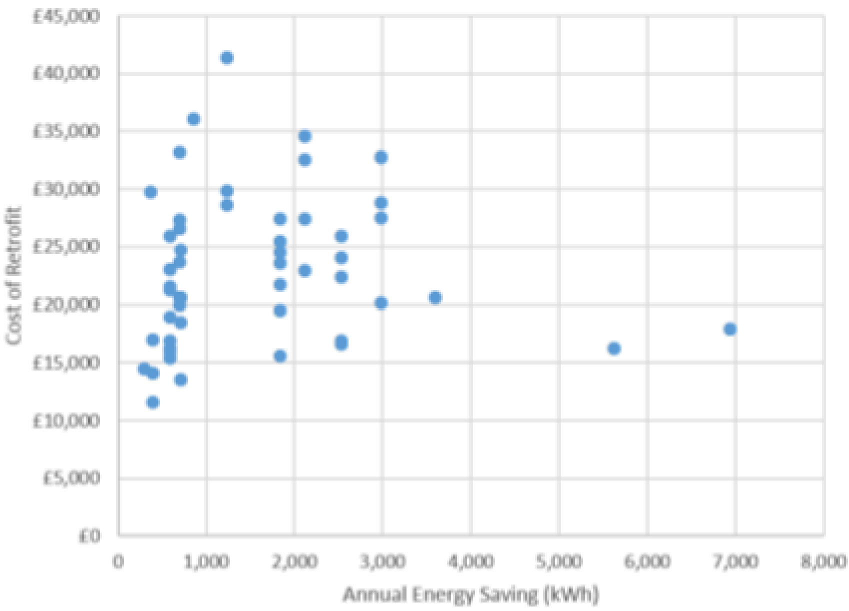


Figure 4-21 Comparison of Retrofit Cost & Gas Saving

Energy Cost per Building

Figure 4-22 shows the predicted influence on annual energy bills for those buildings which have the advanced retrofit package applied during the 2020s. The average decrease is predicted to be around £80 / Year but there are very few properties where this type of retrofit is selected for a cost optimal solution.

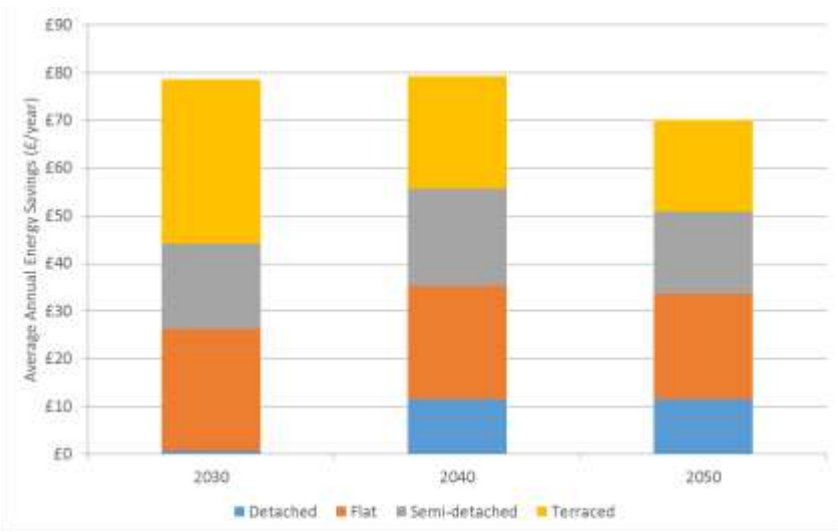


Figure 4-22 Influence on Average Annual Energy Bills of Advanced Retrofit

Influence on Future Heating System Options

Some increase in the modelled use of electric heat pumps was seen in preference to using a district heat solution in those areas where advanced retrofit has been forced. The reduced heat requirement of the buildings with improved thermal efficiency means that these heat pump systems do not require such large heat storage tanks to meet target temperatures.

Influence on Network Reinforcement

There are no significant changes in the predicted network capacity requirements found due of the modelled deployment of an advanced retrofit programme.

Key Points

- Within the constraints of the EnergyPath Networks Modelling framework it is not possible to force retrofit on individual buildings. This meant that an approach was taken that advanced retrofit was forced onto approximately 35,000 buildings spread across those areas of the City which have a high density of social housing.
- The average cost of the retrofit package was £21,300 per building with a range from £11,500 to £41,500. This achieved an average energy saving of 1,600kWh/year or 16% of average gas demand. This equates to an average gas bill reduction of around £80 per year.
- It is clear that any advanced retrofit programme must be carefully targeted to those buildings where substantial energy savings can be achieved. Wider ranging advanced retrofit programmes are unlikely to offer good value for money based purely on reducing fuel bills unless other social factors are also considered.

4.11 Energy from Waste

With increasing costs associated with sending municipal waste to land fill due to rises in the landfill tax, there is increased interest in alternative methods of disposal for waste. One option is incineration which can include production of both heat and power for local use.

Newcastle City Council provided an estimate of the volume of dry waste that is expected to be available between now and 2050. Within the EnergyPath Networks model this was made available as a resource along with options to build three Combined Heat and Power Waste Incineration plants at two different capacities. The costs of these plants were based on similar plants that have been built at Grimsby and Sheffield.

It should be remembered that within the EnergyPath Networks framework we do not consider taxes and subsidies because these are transfer payments and do not influence the overall cost to society of the actions that are taxed, or subsidised. On this basis a negative cost for waste was set at £23.80 / tonne. Within the modelling framework this means that £23.80 is saved for every tonne of waste that is consumed. Incineration of dry waste was assumed to result in emissions of 0.21 tCO_2/MWh of energy available in the waste. Figure 4-23 shows the future waste stream identified by Newcastle City Council and the associated potential cost saving from incineration of this waste used within the modelling framework.

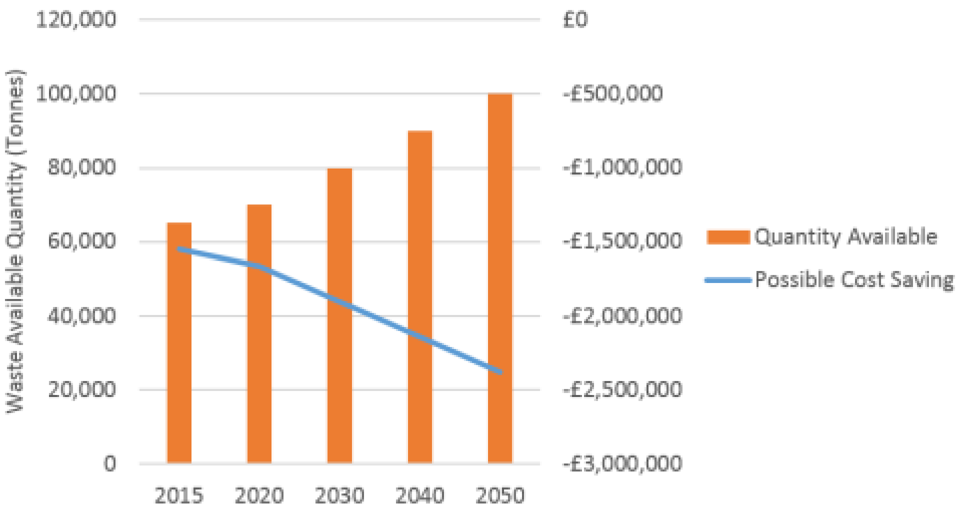


Figure 4-23 Waste availability and associated potential cost saving

The cost of energy generated by waste plants is high, for example a plant in Sheffield cost around £100m to build. With the volume of waste available within Newcastle the savings from incinerating waste (if landfill tax is not included) are insufficient to justify this level of investment and this option is not selected in the Decision Module.

This analysis suggests that the construction of a waste incineration plant could not be justified in terms of reducing the city's carbon dioxide emissions because alternative, cheaper options are available. However, when the influence of landfill tax is included in the analysis, there is a stronger economic case for their construction.

Stakeholder Group Decision

The stakeholder group considered that an option for energy from waste should be included in future analyses to ensure that this decision remains valid.

In the final modelled scenario, where local availability of biomass was limited (the main modelled scenarios are discussed in Chapter 6), a small energy from waste plant was selected within EnergyPath Networks as being viable and operated between 2036 and 2045. This plant has a capacity of only 1MW and consumed around 2400 tonnes of dry waste per year. The plant only consumes around 1 tonne of waste in 2050 due to the emissions associated with waste incineration.

Key Points

- From a purely economic perspective, the construction of a waste incineration plant could not be justified (in EnergyPath Networks) in terms of reducing the city's carbon dioxide emissions.
- However, where EnergyPath Networks works to the World with Limited Biomass scenario, the decision module does select a 1MW energy from waste plant to operate between 2036 and 2045.

4.12 Forced Solar Electricity Generation

Previous work done by Newcastle City Council has identified that 21,944 homes could each have a solar electricity generation system installation of 2.5kW peak power. DECC feed-in tariff data shows a maximum deployment of 546 domestic solar photovoltaic systems in Newcastle in the year 2011. This will need to increase to 650 systems per year to 2050 to achieve the maximum level of 22,000 installations in 2050. Over this time period panel costs were assumed to decrease gradually to cost 27% of their 2015 cost by 2050. Figure 4-24 shows the total amount of electricity that is predicted to be generated by the solar panels for each time period to 2050 (if the level of solar discussed is installed). Generation is less in 2045 - 2050 because the data is for 5 years, rather than 10 years for earlier time periods.

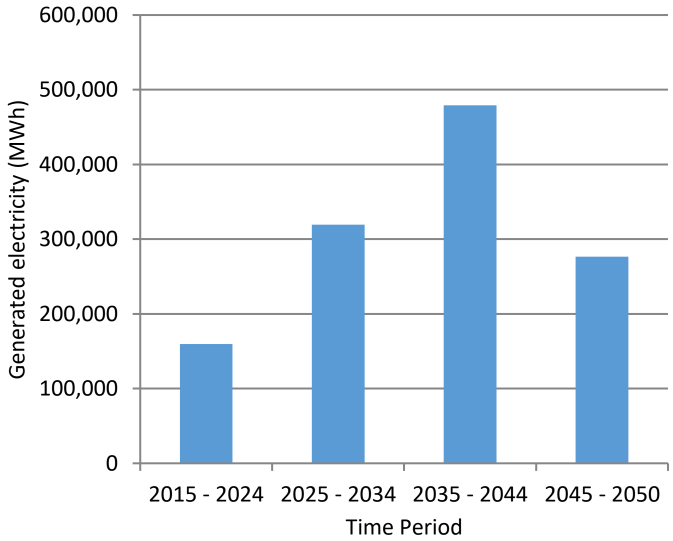


Figure 4-24 Electricity Generated by Solar Photovoltaic Panels

The cost of the imported electricity that has been saved by this generation can be calculated and is compared to the cost of the installed solar panels in Figure 4-25, where it can be seen that in later years the capital investment is predicted to be less than the cost of electricity saved. This will be heavily dependent on the future cost of PV panels.

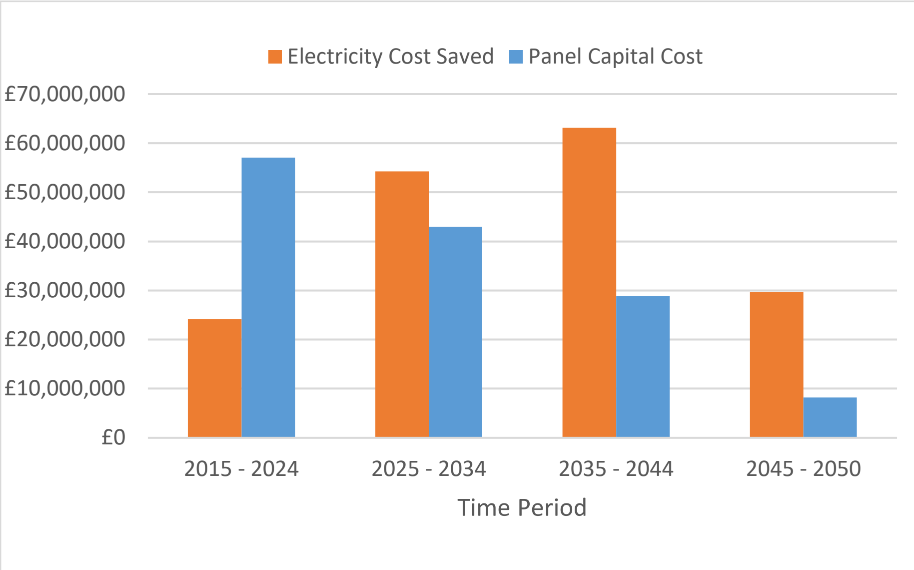


Figure 4-25 Cost of Electricity Saved and Solar Panel Installation

By providing a local source of electricity generation the requirement for network capacity is generally reduced very slightly (less than 1% of current network capacity) in the model outputs as shown in Figure 4-26. There is, however, a requirement for increased low voltage feeder capacity in 2040 due to the transmitting of electricity generated from the PV to sites of consumption elsewhere in the local area.

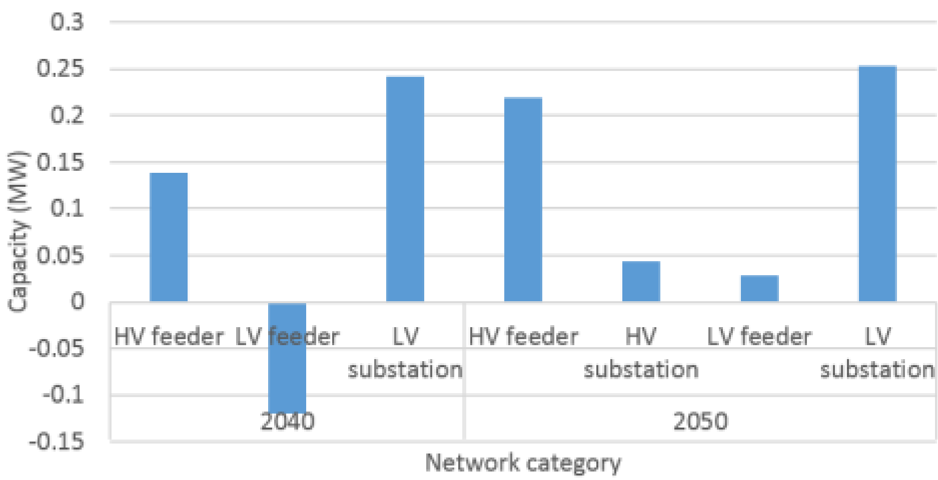


Figure 4-26 Change in Electricity Capacity with High Solar Electricity Panel Deployment (positive values are less capacity)

The overall system cost from 2015 to 2050 with forced PV deployment is estimated to increase by £0.17 billion which is around 1.5% of the cost without high levels of solar electric panel deployment.

The modelling suggests that high deployment of solar panels to generate electricity could be cost-effective without the influence of the feed-in tariff if panel costs reduce sufficiently under the ESME Patchwork scenario.

Stakeholder Group Decision

Newcastle has seen a decline in the deployment of solar panels since a peak in 2011 as a result of decreases in the feed-in tariff. The key stakeholder group felt that in the current environment the maximum potential for deployment of solar photovoltaic panels will not be reached. It was agreed that, in future model runs, deployment of solar PV would be forced at a rate of 100 homes a year spread evenly across the city. This was considered useful to allow communication around the costs and impacts of deployment.

Key Points

- High deployment of solar panels to generate electricity is unlikely to be cost effective without the influence of the feed in tariff.
- The cost of panels is not expected to be low enough that it could be outweighed by the money saved through reducing electricity imports to the city.

4.13 Restricted Biomass

Biomass is an extremely flexible energy source which can be used in many ways including burning directly in individual homes to provide heat; used in combined heat and power plants to provide heat and electricity for local networks; conversion to liquid fuel for use in transport applications and burning in central power stations with carbon capture and storage to create 'negative emissions'. Within the baseline assumptions used in EnergyPath Networks the cost of biomass becomes very high after 2040. This reflects the increasing value of biomass to the energy system as other decarbonisation options are put in place and remaining emissions become harder and more expensive to eliminate.

EnergyPath Networks uses the total system cost to 2050 to calculate the least cost local pathway. In the baseline case this means that biomass is an attractive option because of its relatively low cost over the whole pathway. Despite the high cost of biomass approaching 2050, it is still a cost effective option over the full time period. The result is that individual biomass boilers are often selected within EnergyPath Networks when other technology options are limited or are assumed to have high costs.

Due to the wide range of alternative uses for biomass its availability and price over the long term are highly uncertain. In addition, use of biomass in domestic heating systems has high risks related to air quality and consumer acceptance. Concerns have been raised over the likelihood of biomass boilers being a wide spread heating system choice in Newcastle due to these factors. For example, the baseline assumption is that biomass will increase in cost by a factor of 14 from 2015 to 2050. This results in a highest estimated annual fuel bill increase of over £5,500 with the lowest increase around £1,500.

In order to establish the options available within Newcastle if biomass is not to be considered, a model run of EnergyPath Networks was completed with the biomass cost set to a very high level such that alternative options could be guaranteed to be cheaper where they are applicable.

Figure 4-27 shows the domestic heating systems selected within EnergyPath Networks when a high biomass cost is assumed. In buildings where biomass was previously selected a range of different heat pump led solutions are chosen instead, with the precise choice depending on the nature of the building. The heating systems selected for different types of building are shown in Figure 4-28. It can be seen that different heating systems are favoured for different types of property. Ground source heat pumps are restricted so that they can only be fitted to detached properties where they are widely selected by EnergyPath Networks.

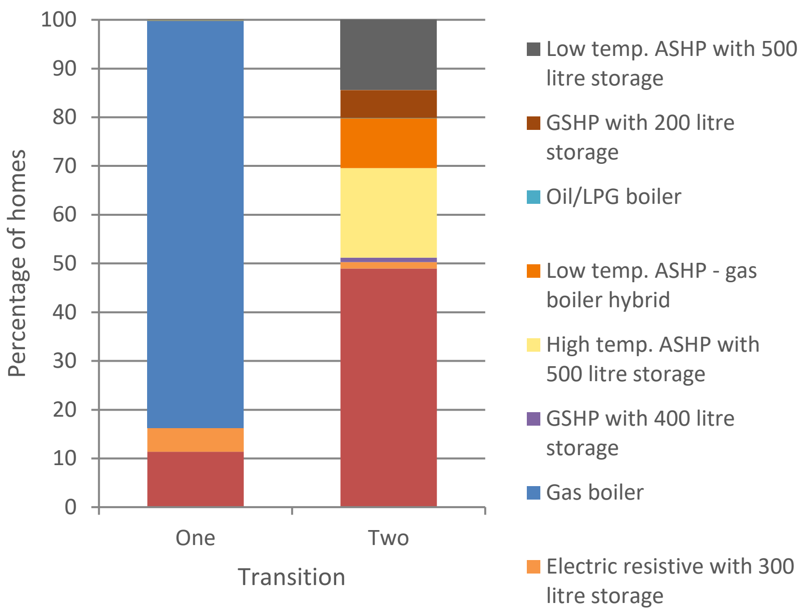


Figure 4-27 Domestic Heating Systems Selected with a High Biomass Cost

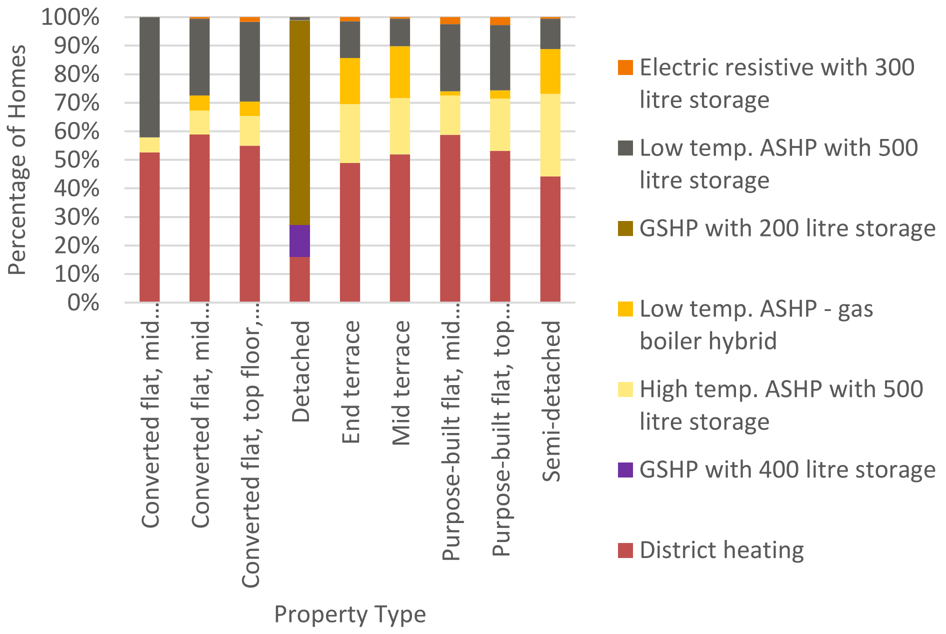


Figure 4-28 Percentage of Heating Systems in Different Property Types Selected with a High Biomass Cost

Around 17,200 buildings are selected for measures to improve the fabric thermal performance. This predominantly involves topping up loft insulation, cavity wall insulation and fitting double-glazing to those buildings that still have single glazing. This improvement of fabric performance is most likely to be required in flats which have high temperature air source heat pumps fitted although some level of retrofit is selected for most combinations of heating systems and building type.

Compared to a sensitivity run with a lower biomass cost, where a significant proportion of buildings are selected for biomass boilers, the increased use of electrically led heat solutions requires a capacity increase in all parts of the local electricity network as shown in Figure 4-29. These increases represent approximately 5% more capacity requirement for HV feeders, 7% more capacity on HV substations and 10% more on LV feeders and substations.

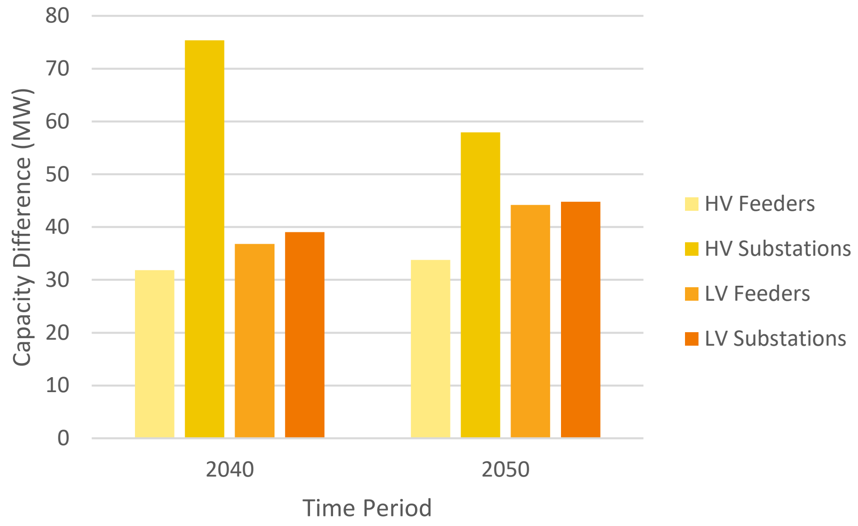


Figure 4-29 Electricity Network Reinforcement Requirement Over That with a Low Biomass Price

The modelled total system cost is expected to increase if the cost of biomass is high such that heat pump solutions are fitted in preference to biomass boilers. The difference is an additional £250m as shown in

Figure **4-30**. This is due to increased use of nationally generated electricity and the additional electricity network reinforcement that this requires. The total spend on biomass fuel with a low biomass cost is estimated to be around £250m over the modelled scenario, so an increase in biomass costs by a factor of 2 would be sufficient to more than offset the increased cost of the alternative solution.

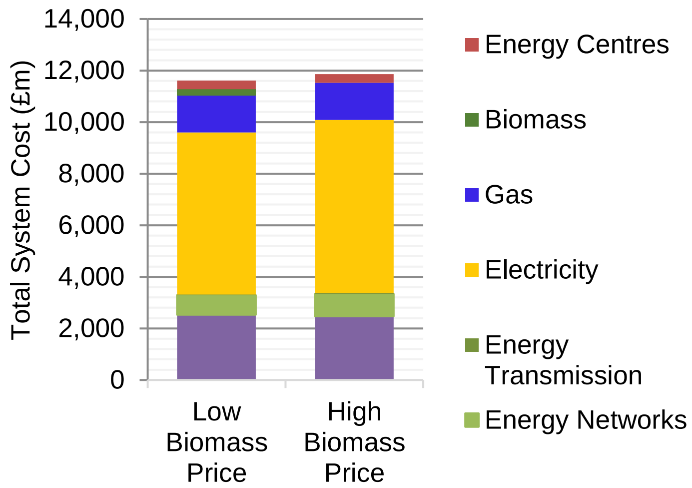


Figure 4-30 Influence on Total System Costs of a High Biomass Price

Key Points

Assuming a high future cost for biomass results in:

- A selection of different heat pump solutions being widely selected in preference to individual biomass boilers.
- An increase in electricity demands with an associated increase (of around 7%) in the level of electricity network capacity required.
- An increase in the whole system cost to 2050 of £250m.

Stakeholder Group Decision

The stakeholder group felt that the results of this run (high biomass price) better reflected their view with regards to the significant use of Biomass to provide heat, although it is noted that it is impossible to determine at this time how the biomass sector will evolve.

5 Future Local Energy Scenarios and Network Choices

This section summarises the analysis, considerations and interpretation of the EnergyPath Networks outputs which are intrinsic to the development of the corresponding Strategy document.

5.1.1 National Transition Context

The UK is legally committed to a reduction target for all greenhouse gases (GHGs) of 80% below 1990 levels by 2050. In order to achieve it there are a number of strategic actions the industry, supported by the UK Government, could put in place.

The 'low regret'[34] pathway to the decarbonisation of the UK's energy system is likely to be achieved through a co-ordinated UK level central planning approach. This would have a wide scale and disruptive effect on the energy sector, including influencing the type of main national electricity generation plant, greater contributions from renewable energy, locally generated energy surplus supplied back to the grid and reductions in domestic demand. Local decentralised electricity generation will have an important role in Newcastle's future energy system. To decarbonise the UK's energy supply system by 2050 will require integration of the whole energy system including gas, heat and electricity. Activities will include:

- *Building or upgrading storage assets*
- *Building, upgrading or decommissioning energy network assets*
- *Upgrading building fabric and converting building heating systems*

5.1.2 Local Transition Context

Newcastle's Local Area Energy Strategy will benefit from and contribute to a national energy decarbonisation approach which includes a mix of technologies including nuclear, natural gas with CCS, and renewables including solar (thermal & photovoltaic), wind (on and off-shore), and wave energy. Decarbonisation of heating in domestic and commercial buildings is an important component to achieve Newcastle's vision of a 100% clean energy city by 2050.

Figure 5-1 illustrates a potential emission reduction pathway for buildings in Newcastle over the planning period based on EnergyPath Networks modelling. In 2020 the greatest contribution will be achieved by reducing carbon in imported electricity. By 2050, non-domestic emissions dominate remaining carbon emissions. These have not been targeted in the analysis[35] and it will

[34] 'Low regret' refers to an option which consistently offers benefits under a wide range of scenarios
[35] There emissions are included in the analysis but emission reduction options have not been modelled.

be necessary for Newcastle to develop a strategy to reduce emissions from non-domestic (commercial) buildings.

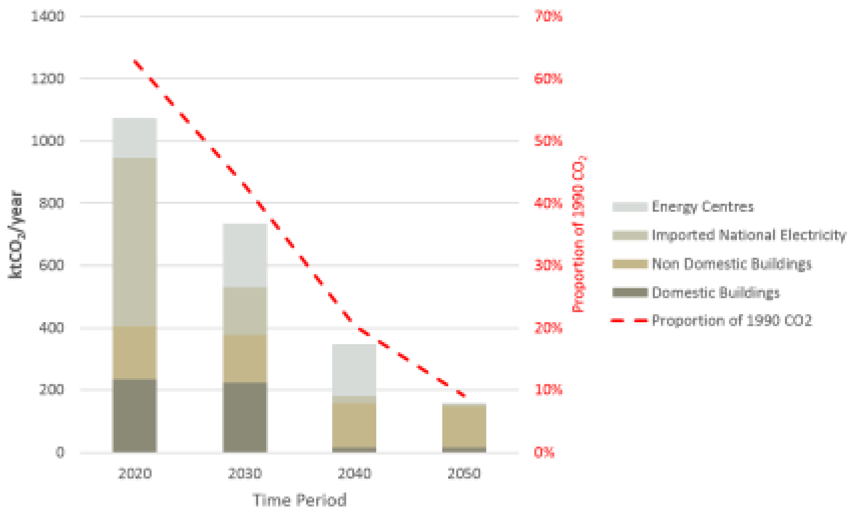


Figure 5-1 Newcastle's Building Related Carbon Emissions Reduction Scenario.

5.1.3 Future Local Energy Scenarios and Stakeholder Inputs

EnergyPath Networks modelling has informed the following four local energy scenarios:

1) Business as usual – no local carbon target: This represents the activities we expect to occur without any requirements to cut carbon emissions. This acts as a baseline against which other results can be compared.

2) No constraints – a carbon target of 90% of 1990 building emissions: See Chapter 5 for a precise definition of the emissions considered. This is in effect the Base Run discussed in Chapter 5 and is not intended to be regarded as a modelled scenario as optimised by EnergyPath Networks as it has been used to set the baseline position to make all future decisions regarding subsequent modelling scenarios/analysis. However, some of the outputs resulting from the Base Run are presented in the following sections as it is useful to assess the variance in decarbonisation options adopted by scenarios 3 and 4.

3) A World of Plentiful Biomass: The same carbon target as above, but with local constraints on the siting of certain technologies and options. This is informed by an engineering review study which examined the outputs of the no constraints run and stakeholder group feedback.

4) A World with Limited Biomass: This run builds on 3 (Plentiful Biomass), but provides an alternative view where biomass may not be available at the previously modelled price. The price of biomass in this run was set such that it would only be used if there were no other options to reach the carbon target.

The results from these modelling runs can be considered together to give a view of the potential decarbonisation scenarios for Newcastle, the common themes and options that are prevalent across the scenarios to decarbonise and where the approach may vary depending on external factors.

This section examines the domestic heating systems present in the four scenarios, the uptake of retrofit insulation and the requirements and options for the development of heat networks and energy centres. It then considers the resulting impacts on gas and electricity networks, the breakdown and timing of the additional costs required to meet the carbon target and the local constraints surrounding progressing any of the identified decarbonisation scenarios.

Figure 5-2 illustrates the dominant heating system by model analysis area in 2050, and shows how it varies between these four modelled scenarios.

The business as usual scenario shows the current predominance of gas in analysis areas, and some potential for a district heat network around the city centre. The no-constraints scenario shows a large increase in district heating in central areas and significant adoption of heat pumps, especially ground source heat pumps, in many outlying wards. In the World of Plentiful Biomass scenario there is a further increase in district heating in central areas and a large increase in biomass boilers in outlying areas. The number of ground source heat pumps drops considerably as greater constraints are applied regarding which property types are considered to have sufficient accessible land to site them. When biomass uptake is restricted by increasing the future cost of biomass, there is a large increase in high temperature air source heat pumps and other electric options, including small numbers of air source heat pump – gas boiler hybrids, in the areas that were previously biomass boilers dominated.

Figure 5-2 shows the dominant heating system by 2050, where the modelling assessed the transition from existing to low-carbon heating system occurring over two transition periods[36]. The transition periods represent two probable opportunities for upgrades to heating systems between now and 2050 and depend on how recently the current boiler was installed for any particular property. This is a pragmatic approach for delivering future technological changes with an obligation that the changes need to be completed by 2050. Broadly speaking, the first transition for any particular property is expected to be completed by 2030 with the second transition between then and 2050. In reality heating systems may change at a greater or lesser frequency, but the two transitions scenario is appropriate for use in the model.

[36] The two-transition situation is derived from the expected lifetime of a typical gas boiler heating system (15 years), where the model assumes that systems will be changed twice between present day and 2050. Due to limitations of the model it generally groups these changes together into transition points as it is impractical to forecast an assumed transition change date for each building in Newcastle. However, it is recognised that in reality there will be an ongoing process of transition that may have multiple transition windows for each building between now and 2050, where heating systems and other measure such as fabric, improved controls, etc. will be installed at different times.

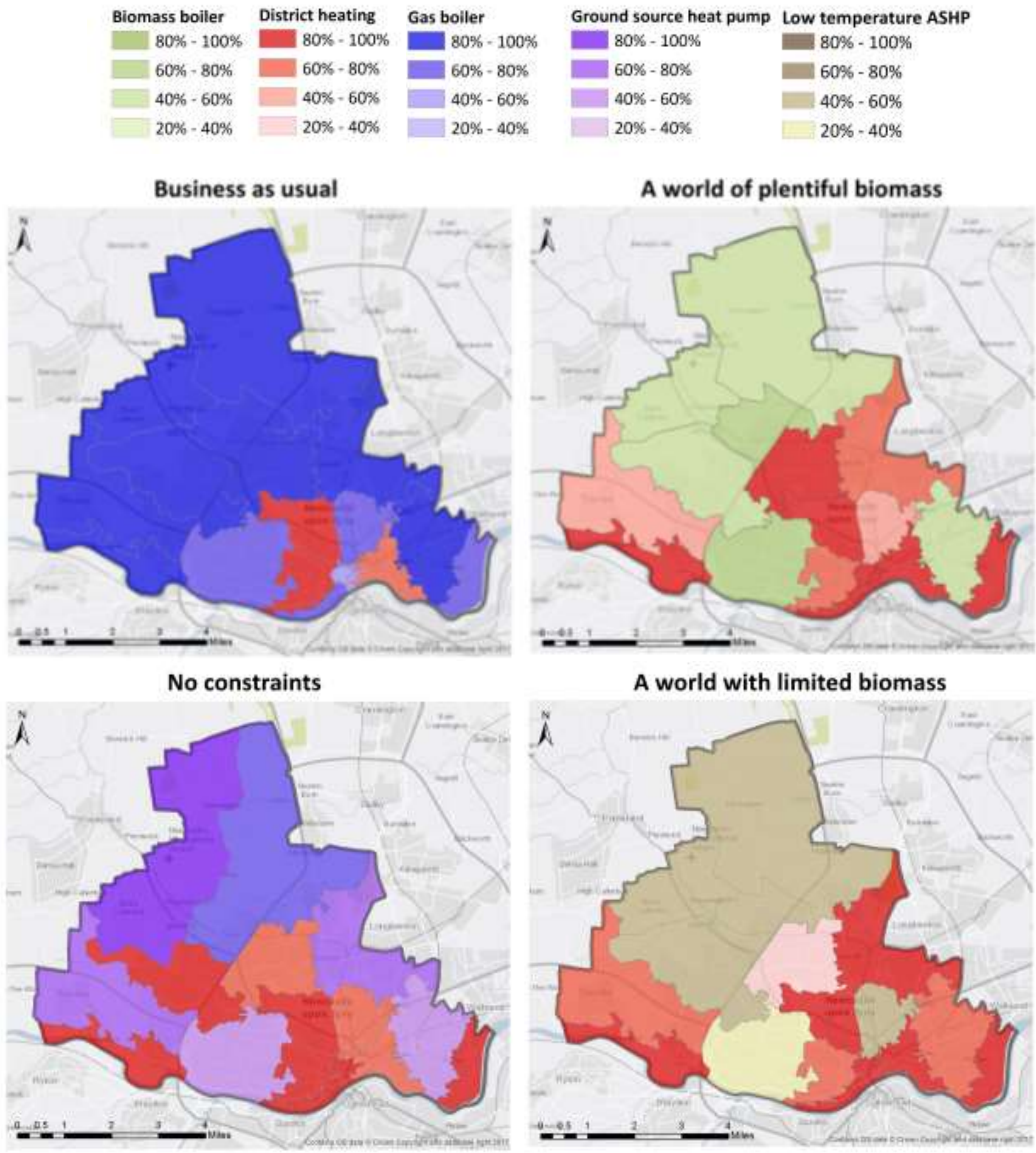


Figure 5-2 Predominant Heating Systems by Analysis Area in 2050 as Modelled by EnergyPath Networks

Figure 5-3 shows an example of this. Looking at the World of Plentiful Biomass scenario run[37], it can be seen that in the first transition the majority of homes are still using gas boilers and electrical resistive heating with some switching to heat networks based on Newcastle's current and planned heat networks. During the second transition period, a large increase in properties connected to heat networks is seen with the remaining properties switching to heat pumps (air

[37] Noting that all following figures in this section are based on the World of Plentiful Biomass Scenario

and ground source) or biomass boilers. The storage numbers refer to the capacity of a hot water tank used to store heat within the building in order to meet periods of peak demand.

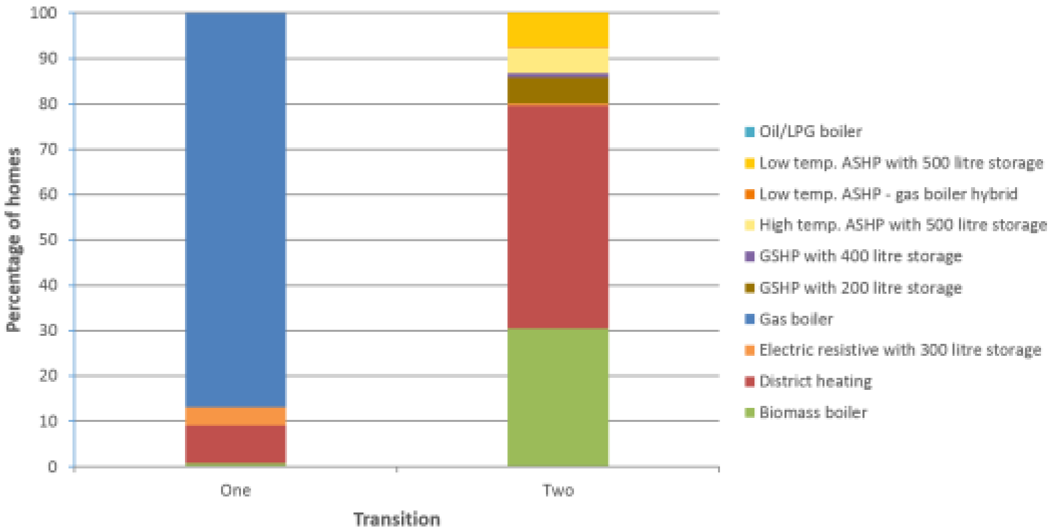


Figure 5-3 Modelled Changes in Heating Types Over the Two Transition Periods for a World with Limited Biomass

The previous maps showed the dominant heating system by ward in 2050. The analysis outputs give domestic heating outputs in much greater detail, looking at the full mix of heating systems present in a ward and the timing of the changes (by transition period). The mix of low carbon heating systems suitable in a ward is heavily driven by the diversity of property types present.

The map in Figure 5-4 shows housing density in analysis areas. This is an important consideration when examining Figures 5-5 to 5-9 as the number of houses differs, for instance analysis area 11 has around 62% of properties transitioning to biomass boilers, a total of 11,000 properties. Analysis area 7 on the other hand shows 69% of properties transitioning – but only a third of actual numbers of properties transition.

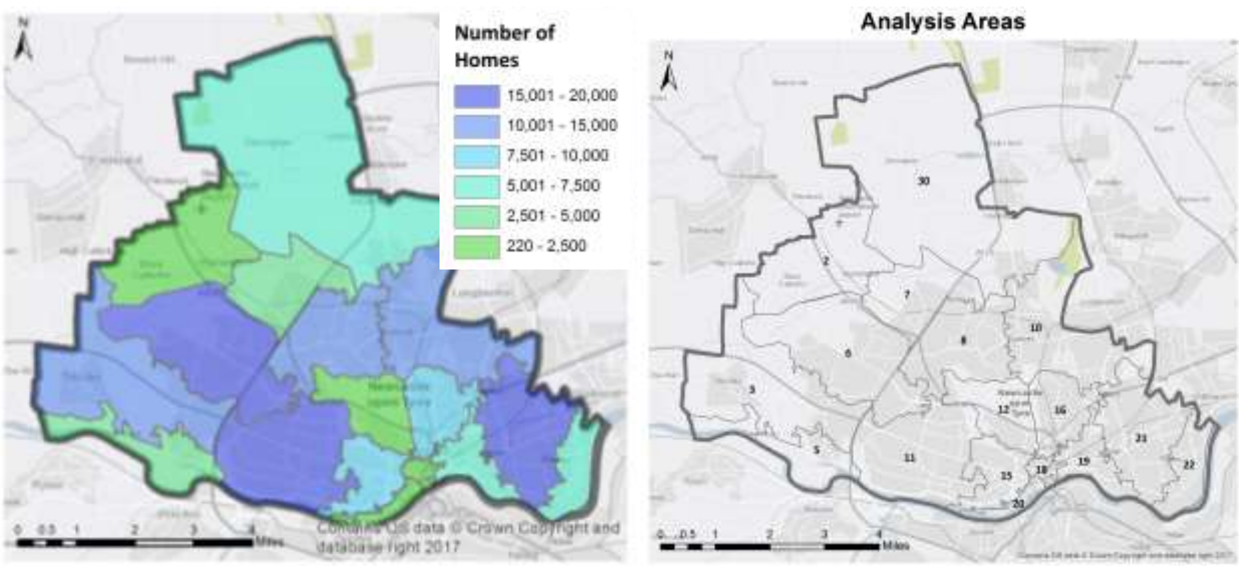


Figure 5-4 Housing Density (Number of Homes) by Analysis Area

Figure 5-5 to **Error! Reference source not found.** presents results from the World with Plentiful Biomass scenario and show an example of the greater detail available from the EnergyPath Networks modelling. Figure 5-5 shows the proportion of domestic buildings using gas boilers as their primary heat source in transition one. By 2050 these have been almost entirely replaced. Figure 5-6 shows the proportion of domestic buildings using electric resistive heating as their primary heat source, likewise by the second transition just one or two percent of buildings in a handful of analysis areas have electric resistive as their primary heating system – these may well be flats with constraints that make them unsuitable for any other heating system. Figure 5-7 shows the proportion of domestic buildings transitioning to ground source heat pumps by 2050, none are present in the first transition. The number of air source heat pumps coupled with a gas boiler as a secondary heating system (a “hybrid heat pump”) was in the 1-2% figure for a handful of analysis areas and is therefore an unattractive option in the Plentiful Biomass scenario. Figure 5-8 shows biomass boilers being strongly preferred in the second transition, even in densely populated areas. Figure 5-9 shows the proportion of domestic buildings transitioning to district heat networks as their primary heat source over time, with four analysis areas showing connections in the first transition.

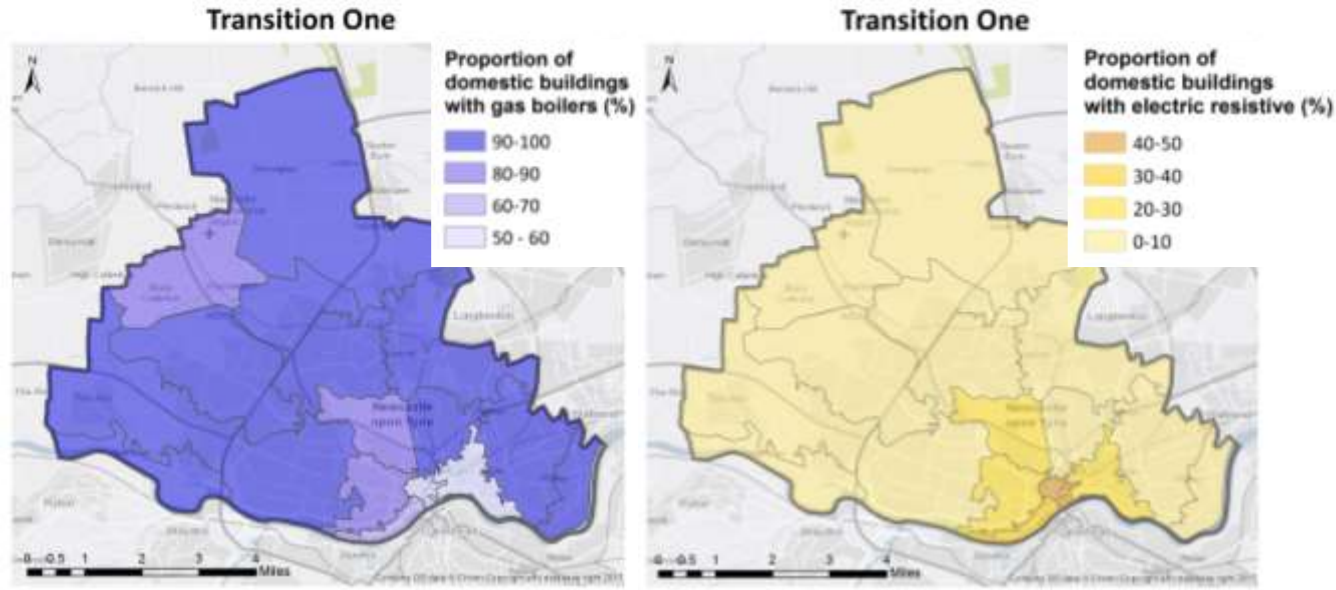


Figure 5-5 **Proportion of Domestic Buildings Using Gas Boilers and Figure 5-6 Using Electric Resistive Heating as their Primary Heat Source**

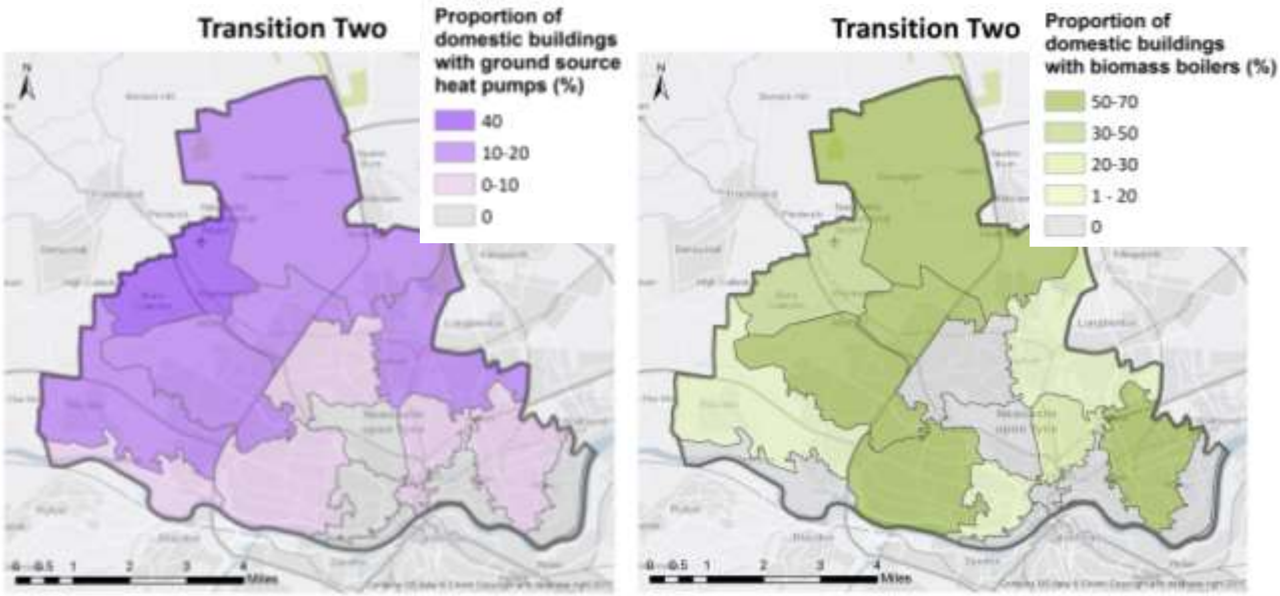


Figure 5-7 Proportion of Domestic Buildings Transitioning to Ground Source Heat Pumps with 200 litres of Storage and Figure 5-8 Transitioning to Biomass Boilers as their Primary Source of Heat

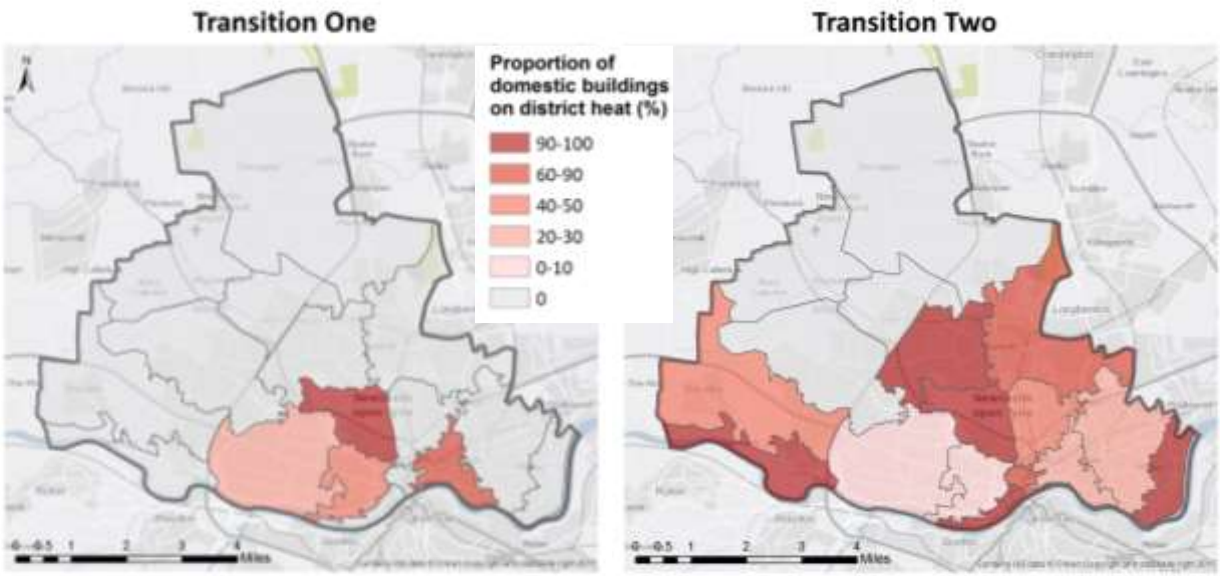


Figure 5-9 Proportion of Domestic Buildings Transitioning to District Heat Networks as their Primary heat source

5.1.4 Building Retrofit Options

Newcastle has over 127,000 households made up from a broad range of property types, 70 % of which were built before 1944. It is safe to assume that properties that would most benefit from building retrofit measures are older buildings which have lower fabric energy performance and require significantly more energy to keep them warm in winter than those built compliant with more recent regulations. There is a range of options available to help reduce heat loss from older buildings. Within EnergyPath Networks the main retrofit measures are applied in packages. All the applicable options within a package will be applied if that package is selected. For example, where an insulation package includes cavity wall insulation this will be applied if the building has unfilled cavity walls. If the building has filled cavities or solid walls then the other parts of the package will be applied without cavity wall insulation. Table 5-1 shows which measures are included in the different packages considered.

Table 5-1 Domestic Retrofit Measures

Domestic Retrofit Measures (Numbers in brackets indicate insulation package)	
Cavity wall insulation (1,2)	Double glazing
Energy-efficient doors	External wall insulation (2)
Floor insulation	Internal wall insulation
Loft insulation (1,2)	Mechanical ventilation
More than triple glazing	New build upgrade to High Thermal Efficiency
Triple glazing (2)	
Reduced infiltration 1 (Draught proofing)	Reduced infiltration 2 (Whole dwelling)

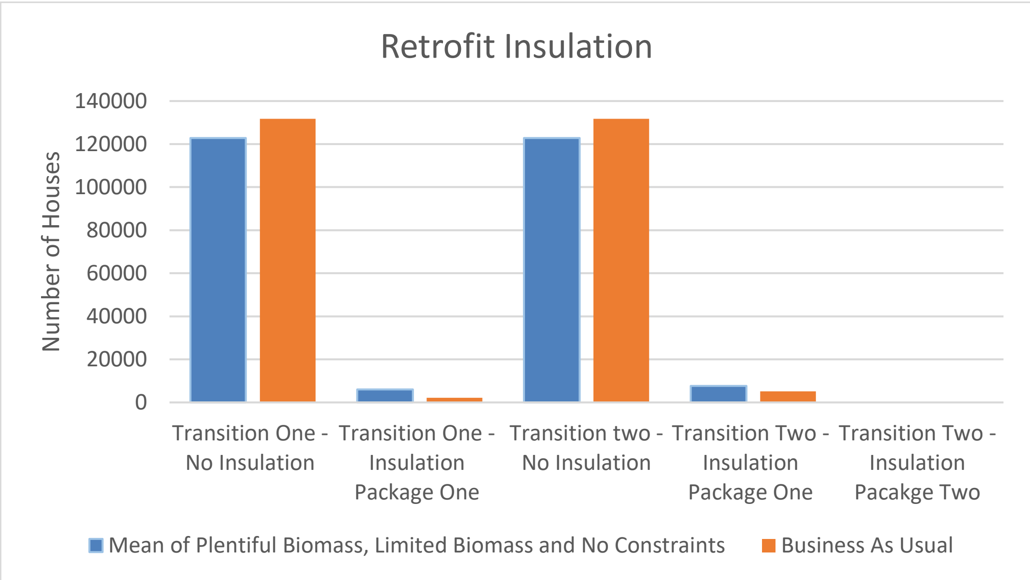


Figure 5-8 Modelled Uptake of Retrofit Options

Figure 5-8 shows the modelled uptake of retrofit options. The small error bars indicate a low degree of variability between the three scenarios. There are greater levels of retrofit insulation in the carbon target runs compared to business as usual, but overall the take up is low as the model does not consider it to be the cost optimal solution. The modelled levels of retrofit vary spatially across the study area. Figure 5-9 shows an example of this spatial pattern for the World of Plentiful Biomass scenario.

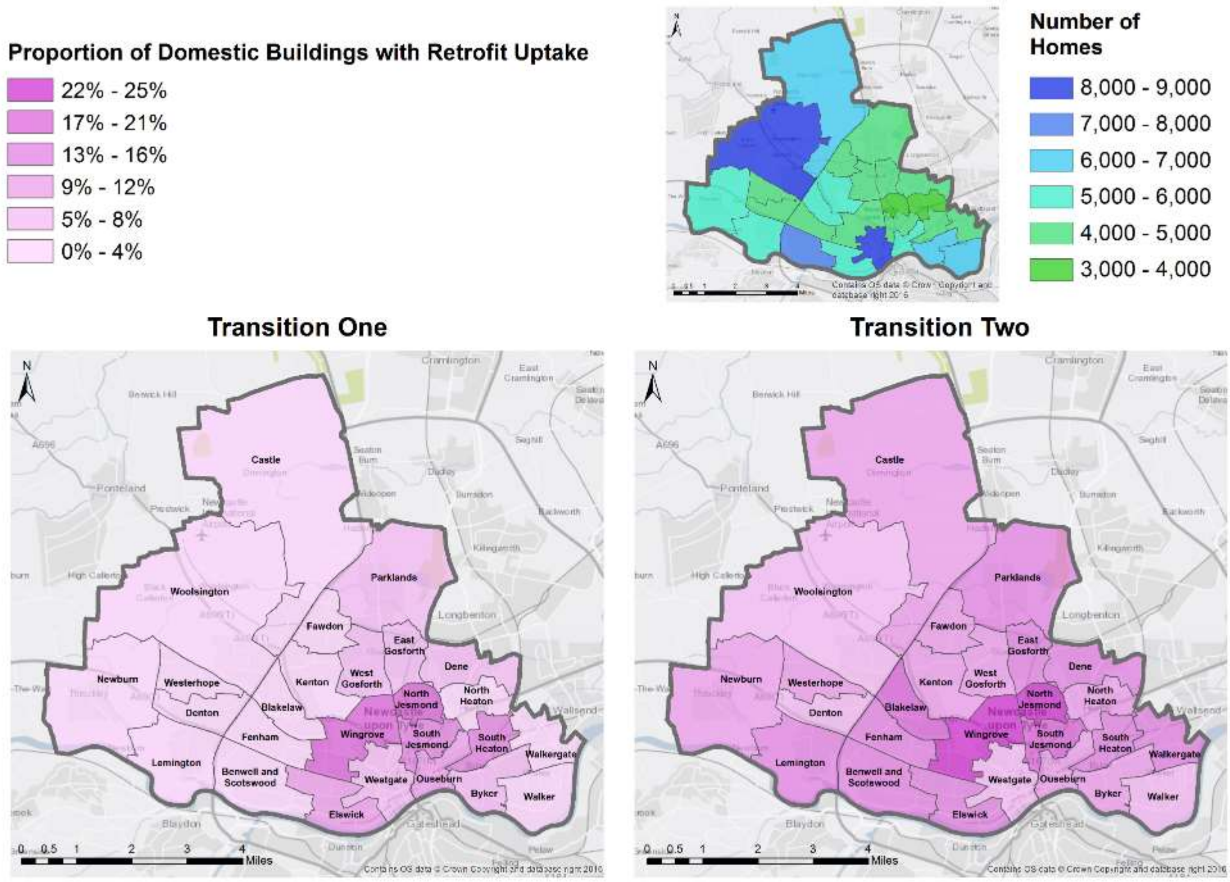


Figure 5-9 Numbers of Properties that will have Domestic Retrofit Measures Across the Proposed Two Transition Periods

Similar to the domestic heating systems, the large degree of the spatial variability in retrofit uptake is driven by the mix of property types present in each ward.

Domestic Retrofit Key Points

- Modelling has shown that domestic retrofit is not a wide scale cost optimal solution to decarbonise as other options are more cost effective.
- The model doesn't highlight a significant variance in domestic retrofit prioritisation between business as usual and in any of the scenarios with a carbon reduction target.
- Retrofit is most suitable in wards with the greatest proportions of older housing stock.

5.1.5 Heat Networks

In all scenarios with a carbon target a significant number of properties transition to district heat networks by 2050. District heat networks provide heat (in the form of heated water) to buildings through pipes that carry the heat from a central heat source. Generally, in today's systems this typically comprises a large (or number of) gas fired boiler(s) or gas fired combined heat & power plant which provides heat to the network as well as generating electricity which is exported to the local electricity network, or used in local buildings. Once installed these systems can be converted from using gas to provide heat using lower carbon alternatives such as a large-scale ground source heat pump or a biomass boiler.

Figure 5-10 illustrates the level of annual heat demand from heat networks across the region as modelled by EnergyPath Networks for the years 2020 and 2050 and provides an example of the further detailed information EnergyPath Networks can provide on heat networks. These examples are based on the World of Plentiful Biomass scenario. Options are provided within EnergyPath Networks to build energy centres at particular locations in the city (these locations were provided by Newcastle City Council). At each location a range of heat technology options are provided which can be selected within the optimiser. In addition, options are given to build heat transmission pipes between different parts of the city. This allows smaller, individual heat networks to grow over time such that an integrated system fed by a selection of energy centres is achieved in later years. Allowing transmission of heat between the individual networks provides increased flexibility and security of heat supply as well as the opportunity to decrease costs through achieving economies of scale. The model outputs include the technologies selected in each energy centre and the annual heat transmissions predicted between the different areas of the city. These heat transmissions are shown in Figure 5-11.

Heat Networks: Annual Heat Demand

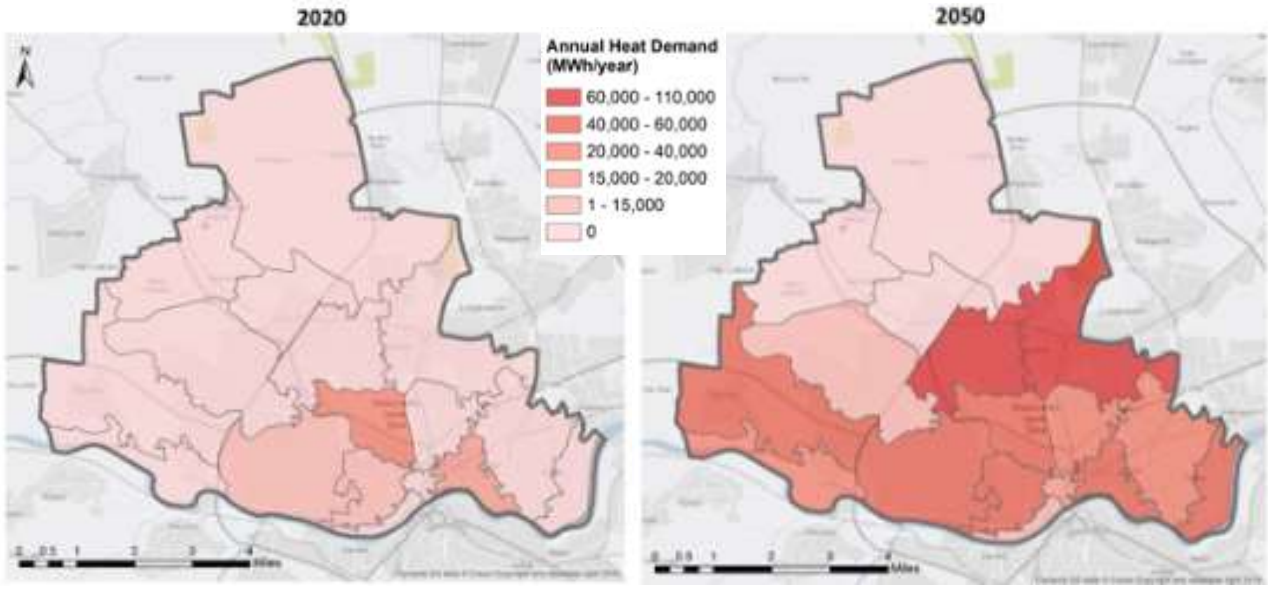


Figure 5-10 Modelled Annual Heat Demand for 2020 & 2050 in the World of Plentiful Biomass Scenario

Heat Networks: Annual Heat Transmission for 2050

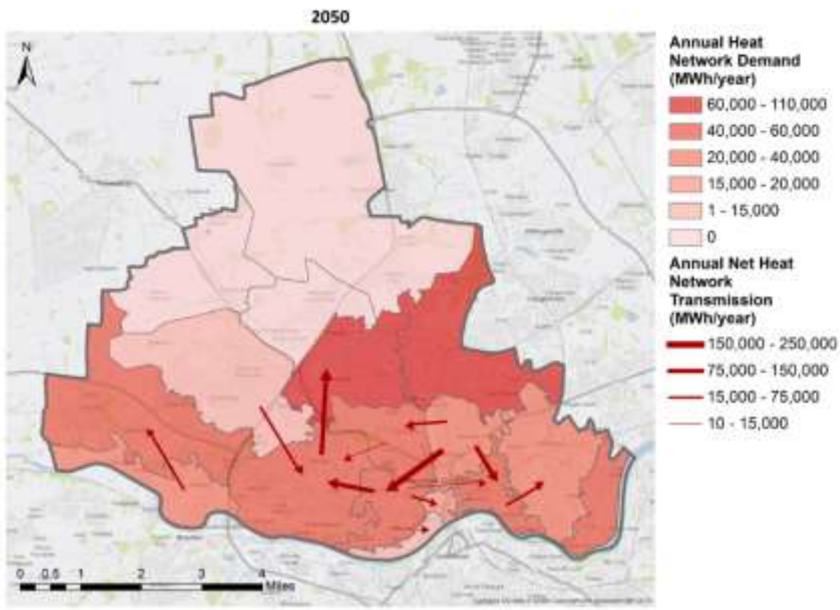


Figure 5-11 Heat Networks Annual Heat Transmission for 2050 associated with a pan-city level deployment

Figure 5-12 shows the heat network capacity for the planning period and indicates the pace and level of growth between 2020 and 2050.

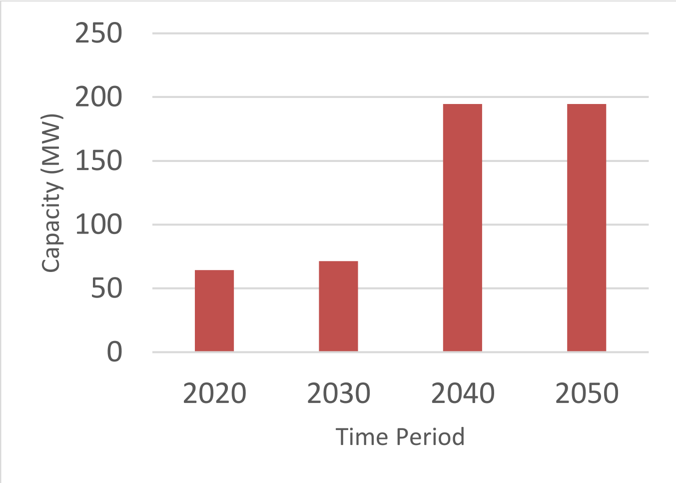


Figure 5-12 Modelled Heat Network Capacity

Domestic Building Connection Constraints

In addition to the supply side of a heat network, consideration must also be given to the type of buildings the network will serve and consequently the connections required. Different housing types come with unique challenges regarding connection, mainly relating to the nature of existing pipework, spatial constraints and the proximity of other connections (or housing density). Some areas of the city have a relatively higher concentration of social housing and therefore represent a more suitable opportunity for deployment of district heat networks from a deliverability perspective. In other areas with a high concentration of privately rented dwellings it might be more difficult to implement. For all connections, a heat exchanger is required at the point of connection. Typically, this will include a single Heat Interface Unit per dwelling (to meter consumption and control temperatures.

Single Dwellings

While the large amount of space for pipework and Heat Interchange Units (HIUs) often makes it technically feasible to connect detached and semi-detached houses to a district heat network, the low housing density (and therefore low heat demand density) typically means that it is currently not cost effective to do so.

Terraced Housing

As with single dwellings or houses, terraced housing could be connected to the network with HIUs located within each dwelling to the primary DH network. If pressure ratings (or the operation of the network) dictate the requirement for an additional heat exchanger, this could be shared between a number of houses (e.g. a single heat exchanger providing pressure break for 10 – 20 houses in single terrace) therefore reducing the cost. This can be located outside, possibly in a garden or on public land to improve access for pipework installation and maintenance. This practicality of technical design would be based on commercial arrangements, phasing of construction and details of design.

Blocks of Flats

Typically, blocks of flats- and especially social housing blocks- have a communal boiler which can be replaced with a large plate heat exchanger. This is usually the most desirable housing type for DH connection because of the readily available space and high heating density. The areas where blocks of social housing flats are concentrated should be considered as favourable DH connection areas.

Where a block of flats is served by individual boilers it may prove to be difficult to get new district-scale pipework into the building if it doesn't already exist as riser space may be limited internally. The pipework could be installed externally to serve the flats although this may require consideration of local planning and building regulation requirements. Similarly, blocks of flats that are electrically heated would have no wet heating pipework or radiators and therefore require both of these to be installed. The costs to install a wet heating system into an electrically heated flat is typically in the region of £2000 – 3000 per dwelling.

Heat Network Key Points

- Widespread adoption of heat networks can be targeted for the urban centre. These networks are expected to spread further out in the city over time.
- Current and planned heat networks will act as a seed for wider growth and adoption and growth of heat networks within the city.
- Energy Centres are likely to initially use gas boilers and gas CHP and should be designed to allow a shift to low carbon heat sources such as large-scale heat pumps after 2030.

5.1.6 Energy Centres

Heat networks require energy centres to provide the required heat (and electricity in cases of cogeneration). Energy centres represent the centre of district heat networks which could be powered by gas boilers combined with combined heat and power (CHP) in the short-term, but can then switch to lower carbon options in the future such as greater proportions of combined heat and power (CHP), biomass boilers (using wood or alternative fuels), large scale heat pumps using decarbonised electricity and 'used/waste heat', being excess heat from suitable sources. The latter can be used directly to provide energy to heat networks and is an efficient and potentially cost-effective source of low-cost, low or zero carbon heat.

Figure 5-13 shows future energy centres capacities and their location in higher population density areas as modelled by EnergyPath Networks. The figure shows the increase in capacity between transition one and transition two. Figure 5-14 shows modelled capacity growth and the changes in heat generation technologies with the increased contribution from large-scale heat pumps relative to gas and CHP boilers over the planning period.

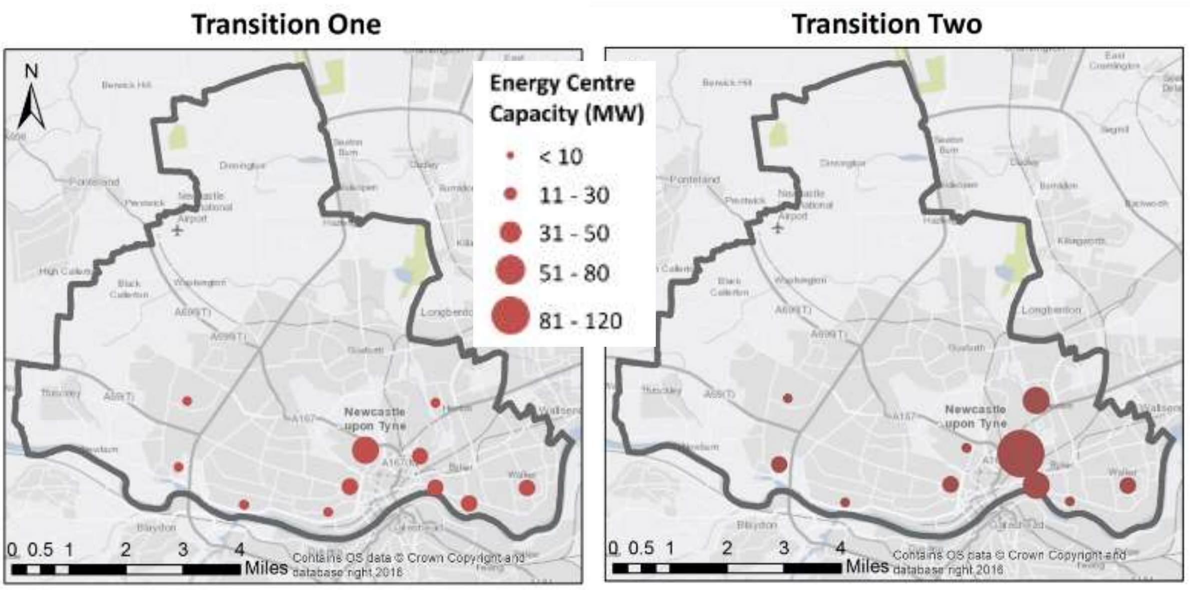


Figure 5-13 Location & Capacity of Energy Centres for (a) Transition 1 & (b) Transition 2 Modelled by EnergyPath Networks.

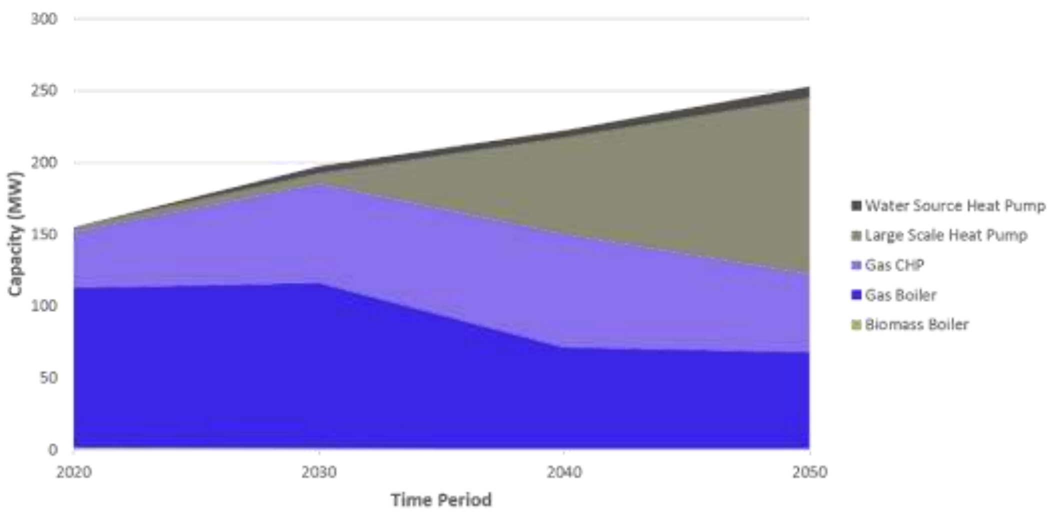


Figure 5-14 Capacity Growth & the Transition for Five Heat Generation Technologies.

Figure 5-14 shows the modelled capacity growth of heat generation technologies serving energy centres over the period 2020 to 2050. Gas is increasingly used to 2030 but then generation starts to shift to large scale heat pumps from 2030 as it is assumed that this system type can provide very low carbon heat, coinciding with the assumed decarbonisation of electricity.

Figure 5-15 shows the balance between electricity, used heat and initially unused heat over the planning period, illustrating a large increase in the amount of heat produced and used. In early years gas powered CHP is run in order to produce electricity (because it is financially beneficial to do so when compared to using grid imported electricity) and some of the heat produced is not initially used[38]. In later years, as heat networks grow all the heat produced from gas CHP is used in the networks. By 2050 it is not possible to meet the carbon target whilst running gas CHP and all the required heat comes from different sources. Figure 5-16 shows modelled electricity and heat production profiles for different technologies. Under this scenario, electricity production from Gas CHP reaches a peak in 2030 before declining to close to zero by 2050.

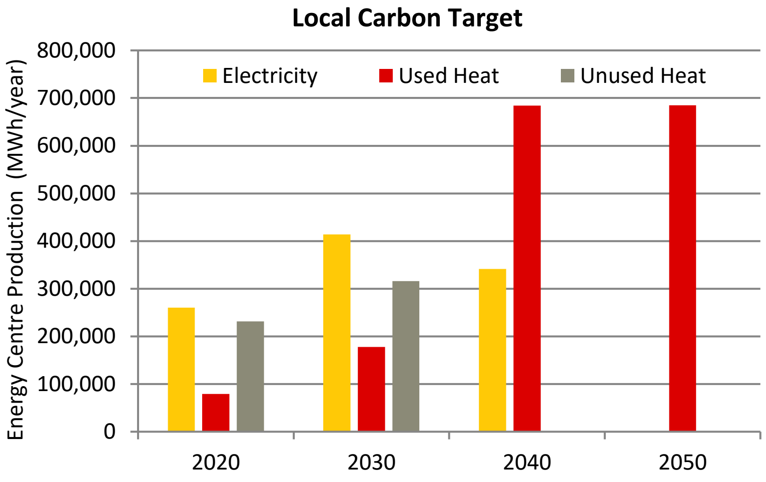


Figure 5-15 Balance Between Electricity, Used Heat & Unused Heat Over the Planning Period

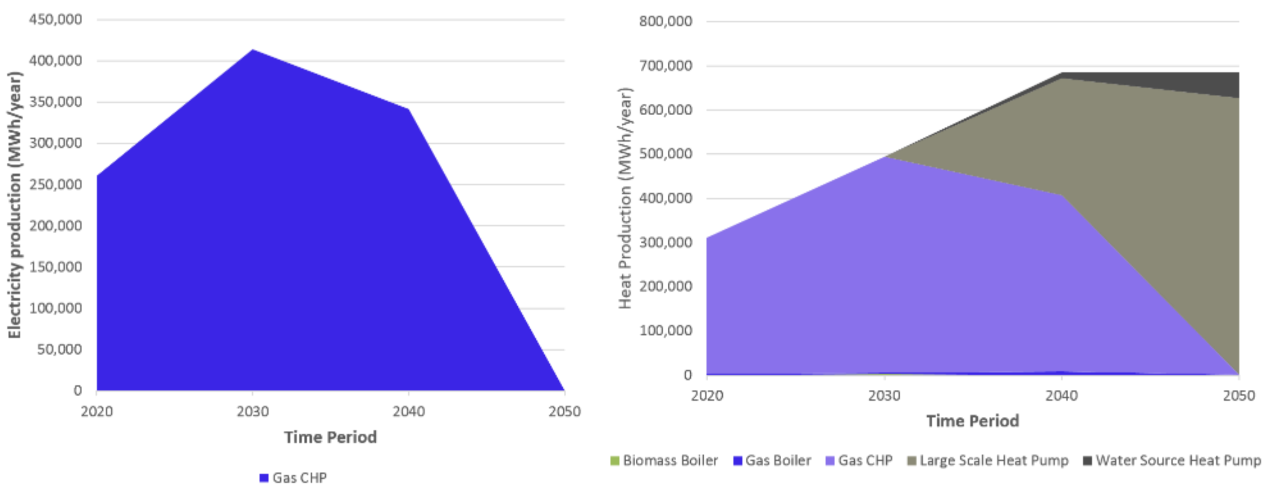


Figure 5-16 Modelled Electricity & Heat Production Profiles for Different Technologies

Energy Centre Locations

Careful thought should be given to the location of energy centres, in order to minimise any potential adverse effects on residents. Finding available land to house an energy centre close to the heat demand can be difficult and requires consideration. Proximity to tall buildings can cause

[38] ENERGYPATH NETWORKS is considering the whole energy system for Newcastle from a purely financial position to achieve an overall carbon emission reduction rather than maximising carbon emission at a heat network level.

problems in terms of flue gas dispersal. To mitigate this, high-level flue stacks allow gases to be dispersed to the atmosphere away from nearby buildings and occupants.

Air Quality

An Air Quality Action Plan (AQAP) has been prepared on behalf of Newcastle City Council to fulfil its statutory obligation under section 84(2) of the Environment Act 1995. This document refers largely to the transport sector but it identifies areas of Newcastle city centre where air quality improvements are required. Indicators of air quality are oxides of nitrogen (NOx) and carbon particulates (PM10) levels. These areas are known as Air Quality Management Areas (AQMAs) and are located in the City Centre and Quayside. Within EnergyPath Networks deployment of energy centres was restricted in these locations in order to comply with the AQAP. District heat networks can improve local air quality by replacing small individual boilers that have shorter flues with large energy centres with high level stacks. Waste gases are then dispersed to the air at a greater height from where buildings and people are located. These waste gases may include oxides of Nitrogen (NOx), sulphur (SOx) and carbon particulate matter. Flue stacks are required to terminate a minimum of 3m to 4m above the top of the energy centre or any other buildings in their zone of influence.

Noise Issues

Engines (either diesel or gas operating in CHP mode) and standard gas/biomass boiler plants have moving parts (i.e. internal combustion engine, associated pumps or electrical generators) which emit noise into the nearby area. Energy centre design and planning should consider the effects of this noise on the local environment. While a gas engine or turbine unit operating in CHP mode usually operates continuously, other intermittently operating parts of an energy centre such as pumps and compressors can be more of a nuisance to local residents. Under the Environmental Protection Act 1990 noises that may damage health or are a nuisance should be investigated by the Local Authority.

Policy CS14 Wellbeing and Health in Newcastle's Planning Policy Document (2010 – 2030)[39] states the wellbeing and health of communities can be maintained and improved by *preventing negative impacts on residential amenity and wider public safety from noise, ground instability, ground and water contamination, vibration and air quality.* Within EnergyPath Networks the deployment of energy centres in locations that will conflict with the above statement was restricted.

Visual Impact

Like air quality and noise, the design and external appearance of the energy centres will be a matter considered by a planning authority when a planning application for the energy centre is submitted. Although design quality matters, context also matters. Energy centres should be in keeping with the surrounding townscape, consequently those proposed in a conservation area or

[39] Newcastle City Council Planning for the Future the Core Strategy

adjacent to a listed building will have more stringent standards applied than one in an urban or brownfield setting. Height and massing are key considerations for energy centres located in close proximity to other buildings. Energy centres in open areas ideally will be more prominent than those in dense urban settings.

After a feasibility review of the energy centre locations in the no-constraints scenario, a number of further constraints were introduced into the with-constraints scenario based on some of the impacts identified above. This limited the location of some low carbon technologies in the model and increased the costs of reaching the carbon target.

5.1.7 Large Scale Heat Pumps

With an increasingly decarbonised electricity grid, integrating heat pumps into a district heat network can reduce the CO_2 emissions associated with heat generation. Water courses and groundwater can provide a source of heat for large scale heat pumps.

The River Tyne runs west to east through Newcastle and could provide a suitable source of heat for Water Source Heat Pumps (WSHPs) subject to planning and environmental issues which would need to be addressed as part of the required planning and regulatory approvals. The *National Heat Map* lists the mean temperature of the River Tyne as 6.18°C. However, the River Tyne temperature plot from 1973-2005 (Figure 5-17) suggests mean temperature to be closer to 9^{o}C at Chollerford and 10^{o}C at Newcastle Wylam Bridge. A temperature range of 5-12°C is suitable for a heat pump where a temperature drop across inlet and return is optimal at 6°C.

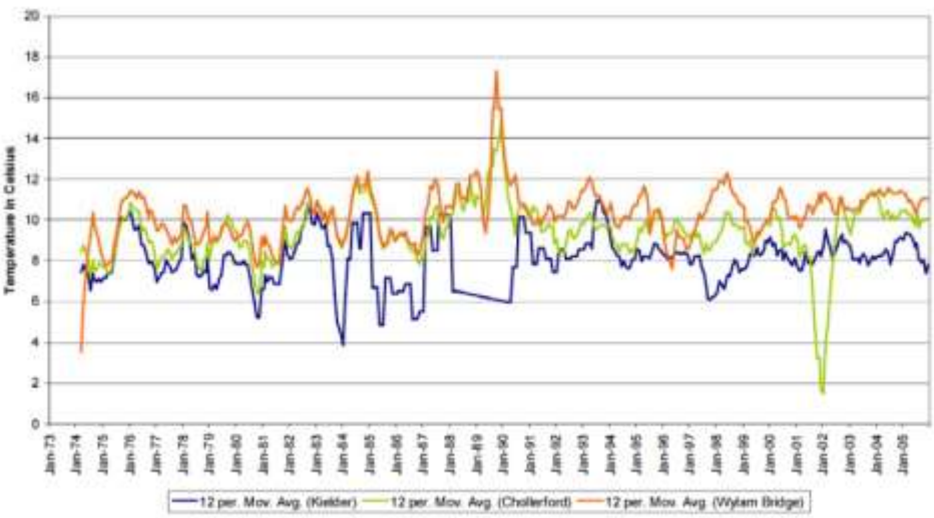


Figure 5-17 River Tyne temperature range at three locations, 1973 - 2005[40]

Ideally, heat pump energy centres should be located closer to the source of heat, as it is preferable for water to be diverted a shorter distance, reducing pumping requirements and therefore minimising inefficiencies. Total costs may also be reduced as a shorter pipe network and associated civil engineering work would be required. Despite the prevalence of canals and

[40] Climate change impacts and water temperature (2007) *Environment Agency*; Bristol, UK

estuaries in the northern modelling areas, WSHPs are not considered suitable here because their relatively small size may result in 'cold sinks' when heat is overdrawn from them. This is also true for Ground Sourced Heat Pumps (GSHPs). Despite the advantages of using heat pumps in a district heat network there are technical issues with respect to network temperatures that should be considered. Few examples of heat pumps in high temperature networks (70°C +) in the UK exist, although there are several in Scandinavia which are commonly centralised heat pumps retrofitted into an existing network. Consequently, while marginal costs and retrofit disruption are reduced so too are the efficiencies achieved.

Decreased heat demand during summer and variable source temperature are the two key factors that may affect heat pump efficiency. Operating at part load can improve efficiency with heat pumps normally fitted with variable speed compressors (and often multiple compressors per heat pump) and can therefore be modulated to 10-20% of full capacity. Variable temperatures can in some cases provide additional flexibility if heat pumps can connect to different sources at different times of the year. Hybrid systems could potentially be used in the future to solve both problems of part load and source temperature. During colder winter months, a boiler or CHP can provide top-up heat to meet peak demand and during the summer a heat pump could be used alone, taking advantage of its improved efficiency during this time of the year. A combination of the two supply sources can also be configured at any time in between. This may be preferable to oversizing a heat pump in order to meet demand throughout the entire year as considerable capital costs can be saved.

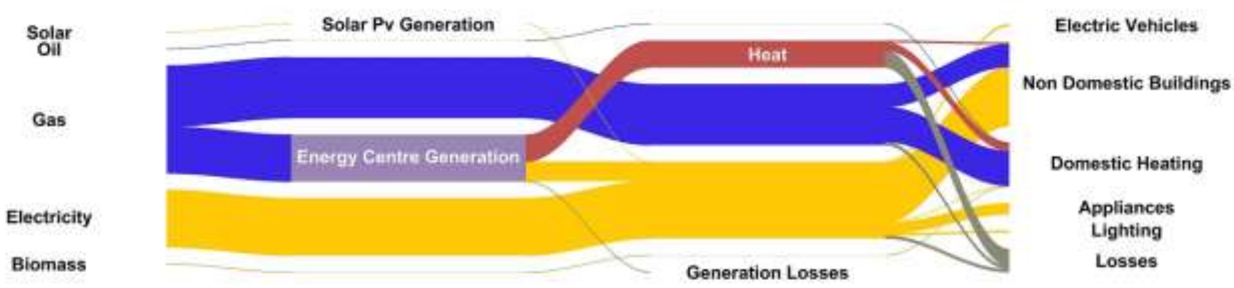
5.1.8 Electricity and Gas Networks

In the transition to a low carbon national energy system, the future electricity and gas network will undergo a significant level of change. The electricity network will need to be developed to support the increased reliance on this source of energy. The gas network might be decommissioned or re-purposed for use with hydrogen or as a conduit for carbon capture and storage.

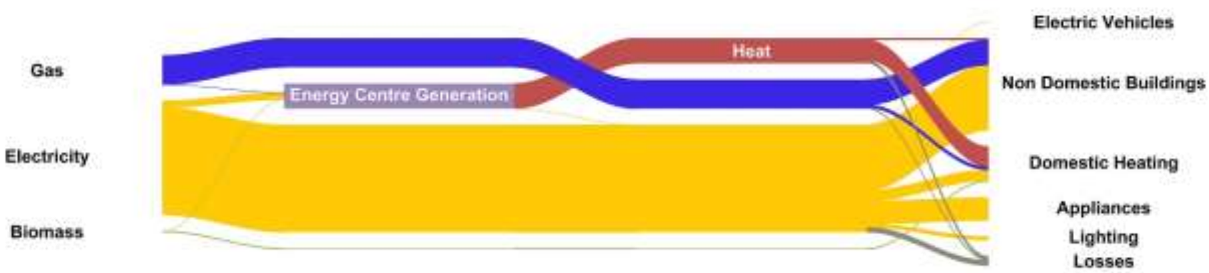
Figure 5-18 consists of four Sankey[41] Diagrams demonstrating how the flow of energy throughout Newcastle, from source to the end user, might change by 2050 as a result of one of the four modelled scenarios. Under the Business-As-Usual scenario gas is the predominant domestic heating fuel and the source of all energy centre generation with the other diagrams showing the different ways this gas may be displaced across the alternative carbon reduction scenarios. Under the no constraints and World with Limited Biomass scenarios the majority of gas displacement in homes is via a district heat network, with some electricity and residual gas, whereas in the World of Plentiful Biomass scenario district heating and biomass are the dominant domestic heating

[41] A Sankey Diagram illustrates the flow of energy. The flows on the left represent the energy inputs into Newcastle's modelled energy systems. The width of the graphic is proportionate to the overall total energy flow. The mid-point illustrates the conversion to the resultant energy end use on the right.

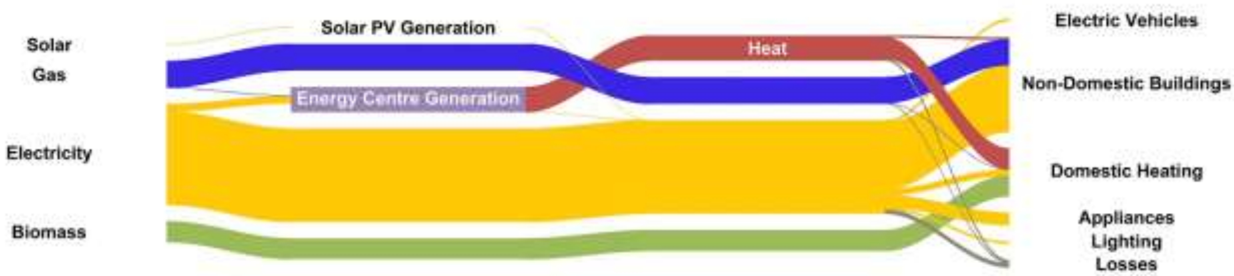
energy sources. In all cases with a local carbon target gas-fired heating is almost completely displaced from domestic buildings.



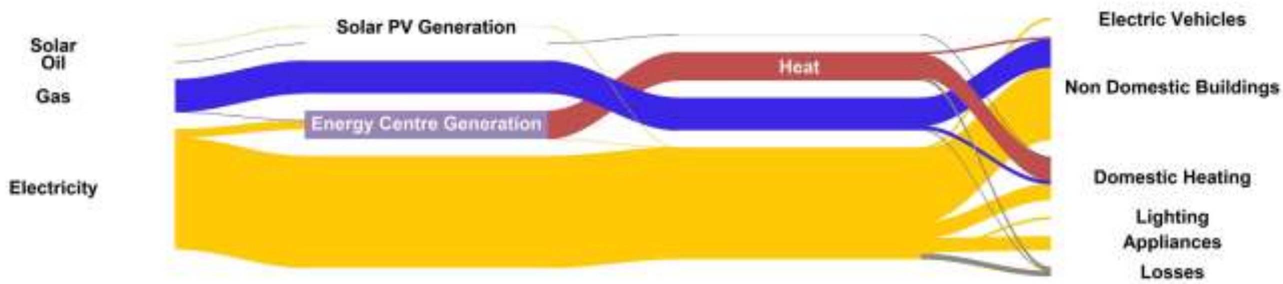
(a) Business-as-Usual Scenario in 2050



(b) No-Constraints Scenario in 2050



(c) World of Plentiful Biomass Scenario in 2050



(d) World with Limited Biomass Scenario in 2050

Figure 5-18 Changes in Energy Flow from Source to End-User in 2050 for BAU and three scenarios

The output of EnergyPath Networks illustrates the demand changes that the proposed transition of heat / energy supply chain will require. The challenge for the distribution network operators is to know which scenario will develop and then plan for the change, and to agree with the regulator the apportionment of cost associated with the required infrastructure alterations. Within the corresponding Local Area Energy Strategy, some suggestions as to the policy, regulation and social economic challenges have been identified. A key aspect being the support to and from the residential and business community to the proposed future changes in the way heat is provided.

Figure 5-19 shows the modelled increase in annual electrical demand over the study period. Non-domestic (ND) buildings comprise the largest source of demand throughout the period with an increasing proportion coming from energy centres and domestic buildings. The much smaller demand from lighting, EV and electric appliances remains approximately constant throughout. The error bar indicates the range of modelled values and shows that regardless of the scenario chosen, there will be a substantial increase in electricity demand. This illustrates the challenge faced by the electricity distribution network operator to manage an increasing demand from a variety of sources.

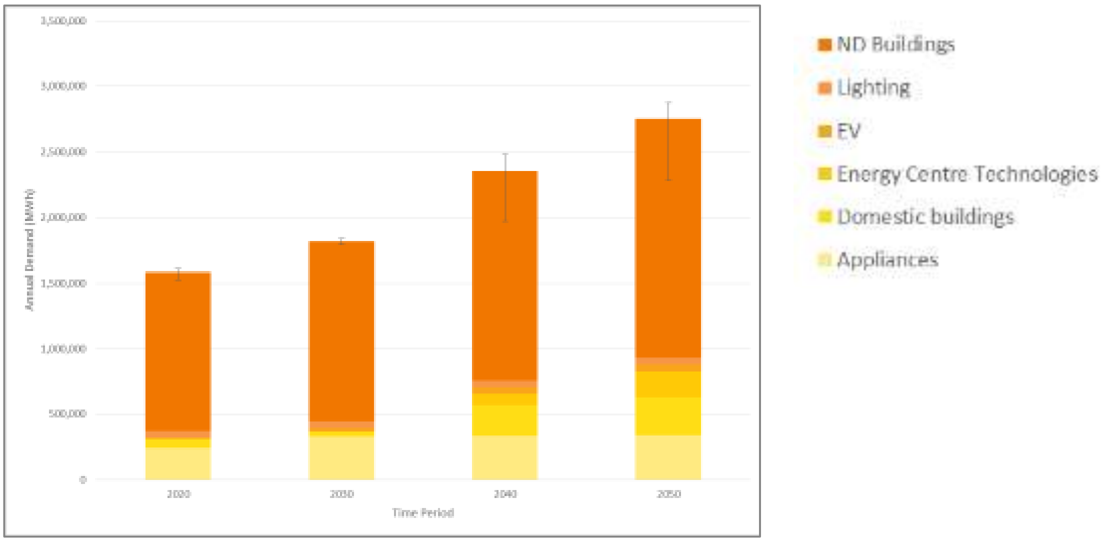


Figure 5-19 Change in the Demand for Electricity by Sector to 2050 - The main bars are a mean of the four modelled scenarios and the error bars indicate the range of results.

Figure 5-20 shows how decarbonising domestic heating increases the demand for electricity significantly over the period of study. Figures 5-22 and 5-22b show an example of how the changes in electricity demand may vary spatially throughout the study area. These maps are from the World of Plentiful Biomass scenario and illustrate how greater levels of network capacity will be required in certain areas of the city.

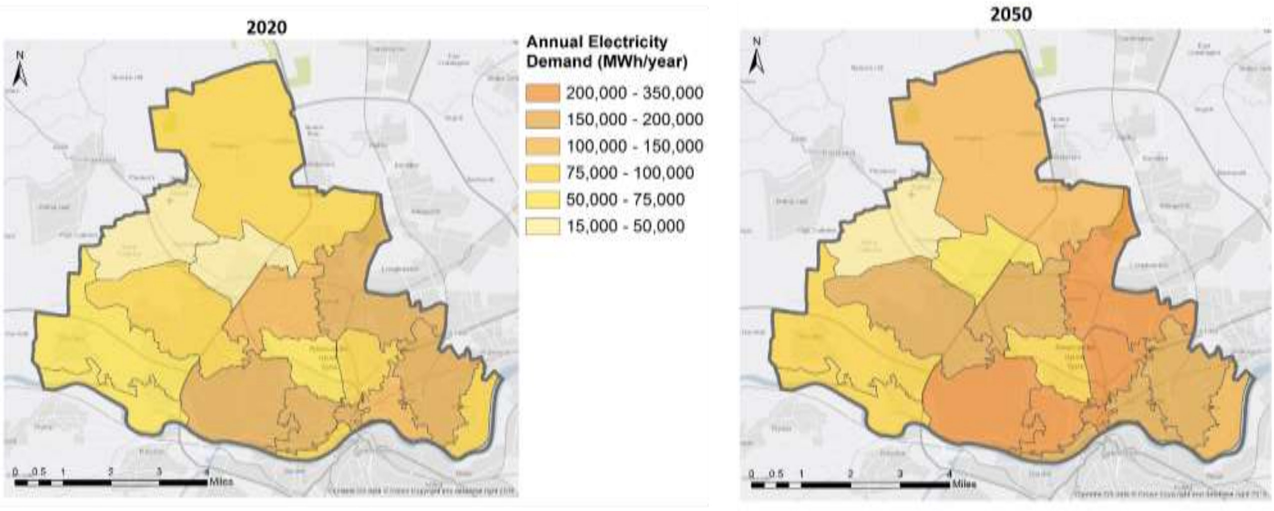


Figure 5-22a: The Potential Spatial Variation in Changes in Electricity Demand Across the Region

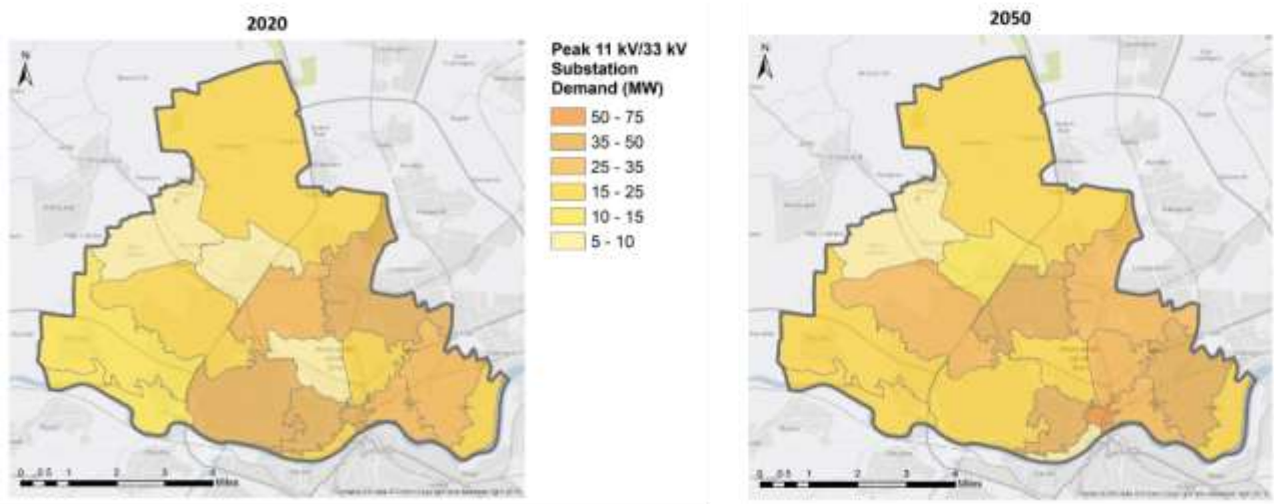


Figure 5-22b: The Potential Spatial Variation in Changes in Peak Electricity Demand Across the Region.

Figure 5-20 Potential Spatial Variation in Changes in Electricity Across the Region

Figure 5-21 illustrates how the change in electricity demand leads to a requirement to increase the network capacity. The figures are expressed as a change from the business as usual scenario, and so indicate the extra network capacity that will be required to meet the carbon target. In 2040 and 2050 there is a requirement to install greater capacity on both high and low voltage feeders and transformers.

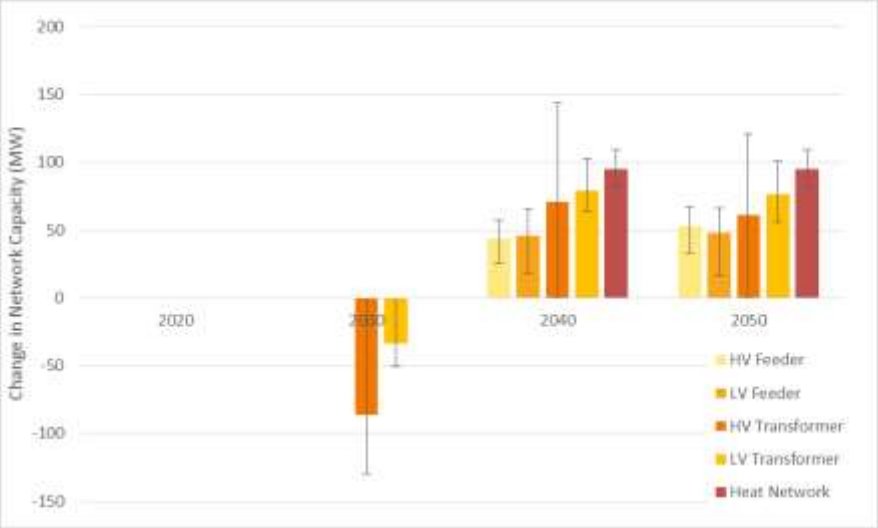


Figure 5-21 Modelled Increase in Electricity Network Capacity Between 2020 & 2050 – (The main bars indicate the mean of the three scenarios, expressed as a change from BAU. The error bars indicate the full range of change values).

Gas Network Impact

The modelled decarbonisation scenarios will impact the gas networks. Whilst it is not currently possible to know what will transpire, potential future scenarios include:

- Gas is still an important part of heat supply solution to 2040 in local areas.
- Short term increases in gas consumption for urban gas CHP energy centres.
- Long term shifts to electricity with homes moving from gas boilers.
- Decarbonisation of gas network could be a significant factor although the options for production of large quantities of low carbon gas are likely to be limited.
- Re-purposing of the gas network to hydrogen.

Figure 5-22 and Figure 5-23 shows the modelled decline in gas demand as domestic buildings are switched to electric heating and heat networks. By 2050 virtually all gas consumed is by the non-domestic properties which are excluded from the transition model. The large range shown represents the Business-As-Usual scenario, where properties stay on gas because there is no carbon reduction requirement under this option. The reduction in gas demand that will be required to meet the carbon target (as properties switch to lower carbon options) provides a challenge to the financial viability of the gas network. The small amount of domestic gas still present in 2050 is generally attributed to the modelled use of hybrid electric-gas heat pumps.

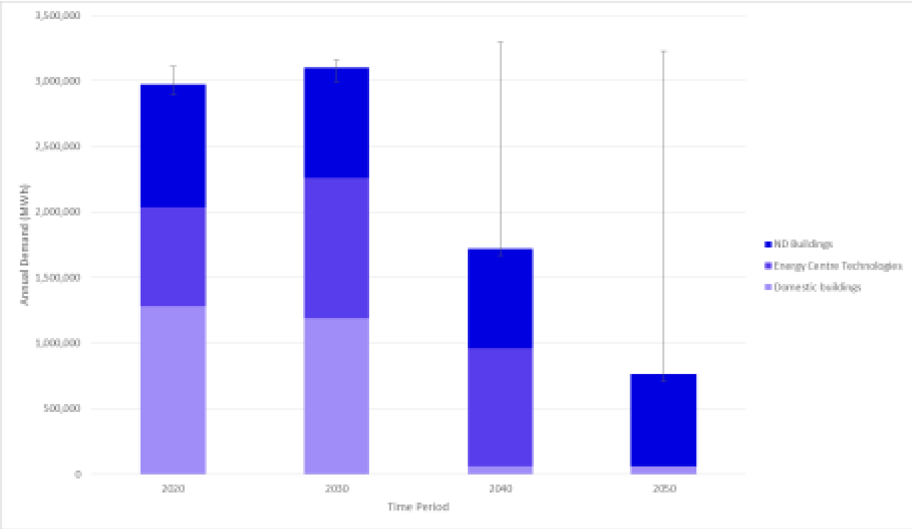


Figure 5-22 **Modelled Shift in the Demand for Gas by Sector – (The main bars represent the mean of the four scenarios, the error bars indicate the full range of modelled outputs).**

Figure 5-23 shows the modelled shift in the demand for gas between 2020 and 2050. Annual gas demand is reduced approximately fivefold (by 160-230000 MWh/year) in central areas over the period.

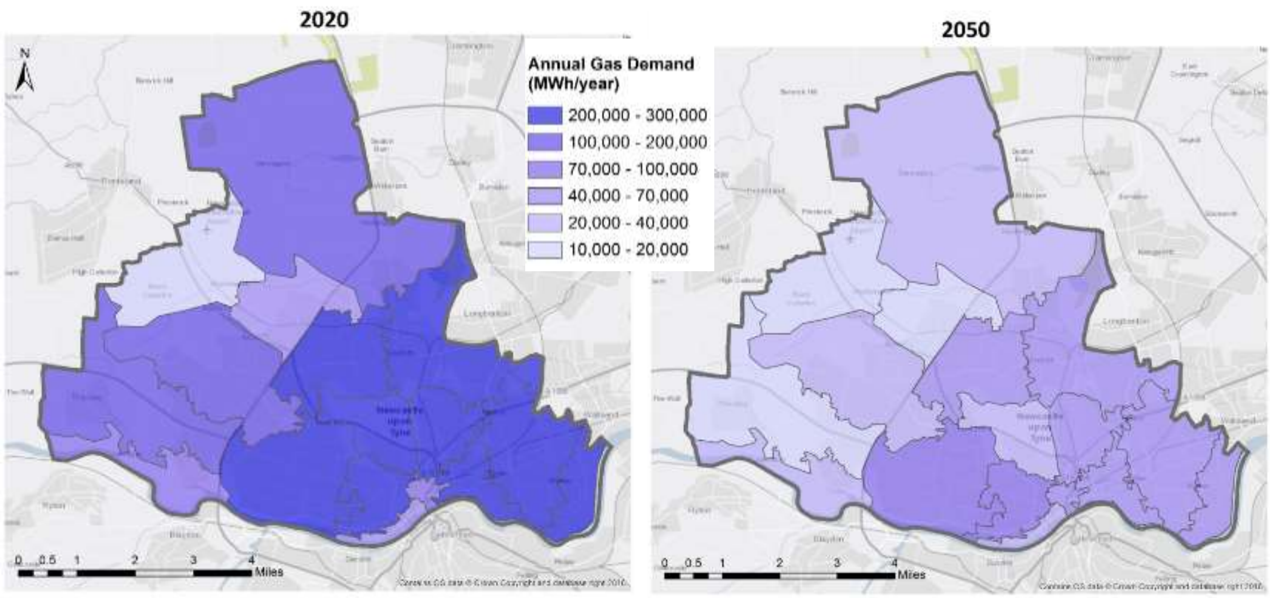


Figure 5-23 Modelled Shift in the Demand for Gas Across the City Between 2020 and 2050 for the World of Plentiful Biomass Scenario

5.2 Cost Analysis

5.2.1 Total Systems Costs

EnergyPath Networks modelling was used to estimate Newcastle's total energy system costs between 2015 and 2050, under the four scenarios. The cost of energy system transition in

Newcastle is estimated to be between £11.6 billion and £11.9 billion. When compared to the estimated £10.4 billion cost of the Business-as-Usual (do-nothing) pathway which only maintains the existing energy system, the benefits should be assessed only in terms of the additional 1.2 billion to £1.4 billion spend.

Figure 5-24 shows the proportion of total modelled costs for the business-as-usual scenario compared to the World with Limited Biomass scenario to 2050. The largest cost is electricity, followed by spend on domestic buildings and then gas imports. Energy networks and then energy centres represent smaller proportions of total costs.

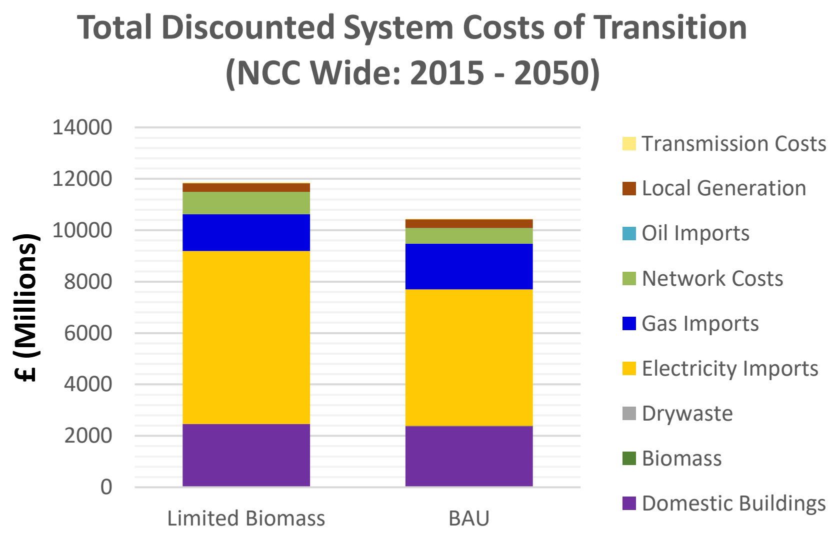


Figure 5-24 Total System Cost Breakdown to 2050 Discounted to 2015 value

Figure 5-25 shows the changes in the total system cost and breakdown for each of the three carbon target scenarios compared to the business as usual situation. Bars shown above the x-axis indicate an increased spend under that scenario, and bars below illustrate reductions. It illustrates a reduction in spending on gas due to the need for carbon reduction which is more than offset by an increased spend on electricity, energy networks and biomass.

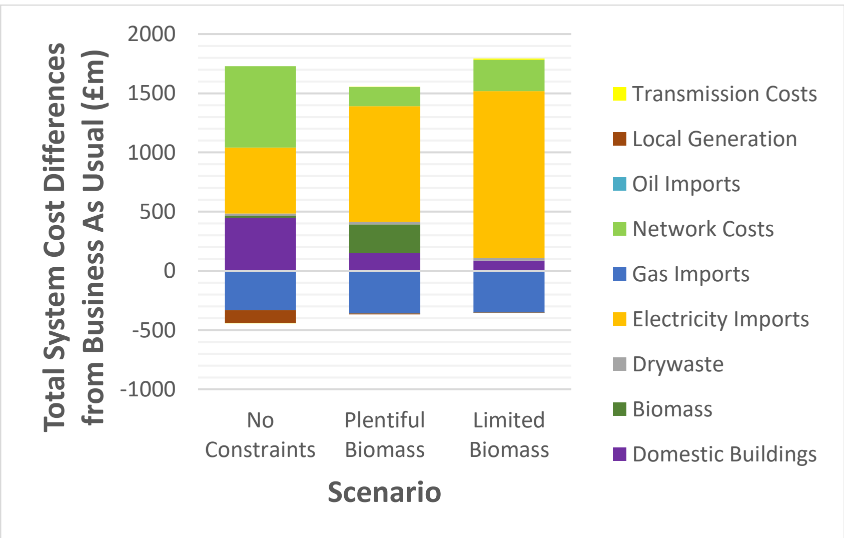
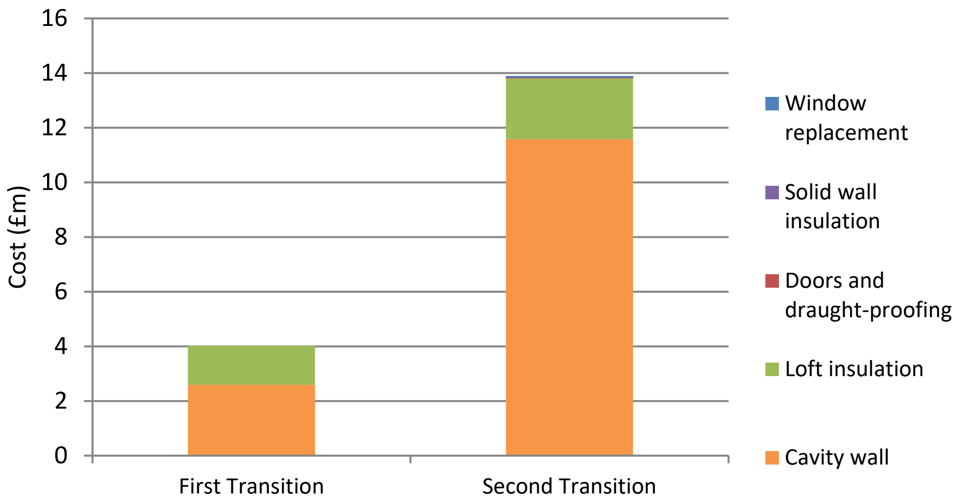


Figure 5-25 Changes in the Total Cost & Breakdown for the Three Carbon Target Reduction Scenarios Compared to BAU

Capital and operating costs were modelled for each of the technology options including retrofit, heating systems, energy systems and network transition. Illustrative modelled costs for each technology employed over the two transition periods are shown below for the World with Limited Biomass scenario.

Retrofit Capital Costs

Figure 5-26 shows capital costs of retrofit within transition one and two timescales for the World of Limited Biomass scenario. Spending on cavity wall insulations is estimated to increase from £3.5m to £10m over the transition period for the with-constraints scenario. Loft insulation spending remains stable at approximately £2m, and spending on improved glazing (window measures) is negligible. Windows and doors are regularly replaced by home owners as part of routine home maintenance and improvement. The figure includes estimates of this business as usual expenditure on windows and doors over the same time period. The additional expenditure expected on retrofit measures to improve thermal efficiency is small compared to this routine expenditure on building fabric.

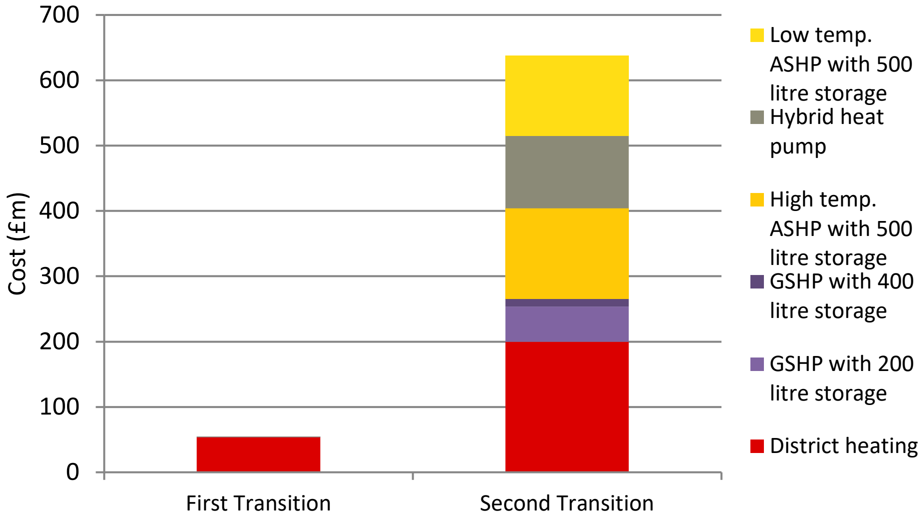


Business as usual expenditure	2015-2050
Windows	£1,583m
Energy-efficient doors & draught proofing	£173m

Figure 5-26 Additional Retrofit Costs to Business as Usual in Transitions One and Two

Heating System Capital and Operating Costs

Figure 5-27 shows the capital costs of heating system over transition one and two timescales for the World with Limited Biomass scenario. Total spending is expected to rise from £50m to over £600 million over the period for the with-constraints scenario, with a very large increase in spending on district heating (£150m) with £70m being directed to GSHP, £260m to ASHP and £110m to hybrid heat pumps. The routine, end of life, replacement costs for heating systems in the city is also shown. It can be seen that the costs of domestic heating system changes required to meet the carbon target are approximately £100m higher than the money that would be expected to be spent on routine heating system replacement over the same time period.



Business as usual expenditure	2015-2050
Gas Boiler	£500m
Electric Resistive	£18m
District Heating	£21m
Oil Boiler	£0.4m

Figure 5-27 Additional heating systems costs to business as usual in transitions one and two

Energy Centre Capital and Operating Costs

Figure 5-28 shows the estimated total capital costs associated with the DHN energy centres distributed over the planning period 2015-2050 (for the World with Limited Biomass Scenario). It shows an increase in capital spending in the later period comprising large-scale heat pumps, water source heat pumps and smaller amounts on gas CHP and gas boilers.

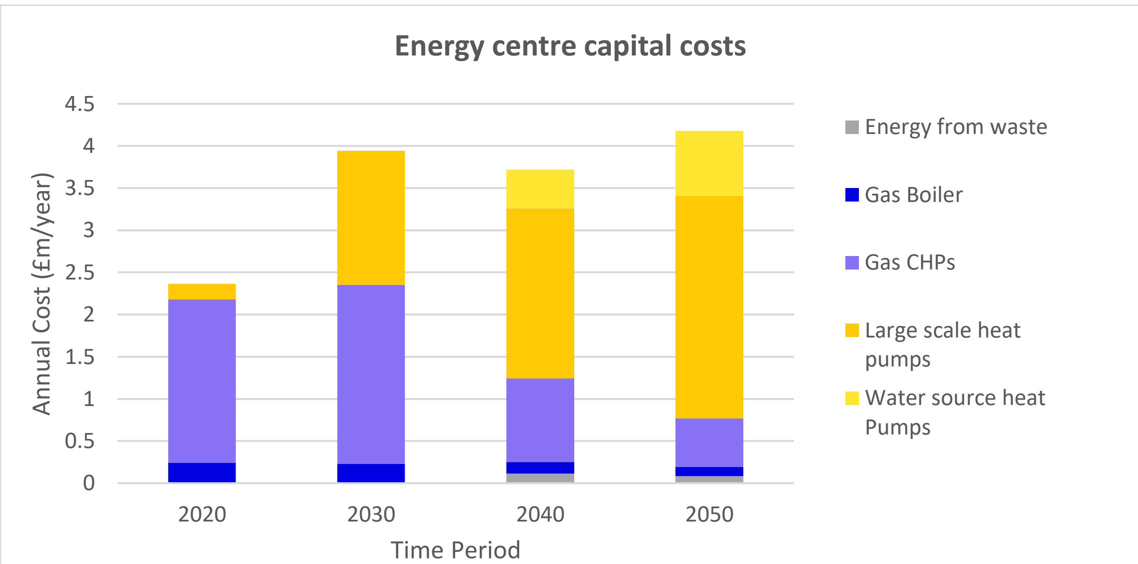


Figure 5-28 Energy centre capital costs over the planning period 2015-2050

Figure 5-29 shows the total operating costs associated with DHN energy centres spread over the planning period for the limited biomass scenario. Operating costs are associated mainly with gas CHP and (in the later period) large-scale heat pumps.

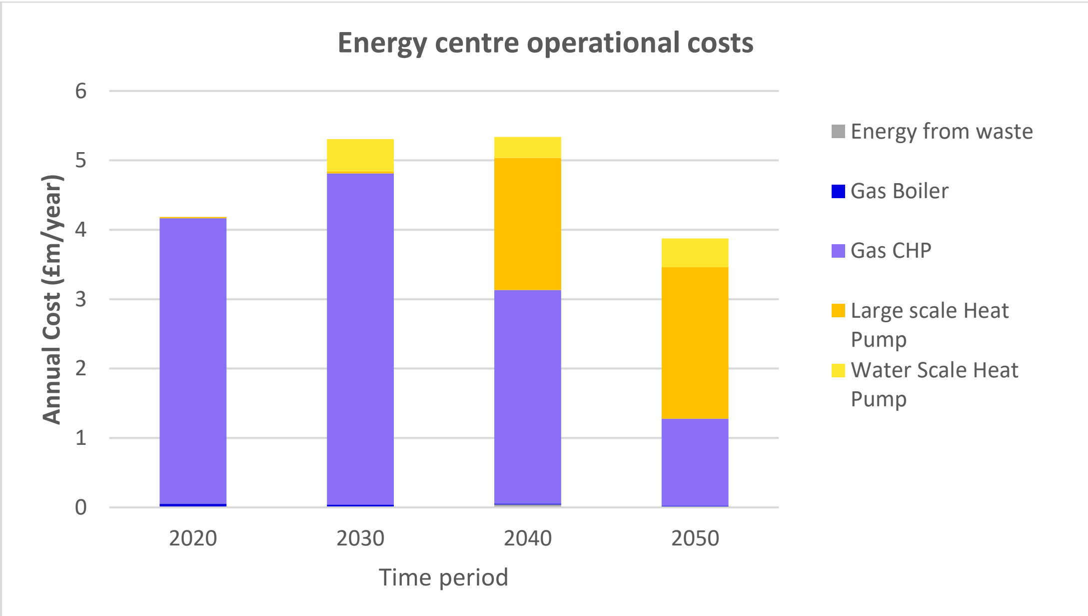


Figure 5-29 Heating System Operating Costs over the planning period

Network Transition Capital and Operating Costs

Figure 5-30 shows the estimated total capital costs associated with heat and electricity network development over the planning period for the limited biomass scenario with most of this spending on heat network development. Heat transmission costs peak in the 2035-2045 period, with a small but increasing spend on electricity networks in the later period.

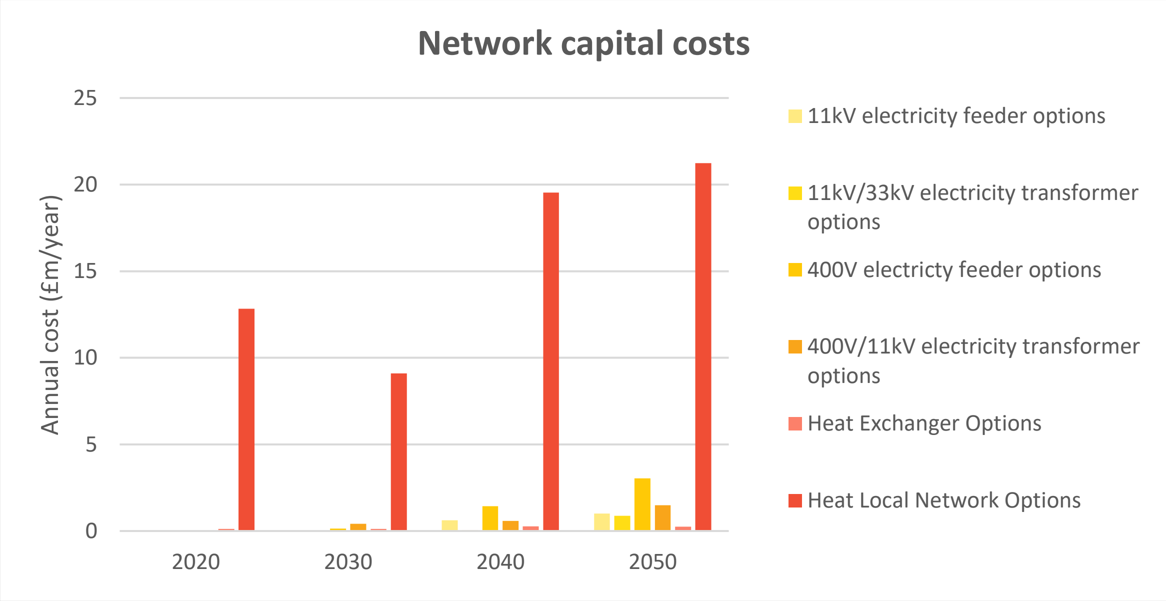


Figure 5-30 Network Capital Costs Over the Planning Period

Figure 5-31 shows the estimated total operating costs associated with distribution network operation over the planning period for the limited biomass scenario (which are part of the total system costs discussed). It shows an increase over the period, gas and electricity operating costs remain stable at around £3m each with the extra costs coming from the developing heat networks.

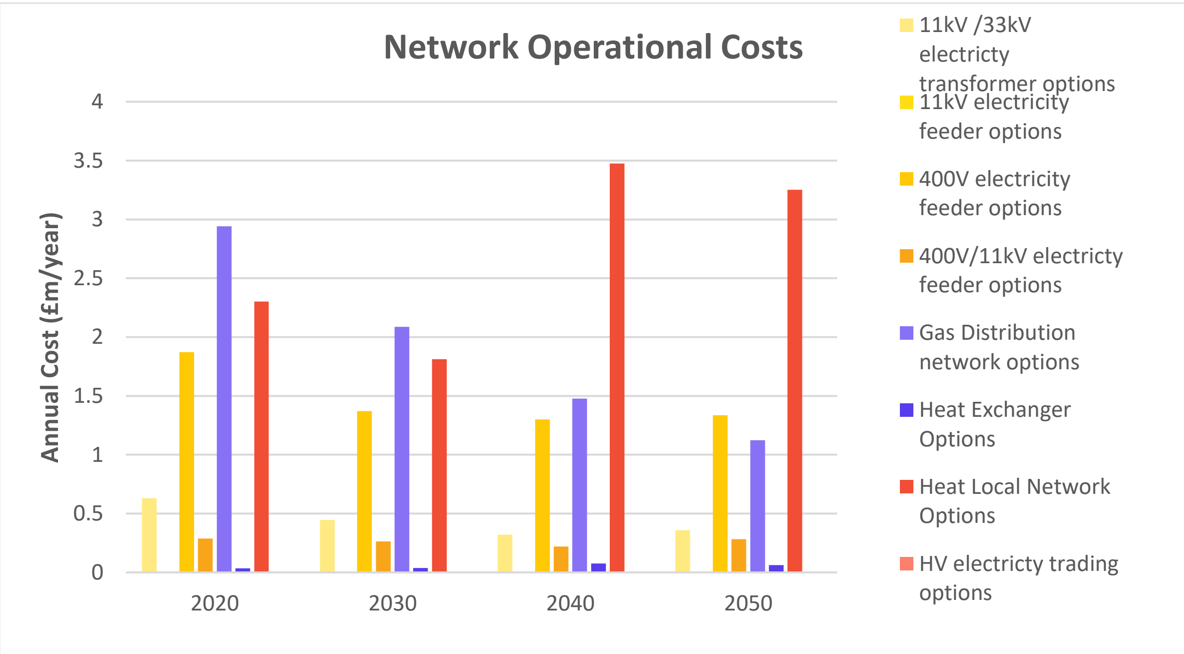


Figure 5-31 Network operating costs over the planning period

5.3 Local Constraints

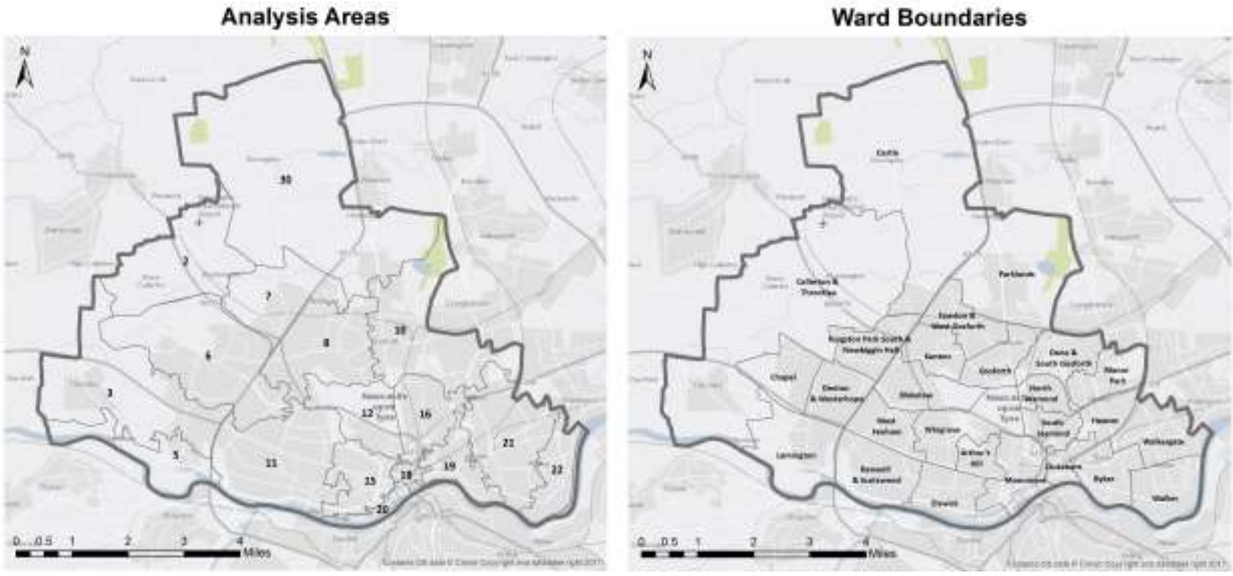


Figure 5-32 EnergyPath Networks modelling areas and the Newcastle City Council ward boundaries

There are a number of local issues which may act as constraints to the deployment of heat networks. For example, where a proposed heat network crosses a major road or railway it may not be feasible or may be costly and time consuming due to disputes over easements. Notable railway crossings are listed below (numbers correspond to areas in Figure 5-32):

- Many in and around the city centre and Newcastle Central station (Areas: 15, 16, 18, 19, 20)
- To Gosforth Industrial Estate in area 10
- Locations where pipework needs to be routed over railway lines routed via road or rail bridge.
- The Newcastle light rail network or Metro passes through several of the areas. In the more central areas (e.g. 15, 18, 21) it is below ground and so heat networks could pass here if the tunnels are at a sufficient depth.

Routing pipework over rivers adds expense to a heat network although work constraints are less stringent given transport routes are typically unaffected during construction. There are also many estuaries and canals in the northern areas (e.g. 2 and 7). The Ouse Burn River runs North-South passing through areas 10 and 16 in the east.

Notable river crossings include:

- Hartley Burn: Two crossings in area 7 between Dinnington and Brunswick Village.
- Ouse burn: One crossing in area 7 South of Woolsington.

- Dewely Burn: Most eastern section of river passes through planned housing development on site North West of Throckley, area 3 (referred to as Policy NV31). However, it is likely that the river will be diverted underground for the development to take place.

The River Tyne bounds several of the modelling areas to the South and forms the southern-most part of the study area. This forms a practical barrier to initial heat network development as the cost of crossing the river is more expensive than typical heat network costs. While there may be reduced (per meter) costs by not having to dig road trenches, there are some additional expenses associated with laying pipework on a road bridge. These include:

- A structural investigation of the bridge to determine whether it is suitable for heat pipework.
- Junctions at the landings on each end of the bridge where pipework emerges from the ground.
- Traffic disruption while scaffolding/cranes are used for installation.

6 Conclusions

The analysis has assessed the low carbon technologies which could play an important role in Newcastle's future local energy system and the locations where they could be used. It indicates trends in potential technology adoption and potential energy demand which can be used to consider near term investment decisions. Selected technology options have also been analysed to assess the impact on existing networks, and requirements for future network planning and infrastructure. The key messages and lessons learnt from the whole system modelling are:

- District heating is always the most common method of providing heat to domestic buildings with electric heat pumps as the second most common solution.
- District Heating is selected in preference to heat pumps for various reasons including a lower total system cost (including heating distribution system replacement) and the presence of existing and planned heat networks which facilitates greater uptake of the technology as the lowest cost option. In general, if the deployment of district heating increases then electric heat pump utilisation decreases.
- Whilst district heating is not currently deployed at scale to areas of low rise residential areas, if the associated issues can be overcome then widespread adoption of heat networks could be targeted for the urban centre, where current and planned heat networks could act as a seed for wider growth and adoption and growth of heat networks within the city. If developed, these networks could then spread further out in the City over time.
- Areas of social housing have been identified in the wards of Ouseburn, Westgate and Elswick with potential for deploying heat networks in the near-term. There are likely to be opportunities to connect any developed networks into Newcastle's existing or planned district heating schemes.
- Electric heat pumps have been selected by the model as the least cost decarbonisation solution in circa 50% of homes in the scenario with limited biomass and 20% in the scenario with plentiful biomass. Whatever type of scenario transpires the modelling therefore suggests that heat pumps are likely to play an important role in the decarbonisation of Newcastle's buildings.
- As with district heating, before heat pumps can be used at scale, there are similar consumer, commercial and policy/regulation technology maturity aspects to overcome. However, in the case of heat pumps, the modelling evidence has shown that there are technical areas that need to be solved. For example, heat storage capacity (relating to physical space limitations in existing dwellings) and areas related to electrical network capacity. For instance, in a future where electrical network demand would need to be

managed through restricting heat storage times outside of peak demand, this may well require an increased system size to produce the additional heat demand and the associated cost would then be placed on the building owner/occupier.

- Before any constraint was applied to the future availability and use of biomass, biomass based heating systems were selected as the least cost decarbonisation option in up to 30% of homes. Even when uncertainty over the future availability of the supply of biomass is acknowledged through significantly increasing the estimated fuel supply cost, biomass is still selected as the least cost measure in areas on the rural fringe of the city. This suggests that it is important to test the suitability of biomass for future consideration.
- Modelling has shown that domestic insulation retrofit is not a wide scale cost optimal solution to decarbonise as other options are more cost effective. However, EnergyPath Networks analysis suggests that around 7,800 homes within Newcastle are identified as suitable for fabric retrofit even without attempting to achieve reduced carbon emissions. This is because improving their thermal efficiency is cost effective i.e. that the cost will be re-paid by energy savings within the lifetime of the measure.
- Finally, the decarbonisation of Newcastle's buildings will significantly impact Newcastle's existing energy systems. If district heating does evolve to be a major decarbonisation solution, then significant investment will be needed to provide a new energy system along with the associated energy generation plant. Peak electricity demand has been modelled to change from 380MW to circa 612MW, peak gas demand from 585MW to circa 300MW and heat network peak demand from 15MW to circa 150MW[42].

The themes listed above are discussed further in the corresponding Newcastle Local Area Energy Strategy document. The Strategy takes these themes forward by assessing the many interdependent consumer, commercial and policy/regulatory aspects that need to be considered alongside the modelling analysis to continue the process of local area energy planning.

[42] Noting that these figures do not account for the decarbonisation of Newcastle's non-domestic buildings.

A Appendix- Renewable Energy System Supporting Information

Table A-1 Renewable Technologies 1

Type		Description
Biofuel		A biofuel is defined as any fuel whose energy is obtained through a process of biological carbon fixation. A fuel that is produced through contemporary biological processes, such as anaerobic digestion, but its main difference between fossil fuels is the time it takes to create it, which can be measure in days, weeks or months. Not millions of years to create.
Biofuel	**Fossil Fuel Equivalent**	**Differences**
Ethanol	Gasoline / Ethane	Ethanol has about half the energy per mass of gasoline, which means it takes twice as much ethanol to get the same energy. Ethanol burns cleaner than gasoline, however, producing less carbon monoxide. However, ethanol produces more ozone than gasoline and contributes substantially to smog. Engines must be modified to run on ethanol.
Biodiesel	Diesel	Has only slightly less energy than regular diesel. It is more corrosive to engine parts than standard diesel, which means engines have to be designed to take biodiesel. It burns cleaner than diesel, producing less particulate and fewer sulphur compounds.

Table A-2 Renewable Technologies 2

Biofuel	Fossil Fuel Equivalent	Differences
Methanol	Methane	Methanol has about one third to one half as much energy as methane. Methanol is a liquid and easy to transport whereas methane is a gas that must be compressed for transportation.
Bio-butanol	Gasoline / Butane	Bio-butanol has slightly less energy than gasoline, but can run in any car that uses gasoline without the need for modification to engine components.
Type		**Description**
Biomass		Biomass is biological material obtained from living or recently living plant matter that can be processed into electricity, fuel and heat. Materials include sustainable forestry and forestry residues, residual agricultural products, such as straw, sunflower seed husks and peanut husks, and purpose grown energy crops. The average carbon dioxide saving, over the full life cycle, resulting from burning biomass in place of coal is above 80%.
Geothermal		Geothermal energy is derived from the Earth's natural heat. It is recognised as being clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water and hot rock. Currently in the UK, this resource is exploited using a geothermal heat pump or as it is more commonly described, a Ground Source Heat Pump (GSHP), which uses pipes, buried in the garden to extract heat from the ground. This can then be used to heat radiators, underfloor or warm air heating systems and hot water. A Ground Source Heat Pump circulates a mixture of water and antifreeze around a loop of pipe, called a ground loop, which is generally buried in the garden. Heat from the ground is absorbed into the fluid and then passes through a heat exchanger into the heat pump. The ground stays at a fairly constant temperature under the surface, so the heat pump can be used throughout the year. The length of the ground loop depends on the size of you're the property and the amount of heat needed. Longer loops can draw more heat from the ground, but need more space to be buried in. If space is limited, a vertical borehole can be drilled instead.

Table A-3 Renewable Technologies 3

Type	Description
Hydropower	**Hydropower** is the electricity generated using the energy of flowing water. Usually these facilities are located in hills and mountains. A typical hydro plant is a three parts system: 1. An Electric Plant where the electricity is produced 2. A Dam that can be opened or closed to control water flow 3. A Reservoir where water can be stored. In simple terms, electricity is produced when the water, stored in the dam flows through the intake to the turbine, causing them spins a generator to produce electricity. The electricity is then transported, usually over long-distance overhead electric cables to the Distribution Network System. At a domestic level, **Micro Hydroelectric Generation** is now a viable alternative
Marine Energy **Wave Energy / Tidal Energy**	This is the exploitation of energy carried by ocean waves, tides, salinity, and ocean temperature differences. The movement of water in the world's oceans creates a vast store of kinetic energy, or energy in motion. This energy can be harnessed to generate electricity. **Tidal Energy** is generated from twice daily change in the direction of sea tides. Wave / Tidal and ocean energy technologies are just beginning to reach viability as potential commercial power sources. **Tidal Stream Devices** are still in their early stages of maturity. **Wave Energy Devices** generate electricity by using water motion caused by winds at the sea surface. There is more design variety in wave power than tidal, and a range of devices is being tested at the European Marine Energy Centre (EMEC). in Orkney[43]. At a global level there is a significant level of interest in this technology[44] in Australia, Canada, China, Denmark, France, German, India, Ireland, Italy, Japan, Korea, Netherlands, Norway, Scotland, Spain, Sweden UK and the USA**.**

[43] European Marine Energy Centre (EMEC) in Orkney
[44] EMEC List of Marine - Tidal Developers Jan 2016

Table A-4 Renewable Technologies 4

Type	Description
Wind Generation	**Wind Power** involves using energy from the wind to drive a turbine to generate electricity. In a global context, wind farms have successfully been operating both on and offshore for some time, and this is a rapidly expanding technology. According to the World Wind Energy Association (WWEA), the top 15 Countries by total wind instillations power on a commercial basis, are led by China, with USA 2nd and the UK 6th Wind speeds are generally higher offshore than on land, where they are not affected by landscape features, so this attenuated the wind resource. As a result, the potential for electricity generation is greater. The size of a turbine can vary; typically, commercial onshore turbines are around 2MW, and offshore turbines are likely to be developed with a capacity of 3MW or greater in order to capture the higher wind speeds. **The Energy Technologies Institute** 49F49F[45], commissioned "Isle of Wight SME Blade Dynamics" [now part of GE] to develop a technology platform to build blades in excess of 100m for use on the next generation of large offshore wind turbines with a capacity of 6MW. New design techniques were used incorporating carbon fibre along with other composite materials. This will see blades weighing up to 40% less and it allows cost savings in the overall blade, turbine and tower structure to be made, when the system is designed as a matched unit. This will help reduce the cost of energy. GE are now funding and testing of the blades manufactured by Blade Dynamics is at the Offshore Renewable Energy Catapult in Blyth, Northumberland, UK.

Table A-5 Renewable Technologies 5

Type	Description
Onshore Wind Generation	This form of renewable electricity generation has lost support from the UK's government and some members of the public as it is perceived by the latter to be visually intrusive and a "blight" on the landscape. The Government sees the profits created by the developers indicate that they no longer need support from the Treasury. The policy framework for renewable generation has been subject to a number of interventions by the UK Government after it took office in May 2015. These include: • The early closure of the Renewables Obligation (RO) to new onshore wind • A delay until late 2016 of the second "Contracts for Difference" (CfD) mechanism auction for "less established" technologies, including offshore wind;

[45] ETI Offshore Wind Programme Brochure

	• The clear signal that Contracts for Difference (CfD) mechanism in its current form is unlikely to be generally available to new onshore wind. • The removal of Levy-Exemption Certificates (LECs) for renewable electricity • The UK currently has a tip-height restriction of 125 metres, which is constraining the introduction of new, more efficient technologies.

Table A-6 Summary of alternative fuels

Technology	Description	Carbon Emissions	Current Status
Biomethane	Methane produced by processing Biogas or Bio SNG. It shares similar properties to natural gas and can therefore be injected into the gas network and used by existing gas appliances.	Still carbon emitting but at a significantly lower value than natural gas.	Currently a small number of connections with many more planned. Total capacity limited by supply of truly biological renewable carbon atoms.
Hydrogen	Hydrogen is a basic element that is highly reactive. It can be used as a fuel like methane but appliances will need to be converted. Hydrogen can be transported using the existing gas distribution network. This will be easier where the iron mains are / will be replaced with plastic.	None at point of use, only by-product is water. However, its production can produce emissions, if made from fossil fuel, but not if from renewables.	Not currently used as a heating fuel, however, Northern Gas Networks 'H21 Leeds City Gate' Network innovation project is examining creating a hydrogen network in Leeds, North Yorkshire, using the steam methane reformer process which removes 90% of CO_2.
Shale Gas	Methane that is trapped within shale rock. Previously very difficult/impossible to extract, the progress made on extraction methods in recent decade has allowed access large volumes at commercial cost (especially in the USA).	Similar to natural gas currently sourced therefore use of shale will not result in any carbon saving.	First planning permission for shale gas extraction in the UK was recently granted 66F66F[46] Shale gas has revolutionised the US market turning it from a net importer to a net exporter. But remains controversial with local residents and the environmental lobby

Table A-7 Summary of alternative low carbon technologies

Technology	Description	Carbon Emissions	Current Status
District Heat Networks	A network hot water pipes supplying a number of buildings from central sources. This source could be industrial waste heat, Biomass plants or a	This will depend on the source of the heat. No / low emissions for some sources.	District Heat networks currently provide around 2% of the heat demand from buildings in the UK. They are most common and effective in high-density areas, but not used for modern low energy demand properties.

[46] North Yorkshire County Council gave approval for the first UK fracking Scheme / Site in May 2016.

	conventional gas or electric boiler.		
Biomass	Generating heating energy through range of bio fuels including wood, animal, food or industrial waste or high energy crops such as maize.	Burning Biomass still produces CO_2 but at lower levels than other fuels. The carbon emissions from some biomass can be contentious.	A proven technology but limited roll-out thus far.
Heat Pumps	Electric powered heat pumps absorb heat from the outside air (air sourced) or ground (ground sourced). This heat is used for space or hot water heating.	Depends on the source of the electricity. The heat they extract from the air or ground is natural and renewable.	A proven technology but limited roll-out thus far.
Prosumer Heating	Customers with the ability to generate and store their own heating energy via a number of different technologies without need to take energy from the grid.	Yes, prosumer technologies use solar powered heat pumps and solar air collectors.	Solar technologies becoming more widespread but a fully 'prosumer heating' property still at experimental stage. These technologies all inherently require space, ideally within the property. Connections to electricity and gas networks may still be needed as 'back-up'.

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C Appendix – Newcastle's Building Types by Ward

Domestic Residential and Non-Domestic Buildings by type

Ward	Domestic Buildings 2014	Total Domestic Buildings > 2050	Increase in Domestic Buildings > 2050	Total Non-Domestic Buildings 2014	Total Non-Domestic Buildings > 2050	Increase in Non-Domestic Buildings > 2050
Benwell & Scotswood	5838	7138	1300	678	681	3
Blakelaw	5085	5085	0	423	423	0
Byker	6155	6355	200	927	927	0
Castle	5108	6574	1466	755	806	51
Dene	4127	4127	0	442	442	0
Denton	4619	4619	0	485	485	0
East Gosforth	4440	4440	0	487	487	0
Elswick	5610	5966	356	978	988	10
Fawdon	4928	4928	0	460	1007	0
Fenham	4843	4843	0	428	428	0
Kenton	5156	5156	0	555	555	0
Lemington	4676	5172	496	670	678	8
Newburn	4388	5738	1350	674	685	11
North Heaton	3958	3958	0	354	354	0
North Jesmond	4020	4020	0	566	566	0
Ouseburn	5888	5888	0	955	974	19
Parklands	4397	4411	14	360	360	0
South Heaton	4567	4567	0	847	847	0
South Jesmond	4273	4273	0	1007	460	0
Walker	5655	6374	719	568	578	10
Walkergate	4722	4722	0	364	406	42
West Gosforth	4261	4261	0	662	662	0
Westerhope	4267	4267	0	282	282	0
Westgate	6760	8935	2175	3544	3615	71
Wingrove	4740	4740	0	588	588	0
Woolsington	4801	8600	3799	736	801	65
TOTAL	83236	88418	5182	10197	10846	102

D Document Control

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