EAST BIRMINGHAM COMMUNITY HEAT TASKFORCE: DELIVERING COMMUNITY HEAT PROJECTS

This reports sets out a detailed methodology for evaluating the cost of different low-carbon heat programmes in the context of East Birmingham. It establishes the costs and benefits for heating programmes with a focus on the case study of the Castle Vale estate

Developing Civic Policy and Delivery Scenarios to Inform Central Government Investment

Executive Summary

This report examines the costs and benefits associated with delivery of low and zero-carbon heating solutions at a community scale. The work recognises that for net-zero strategies for cities such as Birmingham the delivery of solutions for decarbonisation of heat remains the hardest challenge due to the complexity of the problem. Although heating accounts for 40% of UK energy consumption and one third of carbon emissions it has been put to the bottom of the to do list whilst government develops its own thinking around how to deliver net zero via the national Heat and Buildings strategy.

There are many levels to the complexity of delivery. A key question is which technology to opt for in terms of low-carbon heating: heat pumps, heat networks or wait for hydrogen? The uncertainty around which option to choose has led to a separation in the thinking around domestic energy efficiency and how to deliver improvements to the thermal insulation of homes at the same time as delivering low-carbon heat. Given that the design, scale, and cost of thermal insulation needs to be tailored to the heat delivery solution, this separation is problematic and points to the need for holistic planning and strategy.

This report is an important first step in addressing the challenge of understanding the full costs associated with delivering different interventions and their impact on energy consumption and fuel poverty, as well as the potential social and economic benefits in terms of improved health and providing jobs and skills opportunities. An energy efficiency programme on its own has the potential to deliver energy savings. There is a payback period associated with the cost of thermal efficiency interventions, but particularly if the costs are met through public funding, then subsequent reductions in energy bills can reduce the number of households in fuel poverty and improve health and wellbeing. However, thermal efficiency improvements on their own do not deliver net zero. They need to be combined with a low-carbon heating solution. This raises the costs significantly and can also result in higher energy bills under current energy pricing as low-cost gas consumption is replaced by electricity to power heat pumps or hydrogen.

Particularly in areas of high unemployment, there are potential benefits for neighbourhoods delivering a low-carbon buildings heat programme that will generate jobs and attract investment. For early mover communities there is the potential to be at the forefront of developing the skills base that will deliver retrofit programmes to other communities and regions.

To weigh the costs and benefits of delivering low-carbon community heat, an Excel based model has been developed to understand the costs of delivering different technical options in East Birmingham and the benefits that accrue. The aim of this work is to provide a baseline tool and an evidence base that begins to advance the conversations around low-carbon heat delivery and provides the foundations for discussions on how to finance community scale heat decarbonisation programmes.

This report describes the development of a model that can be applied at different scales across East Birmingham. It uses the community of Castle Vale as a case study: a community of 4,300 homes with around 50% social housing owned and managed by the Pioneer Housing Group.

A base line model has been developed that estimated the costs to deliver a net zero heating solutions focussing at this stage on the homes themselves and household level costs rather than the underpinning heat network, hydrogen gas and electricity infrastructure full systems level costs. Future work will develop the system level costs.

Costs and benefits depend on the selected solution but the modelling points towards a mid-range thermal efficiency programme in Castle Vale costing £45m, with a low-carbon heating option being an additional £15-40m, with an overall cost of £60-85m. The modelling points to benefit cost ratios, as per the green book methodology, being around 0.1 to 0.4. These benefits do not include the benefits of the avoided carbon emissions which are estimated to be £16m over a 20-year period. The impact of higher fuel bills from a switch to electricity under current pricing models, particularly for the heat-pump solution, has the potential to increase fuel poverty by up to 60%. On the benefits side, the programme is estimated to create of the order of 1200 job years.

These estimates highlight that the economics of delivering low-carbon heating are challenging and require creativity and innovation to develop financing models that create and leverage partnerships between public and private finance. The next step of this programme or work is to refine the methodology, to capture the carbon savings and the infrastructure costs, as well as incorporate more information on the social, economic and environmental benefits of a community heat programme. Then the methodology will be applied to other communities in East Birmingham, to establish a baseline for the costs of delivering net zero domestic heating to the population of 230,000 people. The overarching ambition is to establish a series of investment propositions that will kick-start the delivery of low-carbon heating to Birmingham.

Contents

1. Introduction

East Birmingham is home to more than 230,000 people and forms a crucial part of the City of Birmingham and region's economy. Major growth is anticipated which will deliver more than 60,000 new jobs and 10,000 homes within and near to East Birmingham over the next ten years. With the coming of HS2 and the proposed Midland Metro East Birmingham to Solihull extension, East Birmingham has significant development opportunities. It is a young place where a third of residents are under 16 years old - one of the highest proportions of children in the country. The Birmingham City Council East Birmingham Inclusive Growth Strategy[1] sets out:

> *"There will be a focus on places, including improving transport connections, stimulating local growth and involving local people and businesses in shaping this growth and benefiting from it. There will also be a real focus on people including partnership working to improve the way that the public sector works, both for local people and with local people. In East Birmingham this work will be led by the East Birmingham Board which brings together the Council with key partners including the NHS and Birmingham Children's Trust. The Board will work closely with the West Midlands Combined Authority, Transport for West Midlands and Solihull Council's Solihull Together partnership which is responsible for delivering inclusive growth in the North Solihull area.*"

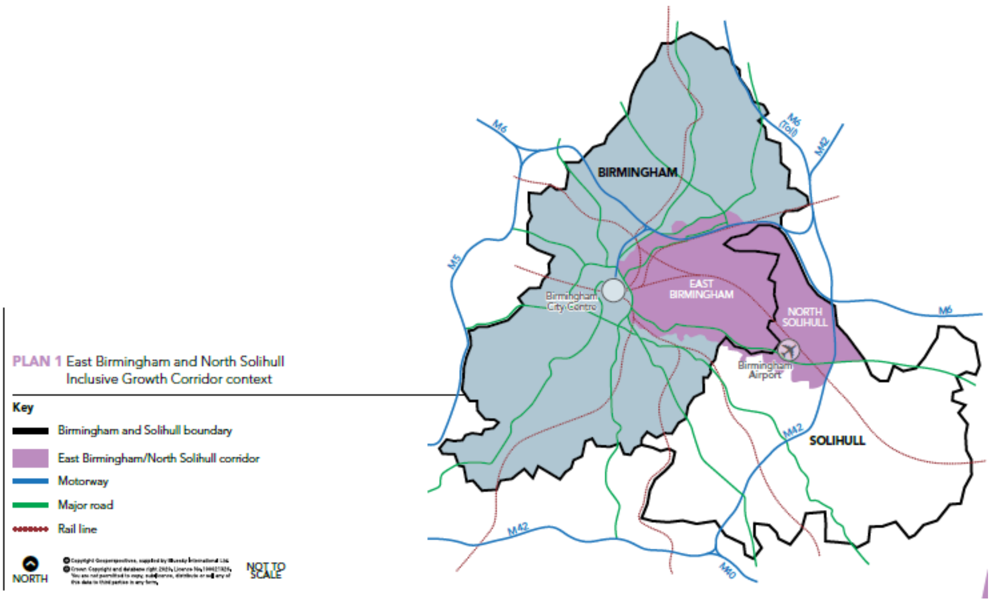

Fig. 1: The East Birmingham and North Solihull Inclusive Growth Corridor. Source: East Birmingham Inclusive Growth Strategy 2021, Birmingham City Council.

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[1] https://www.birmingham.gov.uk/downloads/file/19118/east_birmingham_inclusive_growth_strategy_2021

A key element of that inclusive growth will be the delivery of the net zero transition and the most challenging element will be the delivery of energy efficient homes and low-carbon heating. For many of the citizens of that part of the city there are multiple levels of deprivation and high levels of unemployment. For example, the claimant rate in the Birmingham Hodge Hill constituency is 14.1%, roughly one in seven, the highest rate of any constituency in the UK. As of February 2021, there were 11,045 people searching for a job in Hodge Hill. The delivery of a heat retrofit is hence both a challenge and an opportunity. Challenging to deliver, but with the opportunity to reduce fuel poverty, create low-carbon jobs a demand for skills and training and deliver health benefits.

East Birmingham has many assets that can be drawn upon. Tyseley Energy Park and the Tyseley Environmental Enterprise District is set in East Birmingham, midway between the city centre and the airport. It has presently ~35 MW of electricity generation (including the city energy from waste plant) which is to be scaled up to 60 MW, with potential for capturing the waste heat from these plants into district heating and plans to scale up hydrogen production to feed into the East Birmingham developments for low carbon heat and transport. Most of the energy production of Birmingham lies within the Tyseley Environmental Enterprise District (TEED), or at the biogas injection being performed at the Severn Trent Minworth site adjacent to Castle Vale.

The present project aims to establish a basis for understanding the costs and benefits associated with a low-carbon heat programme in East Birmingham using the Castle Vale estate as a case study. The aim is to establish a case for Central Government and private sector investment. The work will also establish the basis for a programme of delivery initially focussed on low carbon heat along the East Birmingham North Solihull Corridor, EBNSC, and in doing so support Birmingham City Council's (BCC) East Birmingham Inclusive Growth Strategy and Route to Zero Carbon (R20) action plan.

This work builds on two previous reports '*Powering West Midlands Growth: A Regional Approach to Clean Energy*[2]' and '*Road to Low Carbon Heat*[3]. The latter report, co-delivered with the CBI, sets out the national challenges associated with low-carbon heating, whilst this report seeks to provide a basis for how to deliver the heat transition at a local level.

This work contributes to the activity of the East Birmingham Community Heat Taskforce (EBCHT). The EBCHT is charged with developing a suite of housing and domestic heat retrofit 'Test and Learn' projects in East Birmingham to identify technical and financial policy scenarios and inform bids for government funding. These pathfinder projects will be scalable and transferable to the rest of the city, and nationally. The aim is to ensure policy/technical scenarios are supported by a rigorous evidence base, and inform Birmingham City Council,

[2] https://www.energycapital.org.uk/wp-content/uploads/2018/03/powering-west-midlands-growth-regional-energy-policy-commission-report-2018.pdf
[3] https://www.birmingham.ac.uk/documents/college-eps/energy/publications/20200722-heat-policy-commission-final-report.pdf

the West Midlands Combined Authority and Central Government to shape their heat decarbonisation and fuel poverty policy programmes.

2. The case for change

2.1 Strategic context

The Birmingham City Council (BCC) have established a Route to Zero Task Force and a plan to reach net zero carbon emissions by 2030. Decarbonisation of a city of the scale of Birmingham is clearly very challenging and needs to account for everything from transportation to how the city's buildings are heated. The latter element is probably the most challenging as there are about half a million homes and numerous other private and public buildings. Each building or home will require upgrades to the heating and thermal insulation. This is made even more challenging as the energy efficiency of the city's aging housing stock is well below the level required.

The strategic focus of BCC on the corridor that runs from the city centre to North Solihull is articulated through the East Birmingham Inclusive Growth Strategy (EBIGS)[1]. East Birmingham is home to many communities who have been underinvested in for decades, suffer from high levels of fuel poverty and economic deprivation. These same communities are the ones who have had the highest impact from Covid. Historically. Birmingham has been ambitious with its energy assets; its district heating and cooling system placed the city in a leading position for a number of years. However, there is a need to be ambitious again and deliver sustainable heating solutions beyond the city centre, in particular, prioritising the communities of East Birmingham.

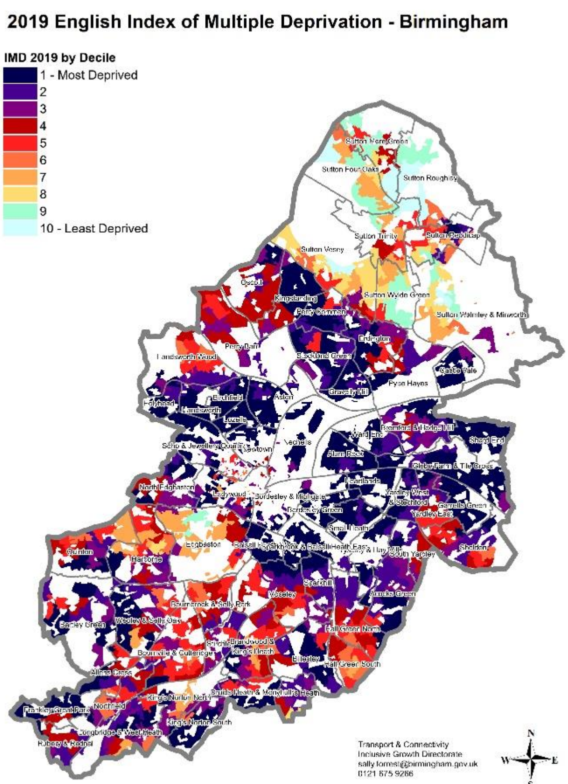

Fig. 2: Index of multiple deprivation data for Birmingham. Source: Ministry of Housing, communities and Local Government (MHCLG) 2019.

The provision of low-carbon heating is challenging: both because the number of homes which need to be retrofitted is significant, and because the supply chains and workforce to retrofit homes and install new heating technologies and systems is not yet established. As well as needing to improve the building fabric and thermal insulation of a diverse set of building types, all of the potential solutions need some element of infrastructure development. Low-carbon heating can be delivered in the form of district heating, heat pump solutions (ground or air source) or alternatively hydrogen injection into the gas grid, potentially requiring reinforcement of the electricity grid, installation of a heat network, or upgrading of the gas network. A house by house approach is difficult to achieve and it is necessary to find the right solutions that may be applied to a zone, district or neighbourhood.

Investment needed for low-carbon heating is not negligible. The cost of heat pump installation and energy efficiency improvements is well over a factor of 10 times more expensive than a gas boiler. Aggregated over the city's housing stock this would be tens of billions of pounds. There will be an expectation that those who are able to pay contribute. However, Birmingham has many communities that cannot afford the investment and, hence, potentially will be left behind.

This report establishes the basis for understanding a detailed heat investment programme in East Birmingham with a focus on Castle Vale as a case study. It is based on a baseline economic evaluation of the costs of different interventions and an initial assessment of the associated social, environmental and economic benefits. It provides an interim understanding into a strategic case for investment into East Birmingham to support pioneering delivery of heat retrofit solutions and projects.

2.2 Organisation Overview

The programme of activity that this business case underpins aligns with delivery of Birmingham City Council's East Birmingham Inclusive Growth Strategy and is overseen by the East Birmingham Community Heat Taskforce (EBCHT), chaired by Liam Byrne MP and a formal subgroup of the East Birmingham Board. The EBCHT is made up of members from local and regional government (Birmingham City Council, WMCA, Solihull Metropolitan Borough Council), business/finance organisations (KPMG and GFI), industry (Tyseley Energy Park, Engie), research organisations (University of Birmingham, Energy Systems Catapult) as well as social housing groups (e.g. Castle Vale Community Housing, the Pioneer Group), local FE provider South and City College Birmingham and consultancy organisations (Places in Common, WSP, Inner Circle Consultancy).

The primary aim of the EBCHT is to identify investment models which can leverage both public and private investment to unlock funding for the communities of East Birmingham. These investment models will ensure they are near the front of the queue to receive the benefits of more efficient, warmer, healthier homes and potentially lower energy bills, as well as able to access improved infrastructure and job and training opportunities arising from scale up of heat decarbonisation supply chains.

The EBCHT also aims to seek funding for and establish Test and Learn projects that will create the evidence base to feed into and underpin future funding asks to deliver heating retrofit. As part of this, the Cadent Foundation (a charity established as part of the Cadent network) are co-funding a project with University of Birmingham, Places in Common and The Active Wellbeing Society. This project will create a Community Learning Platform that will facilitate engagement with East Birmingham communities on the Route to Zero and heat retrofit and inform technical and business case development.

The governance structure for the EBCHT is set out below:

BIRMINGHAM CITY COUNCIL AND WEST MIDLANDS COMBINED AUTHORITY

EAST BIRMINGHAM BOARD
(Delivering East Birmingham Inclusive Growth Strategy)

East Birmingham Community Heat Taskforce
(Oversight of test and learn projects and reporting back to EB Board)

Test and learn projects

Strategic Case for Investment in EB Community Heat projects (UoB)	
EB Community Heat Test and Learn (UoB, Places in Common, Cadent Foundation) Data model and community learning platform	Other future projects East Birmingham Digital Twin development Scale up of hydrogen production

2.3 Alignment to existing policies and strategies

Net-zero by 2050

The UK Government released its Energy White Paper *Powering our Net Zero Future*[4] in December 2020. This set out how we will decarbonise home heating by shifting away from natural gas and by better insulating the buildings in which we live. The strategy required large scale transformation and intervention to decarbonise domestic heating. There are around 27 million homes in the UK and almost 90% use fossil fuels for heating, cooking, and hot water. The large majority of these will need to undergo some level of retrofit to improve the building fabric and be fitted or connected to alternative heating appliances; two thirds of English homes are at Energy Performance Certificate, EPC, D or worse.

The White Paper commits to investing £9.2 billion in improving the energy efficiency of homes school and hospitals and sets out steps to support the move to low-carbon heat including the Future Homes Standard which will ensure all new-build homes are zero carbon

[4] Energy White Paper Powering our Net Zero Future https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/945899/201216_BEIS_EWP_Command_Paper_Accessible.pdf

ready. For existing homes, *The Green Homes Grant Voucher* and *Local Authority Delivery Schemes* were launched in September 2020 and were intended to support the development of the housing retrofit market ahead of new regulatory measures to be introduced later this decade. The withdrawal of the Green Homes Green Scheme in 2022 illustrates the challenge of getting consumer engagement and ensuring that there is the capacity to deliver. The Governments Ten Point Plan for a Green Industrial Revolution[5] sets out an ambition to deliver the installation of 600,000 heat pumps a year by 2028. A dedicated Heat and Buildings Strategy is due to be published shortly (June 2021).

The UK retrofit challenge

Much of the UK housing stock is energy inefficient with low building performance standards meaning damp, leaky, insufficiently insulated homes. The UK has some of the oldest housing stock in Europe with a high proportion of pre-war (and indeed pre-1900) residential buildings. These older buildings with mainly solid wall construction are particularly "hard to treat" and insulating them to a high standard is resource and cost intensive. In their report "UK housing: Fit for the future?", the Committee on Climate Change observe "The quality, design and use of homes across the UK must be improved now to address the challenges of climate change. Doing so will also improve health, wellbeing and comfort, including for vulnerable groups such as the elderly and those living with chronic illnesses." [6]

In addition, to the poor condition of the stock, the UK has many different house archetypes due to the combination of house types (e.g. detached, semi-detached, terrace and flats) and the wide age range and different construction methods. This combined with the poor condition of the housing stock means decarbonisation does not have a simple or one size fits all solution, particularly when there is not currently one nation-wide policy solution for replacing existing heating systems.

In Birmingham, the retrofit challenge mirrors the national picture with significant variation in housing and neighbourhood types across the city requiring different retrofit solutions. Birmingham also has some of the highest levels of fuel poverty in the UK, significant issues with overcrowding and many wards that fall within the 20% most deprived areas of the UK. For East Birmingham business models need to address the retrofit challenge whilst enabling a just transition that addresses these issues, prioritising housing and areas of the city where there is greatest need.

Housing Retrofit in the West Midlands

The West Midlands Combined Authority (WMCA) published their Climate Change Action plan #WM2041 in 2020 which agrees the need to invest in comfortable homes and buildings, old or new, so they are easy and affordable to keep warm (or cool). The plan identifies that this investment will also help to address homelessness, fuel poverty and waste. The WMCA

[5] https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution
[6] https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf

commits to meeting both domestic and international climate change targets with all buildings net zero carbon in operation before 2050, with new buildings meeting this standard by 2030.

The National Centre for Decarbonisation of Heat proposed by the University of Birmingham, the Manufacturing Technology Centre, Energy Systems Catapult and the Energy Research Accelerator would be based in the West Midlands at Tyseley Energy Park in East Birmingham. The NCDH would enable the rapid scaling up of manufacturing, skills and deployment of heat solutions and create new programmes designed to enable the rapid growth of promising technologies and business models, in turn creating tens of thousands of skilled jobs.

East Birmingham Inclusive Growth Strategy

The East Birmingham North Solihull corridor is a political and economic priority policy area for both the WMCA and BCC. This makes it a suitable area to bring together multiple partners across the city and region and create a Living Lab area where pioneering technical solutions and economic and business models can be developed and demonstrated. East Birmingham is a key focus of BCC's Route to Zero Action Plan, as well as post-pandemic economic recovery plans. In addition, there is the opportunity, in East Birmingham, to explore how the city's energy assets, largely located in East Birmingham, and innovation in technologies and energy systems being developed at sites such as Tyseley Energy Park, can underpin the delivery of heat decarbonisation across the East Birmingham Corridor.

The housing stock in East Birmingham largely mirrors the national stock in terms of the proportions of different housing types and building ages. There is a significant proportion of older housing with 20% built pre-1919, and mainly located in Small Heath, the area around Tyseley Energy Park and Hodge Hill. The high proportion of older housing means the average Energy Performance Certificate rating is D, with the majority housing between a C and E rating. Area within East Birmingham where there is a higher level of social housing such as Castle Vale, West Saltley and Shard End, have better average energy efficiency ratings, fitting

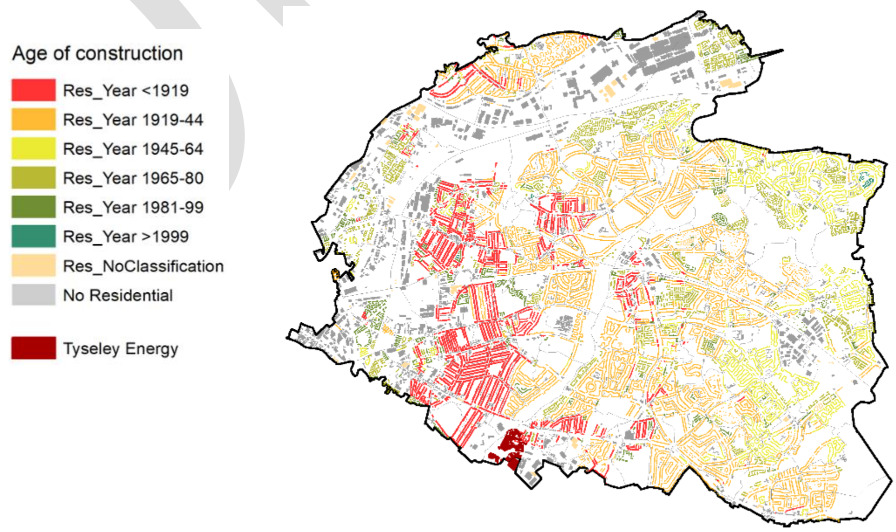

Fig. 3: Age of construction of housing stock in East Birmingham.

the national picture where overall social housing is more likely to have had some level of energy efficiency improvement through public sector funding schemes.

A recent study by Birmingham Energy Institute has mapped energy deprivation in East Birmingham to identify "Priority Intervention Areas". Urban typologies were developed to model theoretical energy demand defined by a combination of factors (housing age, type of house (e.g. detached, terrace, flat), total height and floor height, floor surface area surface). This was compared with actual energy consumption and mapped against levels of deprivation for each Lower Super Output Area (LSOA) in East Birmingham. The modelling assumed that in areas where actual energy demand is lower than theoretical energy demand, householders cannot afford to consume the level of energy required and hence they are energy deprived.

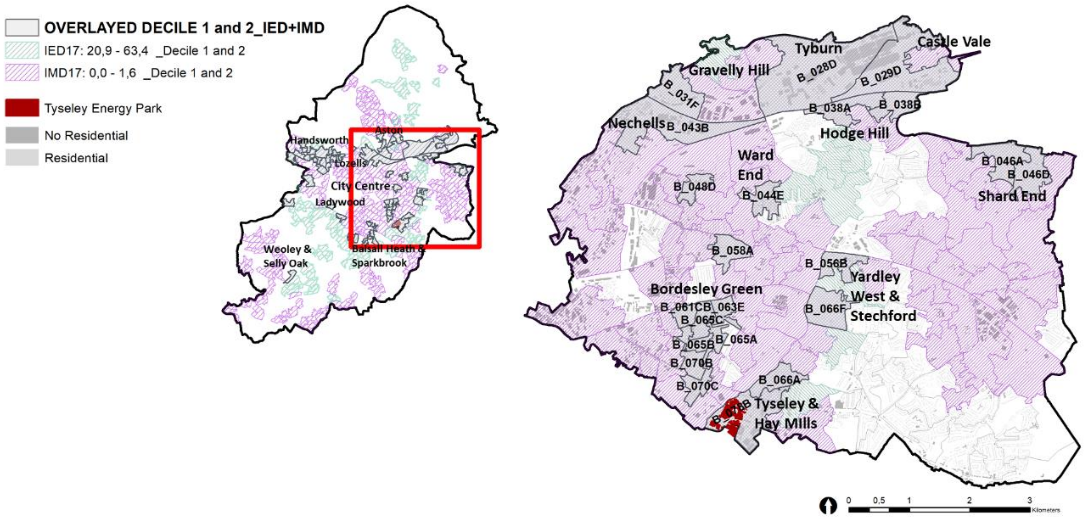

Fig. 4: Areas of high energy deprivation in East Birmingham.

The study identified that East Birmingham is on average more energy deprived than Birmingham as a whole with neighbourhoods named on the map in most need of priority intervention. These are Bordesley Green, Castle Vale, Gravelly Hill, Hodge Hill, Nechells, Shard End, Tyburn, Tyseley and Hay Mills, Ward End, Yardley and West Stechford. Section 3.4 Case study: Castle Vale focuses on the Castle Vale neighbourhood.

2.4 Energy Infrastructure

Development of low carbon heating solutions will be influenced by the available energy infrastructure within East Birmingham and the not insignificant costs associated with installing new infrastructure, e.g. electricity, district heating or upgraded gas networks.

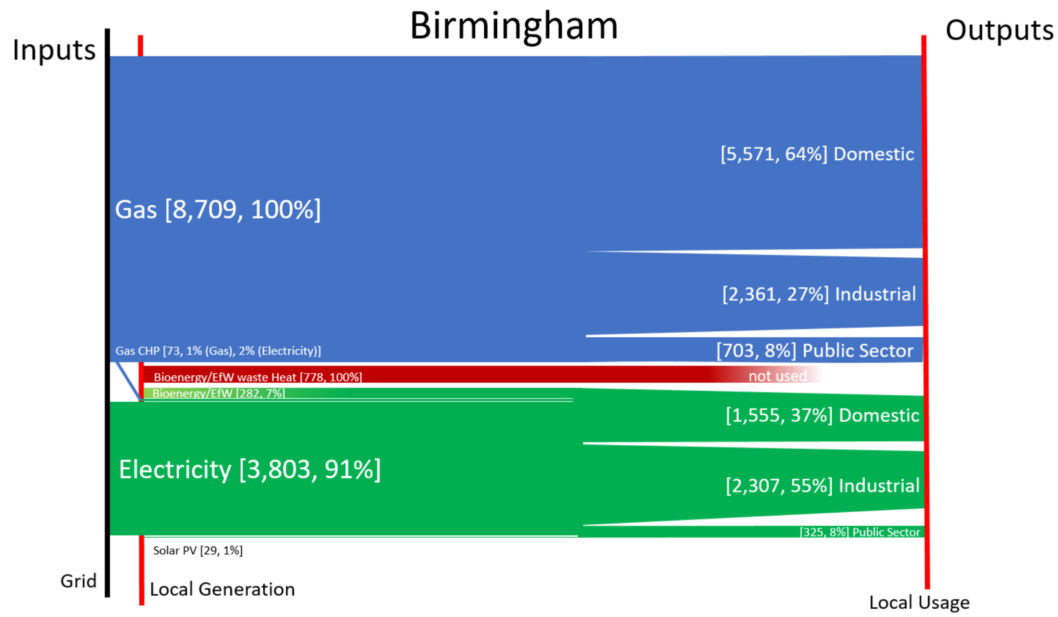

Fig. 5: Analysis of the energy inputs and outputs for Birmingham.

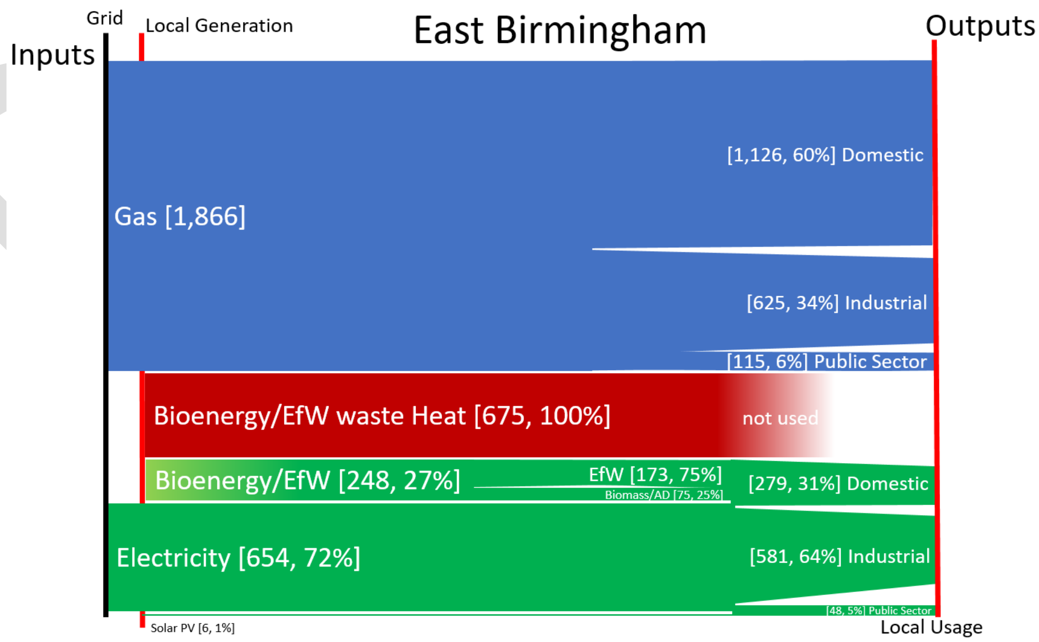

Fig. 6: Analysis of the energy inputs and outputs for East Birmingham.

Figures 5 and 6 illustrate a detailed analysis performed by the Birmingham Energy Institute of the energy flows within Birmingham and East Birmingham in terms of the energy vectors gas and electricity, but also recognising the production of energy from the Energy from Waste (EfW) plants and biomass sources of energy production. The full analysis is provided in Appendix C. There are two clear points illustrated: i) pro rata, East Birmingham generates a great deal more energy than Birmingham as a whole. It is the location of the Tyseley EfW plant and energy generation is set to increase with more capacity being created in Tyseley. There is also the biogas production at the Severn Trent Minworth site in East Birmingham, ii) EfW plants produce a lot of heat, which is presently not being exploited. In developing future energy schemes, it makes sense to recognise that East Birmingham hosts the majority of the energy generation for the City of Birmingham. Resource should optimally be deployed locally and at present there is a large, un-tapped, source of heat which is being wasted and could be deployed for heat schemes.

3 Understanding the Case for Investment

3.1 Determining investment objectives

The objectives for the investment into East Birmingham align with the national, regional and local policy and strategic context outlined in Section 2. The main rationale and drivers for heat decarbonisation interventions in East Birmingham are:

- To reduce CO_2 emissions in line with government and regional targets for moving to a net-zero carbon energy system.
- To move households out of fuel poverty by improving the energy efficiency of homes and heating systems.
- To support inclusive growth through the creation of training and employment opportunities for residents in and near to neighbourhoods receiving interventions.
- To support business and process innovation in the delivery of alternative heating technology and retrofitting of homes.
- To enable neighbourhood and community renewal through improvements to housing and local infrastructure
- To improve health outcomes for residents in and in nearby intervention areas through warmer homes and reduced air pollution.

3.2 Previous National Projects

There have been several national pathfinding projects that have explored the installation of low carbon heating and energy efficiency. The Smart Systems and Heat (SSH) programme was delivered by the Energy Systems Catapult. This was aimed at overcoming the barriers to the decarbonisation of residential heat. The programme was divided into two phases. Phase 1 focused on developing capabilities, tools and insights, whilst phase 2 performed consumer trials of smart energy services, exploring new business models and market structures and developing Local Area Energy Plans with three local authorities in Newcastle, Bury in Greater

Manchester and Bridgend in Wales. This programme has helped develop three Smart Energy Plans for Newcastle, Bridgend and Greater Manchester[7]. The scale of this programme is, however, limited.

There have been a series of other national retrofit programmes which include examples such as[8]:

- Arbed in Wales: The was a £100m programme in two phases focussed on 6,000 homes. The retrofit was to lift the homes with EPC rating F to C and those in E to D.
- Kirklees Warm Zone project, was a £21m programme, involving an assessment of 133,000 homes and with a subset of interventions which aggregated into an estimated improvement of homes by one category in the EPC rating.
- The Energiesprong approach. So far 1300 net-zero energy retrofits have been carried out with 15,000 more in the pipeline. Nottingham City Council participated in an EU funded Energiesprong programme featuring 10 homes, which the retrofit costs were £90k for houses and £80k for bungalows. This provides increased energy efficiency, but only a marginally improved house value: houses were valued at £80k before the retrofit and £100k after retrofitting.

These are valuable projects but miss the need to combine the thermal insulation retrofit with the provision of low-carbon heating sources at a scale which is meaningful and allows an economy of scale. Cost effective solutions are absolutely key in creating the balance between energy efficiency and what is pragmatically possible within a reasonable project budget.

[7] https://es.catapult.org.uk/impact/projects/smart-systems-and-heat/smart-systems-and-heat-phase-2/
[8] https://www.theiet.org/media/5276/retrofit.pdf

3.3 Low-carbon heating delivery

The investment into low-carbon heating infrastructure and housing thermal efficiency improvements is a key component of the delivery of net zero. In the UK, 40% of energy consumption is for heating and one third of UK CO_2 emissions[9], and a significant proportion for domestic heating. The delivery of low-carbon heating solutions can be via a series of options, which in essence boil down to three possible technology solutions (although hybrid solutions and variations are possible). These are i) air-source or ground source heat pumps, ii) district heating, or iii) hydrogen boilers replacing natural gas boilers. In all cases it is optimal to upgrade the thermal efficiency of the home at the same stage as upgrading the heat source to offset any increased cost of switching from a low cost source of heat (i.e. natural gas) to potentially higher cost sources such as electricity or hydrogen. In the case of heat pumps, although they have high efficiency, they have much lower heat generation capacity than the other two approaches and therefore it is mandatory that any installation is accompanied by thermal efficiency upgrade.

In each case there is a need to consider not only the delivery into the home, but the upgrading or installation of the infrastructure to deliver either the heat, electricity, or hydrogen. The electricity demands of heat pumps are several kilowatts and integrated over thousands of properties will be constrained by the current capacity of local grid infrastructure. This means that the grid will need to be upgraded, with an additional cost beyond the heat pump and thermal retrofit.

Similarly, **the gas pipe infrastructure needs to be sufficiently modern to transport hydrogen**. Hydrogen can degrade old steel based pipework through embrittlement causing cracking and failure. As yet there is no national supply of hydrogen into the gas grid and therefore the local generation of hydrogen, with suitable backup, needs to be considered.

District heating needs a heat supply, which is ideally low carbon, or a source of waste heat, and a pipework infrastructure to distribute the heating to the homes. The cost of the district heating infrastructure and the limited distances over which it is possible to transport the heat efficiently have often pointed towards installation in areas of high population density and where local sources of waste heat exist.

Due to the need to develop high cost local infrastructure to deliver the low-carbon heating solutions, the associated investment can only become tenable if it is exploited by a critical number of homes. As such there is a national discussion linked to the concept of zoning, where rather than customers having a range of options, there will be a preferred solution for residents in a particular area based on the cost of infrastructure and the local generation assets, such as the availability of hydrogen or waste heat.

This **complexity will be difficult to manage as it will open up inequality and an element of a post code lottery**. Different low-carbon heating solutions have different installation costs on a home by home basis. There are very complex questions as to who pays and how this is

[9] https://www.cbi.org.uk/media/5123/heat-policy-commission-final-report.pdf

financed and indeed who pays for the associated infrastructure. For example, is this a national or a local burden? There are also issues of how to measure the costs against the benefits. It is clear that a thermal efficiency improvement to a home is beneficial if it reduce energy bills, but then there are questions around the payback period and as well as side effects from poorly installed insulation with consequences for the potential of increased levels of mould.

In addition, **for the low-carbon heating, the move from delivering heat by the combustion of a very low cost fuel, natural gas, to a relatively high cost fuel, e.g. hydrogen or electricity increases the payback period for a combined programme of thermal insulation and upgrade to a low-carbon heat source**. The difference in cost of energy outweighing the cost saving from the energy efficiency measures. This is the extreme case, but there is the potential for extremely unattractive pay back periods when rather than lifting families out of fuel poverty, an increasing number of households will find themselves pushed into fuel poverty.

On the positive side, **improvements to the energy efficiency of homes does have the potential to make them warmer with the associated health benefits and there is significant employment and skills development potential associated with the low-carbon sector**. At present there are about 150,000 heating engineers across the UK who install, service and maintain existing gas boilers. There are, however, very few low-carbon heating engineers. The difference between the former and the latter is that gas boilers are able to supply more than enough heat to a home, whereas a heat pump solution needs to be tailored to the characteristics of the house. The calculation of what capacity gas boiler is required is straight forward, whereas the installation of a heat pump is a rather more sophisticated calculation requiring a greater level of training and expertise. The case is similar on the thermal insulation side. Regional or local low-carbon heat programmes can create a volume of jobs and employment that may directly benefit communities. Skilled engineers could be drawn from the communities which are being retrofitted.

It is complex to weigh the costs and benefits in the abstract, and a detailed analysis is required to arrive at clear conclusions. What follows is an analysis of one neighbourhood in Birmingham, Castle Vale, in order to understand the costs and benefits of low-carbon heating and thermal efficiency improvements. A model which exploits green book principles has been developed to evaluate the costs associated with different options. The focus is on the integrated cost across Castle Vale homes and the present approach does not include the additional costs of installing the infrastructure to deliver the heat, hydrogen or electricity. The aim is that this detail then becomes a basis for understanding the types of investment models that might be used to finance such projects. This naturally will be a combination of public and private finance.

3.4 Case study: Castle Vale

Overview – Castle Vale

Castle Vale lies in the far east of Birmingham on the border with Solihull Metropolitan Borough Council and just north of the M6 near the junction with the M42. The area is predominantly a white working class community and in the 10% most deprived wards in England on the Index of Multiple Deprivation. The population of around 10,000 people is older than the average population of East Birmingham, meaning there are greater health needs in comparison with other areas. There are also very high unemployment rates due to the automation of industry jobs; Jaguar Land Rover who are located nearby no longer recruit from the area as jobs are now robot operation.

The housing in Castle Vale is a mixture of poorly insulated 1960s housing and better insulated housing built more recently in the 1990s. There is also a proportion of new build properties (5%) which tend to be larger than the existing housing. In terms of tenure, 50% of households are social housing, managed by the Pioneer Housing Group, with the majority of the remaining homes owner occupied. There are a variety of land uses in the area besides residential: a commercial high street, a trading estate with around 20 Units, sporting facilities including a swimming pool and a football stadium, areas of open green space, and heavy industry. Figure 7 shows Castle Vale area and the different Lower Super Output Areas (LSOAs)/postcode areas comprising the area. Table 1 shows index of multiple deprivation data for 6 LSOA areas. All are in the 10% most deprived wards expect for area 029F.

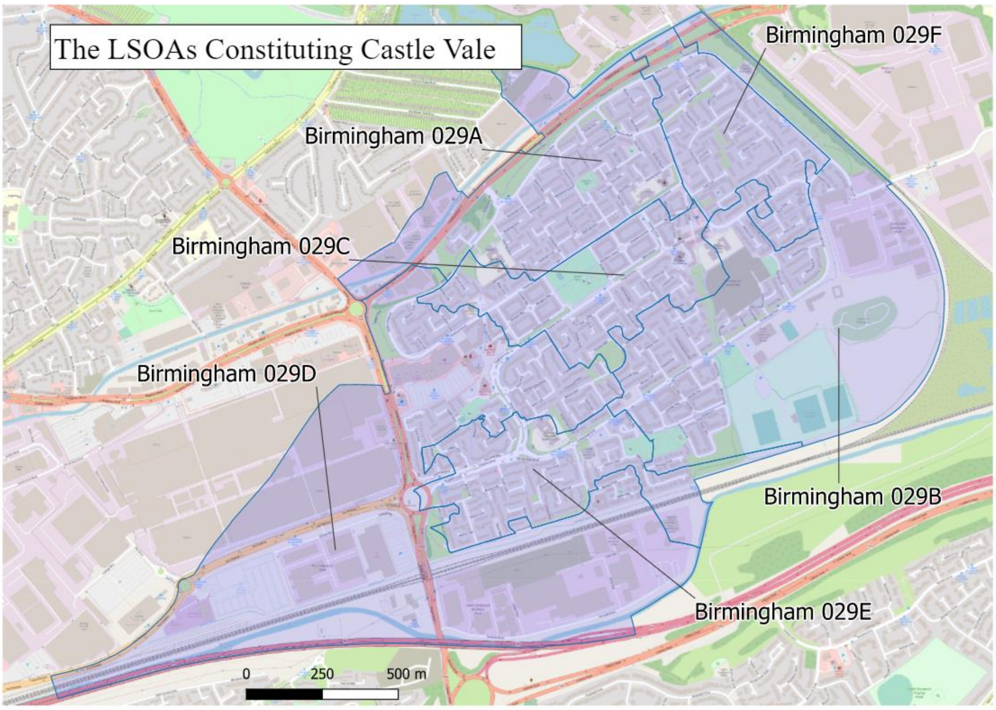

Fig. 7: The Lower Super Output Areas (LSOAs) that make up Castle Vale.

Castle Vale	LSOA Name	029A		029B		029C		029D		029E		029F	
	LSOA Code	E01009096		E01009097		E01009099		E01009101		E01009103		E01009106	
		Rank	Decile	Rank	Decile	Rank	Decile	Rank	Decile	Rank	Decile	Rank	Decile
Indices of Multiple Deprivation	IMD	1540	1	952	1	414	1	2518	1	877	1	6632	3
	Income	1824	1	1450	1	707	1	3999	2	1078	1	8488	3
	Employment	1529	1	1184	1	604	1	2771	1	1441	1	6704	3
	Education, Skills & Training	2717	1	282	1	329	1	2445	1	298	1	3961	2
	Health Deprivation & Disability	1079	1	1221	1	449	1	1427	1	899	1	4737	2
	Crime	7579	3	12777	4	7534	3	10071	4	9259	3	17867	6
	Barriers to Housing & Services	4325	2	3479	2	4176	2	5665	2	8432	3	8519	3
	Living Environment	15114	5	18882	6	19669	6	9658	3	11335	4	11821	4

Table 1: Index of multiple deprivation data for LSOAs in Castle Vale.

The Pioneer Housing Group

The Pioneer Housing Group manages around 2,500 housing units in Castle Vale. There are a further 2,500 units that are owner occupied. The Pioneer Group managed housing is broadly spread across the Castle Vale area except for in the LSOA area 029F, marked on the map above, which is predominantly owner occupied and less deprived than the other parts of Castle Vale (in the 3rd decile on the IMD unlike the other areas which are in the 1st decile).

The Pioneer Housing Group is an anchor organisation in the neighbourhood and in the City of Birmingham, and a partnership of people and organisations using its collective regeneration expertise to support the development of communities. It works closely with a variety of local partners, service providers and stakeholders, to deliver community-driven traditional and non-traditional housing solutions, and essential support services such as youth, family support, health and employment. It has established relationships with Jaguar Land Rover and other nearby industry, as well as with local Universities and other anchor institutions, including Birmingham City Council who the group collaborates with on community safety and environmental issues.

Pioneer Housing employs 170 people in total and 95% of its operations are based in Castle Vale. 20 people are managing the delivery of retrofit measures in Castle Vale. The group is adapting to a policy agenda that is low carbon to develop strategy and an approach on social housing as a landlord. They are part of a group of asset managers in the region, trying to understand the 2050 goals and how they can be delivered. The asset management agenda is focussing mainly on safety and fire and retrofitting is not always in the forefront of the groups mind as they have limited resources to deliver improvements.

Initial engagement with the Pioneer Group identifies that is a small association committed to providing the best solution possible for its tenants and communities. The group needs to be able to make the right decisions, first time that will ensure there is no detriment to people through new retrofit or heating solutions. They need to take a pragmatic approach to the climate imperative. They are clear that they cannot be seen as being at the front of the queue for applying decarbonisation solutions that have not been analysed and found to be cost effective and beneficial to householder. They cannot be "an expensive guinea pig" for pilot schemes..

An approach that aligns spending objectives with community need

The spending objectives of the Case for Investment in section 3.1 set out the rationale for investing in heat decarbonisation projects in East Birmingham. However, at the neighbourhood level there is a need to ensure that technical options have buy-in from social housing providers and landlords, as well local communities, are of proven benefit and minimal risk. Without this sense checking, project delivery is likely to stall if solutions are seen as too risky to on the ground partners to commit to delivering.

From initial engagement with the Pioneer Housing Group and Castle Vale Community Housing **there is a neighbourhood level objective that goes beyond creating social cohesion, decarbonisation or inclusive growth and is about a community-driven organisation being able to deliver a benefit to the community and making people's lived better not worse**. Therefore, there is an important check needed on preferred options that they should be acceptable to both Pioneer Housing Association who have around 50 per cent of housing stock and residents in Castle Vale to increase the likelihood of adoption.

The creation of training and employment opportunities for residents in Castle Vale is of value in getting buy-in to projects. However, Options should show how CO_2 emissions can be achieved within a tightly defined East Birmingham geography of Castle Vale without increasing the cost to householders of heating their home or pushing people further into fuel poverty.

Case study justification

In selecting Castle Vale and the Pioneer Group as a Case Study area to focus on in developing an Options Model a range of factors were considered that justify the choice of this area:

- The **Castle Vale community is more organised** than most others in East Birmingham due to the Pioneer Housing Group. This makes it easier to engage with as a pilot area for developing a robust costs-benefits economic model: there is more information available plus expertise and local knowledge to inform selection of a preferred option.
- **The majority of the Castle Vale LSOAs are in the 10% most deprived wards in England**. This means that there is a potentially a bigger impact of any socio-economic benefits of retrofitting.
- However, **the average energy efficiency of housing in Castle Vale is higher than the East Birmingham average** (see Figure 8 below) and fuel poverty levels are average. This makes the area a realistic proposition for investment where more challenging areas might be seen as too risky or costly for pilot projects.

- There is **high percentage of social housing in Castle Vale managed by one social housing group**. This provides the opportunity to develop business models for a particular tenure type in a neighbourhood where householders via the Pioneer Group have a reasonably high level of control over how costs and benefits are realised.
- The **location of Castle Vale close to energy and industrial assets and potential sources of waste heat** provides more options for changing heating systems then other areas of East Birmingham.

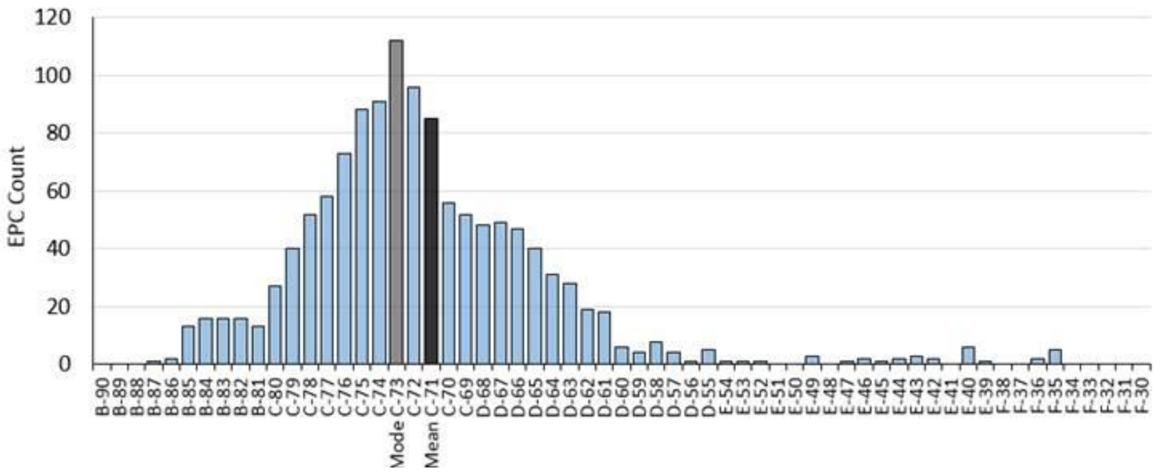

Fig. 8: EPC ratings for Pioneer Group managed housing in Castle Vale.

4. Exploring the preferred way forward

The different technology options for decarbonising domestic heating are described in numerous reports including recently by the Committee on Climate Change (CCC) in UK Housing: Fit: for the Future[10] and by the University of Birmingham and the CBI in Net Zero: The Road to Low Carbon Heat.[11] One main challenge in determining the appropriate decarbonised heating solution for different housing types and neighbourhoods in the UK lies in matching the technology with good standards of thermal efficiency in homes so that the technology is energy and cost efficient in comparison to our current solutions – predominantly gas boilers.

This section sets out the potential different options focussing on the three main heating alternatives highlighted (ground source or air source heat pumps, new district heating networks and hydrogen in the grid), an option where we keep existing heating systems but do a significant retrofit, and a business-as-usual (BAU) option. In the BAU option there is no change to heating systems and only minimal retrofit of properties.

[10] https://www.theccc.org.uk/publication/uk-housing-fit-for-the-future/
[11] https://www.birmingham.ac.uk/Documents/college-eps/energy/Publications/heat-policy-commission-final-report.pdf

4.1 Technical options

Business as usual technology option

The business as usual option, assumes we continue as we are with minimal retrofit of properties. For Castle Vale (and most areas across East Birmingham) this means the majority of properties will remain in the C-D Energy Performance Certificate band as they will not receive any of the additional measures required to make homes significantly more energy efficient. These are measures such as external wall or under floor insulation. The majority of homes will retain their existing heating system – predominantly either gas central heating or electric heating

In this scenario there will be minimal energy and emissions reduction across the Case Study area, and minimal growth in training and employment opportunities without any scale-up of retrofit delivery. However, this will be the lowest cost option and will provide a baseline for comparing the costs and benefits of other options.

Retrofit only

The retrofit only option assumes that there will be a high level of retrofit of buildings to improve the building fabric and energy, but houses will keep their current heating system predominantly gas boilers or electric heating. The retrofit measures costed were those that it was considered would be needed to move homes with and EPC rating of C-D (the majority of homes in the UK) towards an A-B rating. These measures, external wall insulation, underfloor insulation and replacement double glazing are in addition to those that the majority of C-D rated homes already have roof insulation and cavity wall insulation (non-solid wall properties). Additional measures and costs could be included for a maximal retrofit option, however, a medium cost option was chosen to develop the baseline economic model.

The energy savings from double glazing (from Band E) were used in all cases as this was the closest value available from (2) as the average EPC rating in Castle Vale is C (followed by D). To calculate the costs, it was assumed that all properties in Castle Vale could be considered small, this could not be verified with the available GIS data but was considered appropriate given the age of the properties. It was also assumed that data for mid-terraced properties would be a suitable approximation for all terraced homes, as they would outweigh the number of end-terraced properties

Costs: For retrofit, it becomes increasing more expensive to achieve each 10 per cent improvement in CO_2 emissions and this extends payback for individual households from savings in energy bills. Therefore, as mentioned, a medium level of retrofit was used, with the costs set out in Table 2.

		House Type				
Retrofit Measure	Retrofit Cost Level	Small mid-terrace house (<76m²)	Small flat (<54m²)	Small semi-detached or end-of-terrace (<80m²)	Small detached house (<117m²)	Bungalow (around 117m²)
External Wall Insulation	Medium	6800	5300	7800	10200	9800
Underfloor Insulation		588	604	590	608.5	667
Replacement Double Glazing (panes and frames)	Medium	3900	2400	5500	5900	6600

Table 2: Costs of retrofit measures (£).

Market barriers and opportunities: Deep retrofitting will require a more highly skilled workforce to design and deliver retrofit options for different homes. There is a significant market opportunity for the West Midlands to be at the forefront of creating this workforce and the supply chains to retrofit homes at scale. In addition, some of these skills will be transferable to projects involving heat pumps as well.

The main market barrier is the cost and lack of demand for deep retrofit. Funding and new business models are needed that incentivise householders and landlords to carry out a deep retrofit on properties to create the demand and enable rapid development of training and reskilling courses to create the workforce needed.

Heat Pumps and Retrofit

Heat pumps draw heat from the environment (the air or ground) which can be used to heat homes. Powered by electricity, heat pumps use a compression cycle to provide heating and/or cooling to a building. Air Source Heat Pumps (ASHPs) use the thermal energy of the outside air whereas Ground Source Heat Pumps (GSHPs) use the thermal energy of the ground. Once installed, the carbon intensity of the heat pump depends on the carbon intensity of the electricity used to power it. This means that if the electricity is from renewable sources heat pumps are a zero-carbon heating solution.

Heat from heat pumps is distributed around the house in two ways. Through water-based systems such as radiators or underfloor heating, requiring an energy store, or air-based systems using air ducts. Water-based systems have the advantage that they can use existing systems such as radiators connected to a heat pump, reducing the potential disruption to households. However, air-based systems can provide both heating and cooling and as well as dehumidification, which can be an advantage in houses which have been well insulated and are more 'air-tight' where there can be problems with damp and mould.

The **efficiency of heat pumps depends on several factors**:

- The size of the heat pump compared to the heating requirements of the house
- The type of heat pump
- The thermal efficiency of the house
- The outside temperature, especially in the case of ASHPs

Currently GSHPs are more efficient as the ground temperature is less affected by changing outside/air temperature and they don't have to use a refrigerant as they can circulate the water in the ground. However, they are difficult and expensive to install at scale in urban, built up areas outside of new build developments because they require a large loop of pipe to be buried in the ground. This means that in urban areas ASHPs, installed outside the house, are currently the preferred solution.

Heat pumps draw several kW of electrical power and so scaled-up deployment across cities and towns will place greater demand on grid capacity. In addition, heat pumps do not deliver heat in the same way as gas boilers. Delivery is slower and at a lower temperature. For heat pumps to effectively heat homes there must be a good standard of thermal efficiency. Heat pumps are only a viable option if installed in an energy efficient house with sufficient space for installation.

Technical requirements in addition to installation of the heat pump:

- High standard of building thermal efficiency through improved insulation, triple glazing etc.
- Additional thermal storage such as hot water tanks
- Changes to radiator systems and size
- Electricity network reinforcement to meet increased demand

Installation of smart technologies to balance supply and demand

Costs:

The costs of different heat pumps are compared in Table 3. GSHPs are more expensive than ASHPs due to the requirement for a length of pipe underground. In addition to the cost of installing the heat pump there will also be costs to upgrade radiators. Review of relevant literature suggests and average capital cost for installation of an air source heat pumps and radiator upgrades of £11,747 (From Heat Pump Retrofit in London, The Carbon Trust[12]). This is the costs used in the economic model for the heat pump option. These costs are in additional to the household costs calculated for different house types in the retrofit only option.

[12] https://www.carbontrust.com/resources/heat-pump-retrofit-in-london

Heat Pumps	Cost/kWh	Cost/Unit	Average SCoP	Cost of electricity (p/kW)	Cost of thermal energy (p/kW)	Size of system*	Space requirement
Air-source	£600-£1,800	£6,000 - £9,000	2.5 (up to 4)	14.25	5.70	6kW-15kW, 10kW ASHP delivers 10kW of heat to building if the air temperature is 7oC and the indoor flow temperature is 35oC	"no larger than a washing machine"
Ground-source	£1,300-£2,900	£10,000 - £18,000	3.5 (up to 5)	14.25	4.07		50m-80m of pipe/kWh or 10m of slinky pipe/kWh at 1.2m deep or boreholes 70-100m deep
Hybrid Heat Pump	~£1,300	~£6,700	-	-	-		

**depends on: outdoor design temperature, desired room temperature, flow temperature*

Table 3: Costs associated with heat pump installation (£).

Market barriers and opportunities:

The UK needs to significantly increase the installation of heat pumps at pace for the market to be established and bring costs down. Currently, there are very few heating engineers trained to install heat pumps and design the in-house heating systems with the necessary level of care. There are capacity constraints due to a skills shortage and a market opportunity for East Birmingham is to become the centre for creating the skilled workforce require for scaled up heat pump installation. Heat pump installation needs to be considered holistically alongside building fabric retrofit to ensure there are no avoidable future problems with homes such as lack of ventilation, damp and overheating in houses with significantly increased levels of ventilation. This is a potential market barrier as the complexity of delivering heat pumps and retrofit at scale makes it challenging to create the skilled workforce required.

Hydrogen network and retrofit

Hydrogen gas can be produced though electrolysis using renewable energy (green hydrogen) or through processes such as steam reforming utilising hydrocarbon fossil fuels and used as a fuel. If produced through electrolysis, hydrogen can be considered zero carbon if the electrolysis is powered by renewable energy. In comparison, steam reforming of methane to produce hydrogen is carbon intensive unless Carbon Capture Utilisation and Storage (CCUS) technology is used.

The option to inject hydrogen into the existing natural gas networks is seen as a relatively simple option by many, however, the emissions reduction potential compared to gas is limited if non green production methods are used without CCUS. The feasibility of blending hydrogen in the existing gas grid is another option that is being explored in cities and regions in the UK in projects such as HyDeploy[13]. So far findings show that end users detect no notable differences with natural gas and domestic gas appliances are just as safe operating with a blended gas of up to 20 per cent hydrogen.

Hydrogen-ready boilers are already being manufactured (e.g. Worcester-Bosch, Baxi and Valliant [14]) and tested for safety and energy efficiency and the existing distribution infrastructure mean the conversion would be relatively straightforward for many homes compared with heat pumps or connection to a heat network. The existing gas network also acts as an energy storage facility that can cope with seasonal trends and rapid fluctuations in heat demand during the day, so in comparison with an electrification of heat solution there are fewer concerns about balancing the additional demand on the network.

However, **the uncertainty around the availability of adequate supplies of low-cost low-carbon hydrogen make it an unlikely solution on its own** as well as concerns that using non-green hydrogen will lock us in to continued fossil fuel use for longer. In addition, the energy density of hydrogen as a gas is less than methane, and long-term exposure to hydrogen damages materials. Hydrogen gas can be transported in the current low-pressure natural gas network but at high pressure, old iron mains may be subject to embrittlement. It is worth noting that all iron mains are currently being replaced with PU (polyurethane) pipes across the UK, as part of the replacement programme (REPEX), set to be completed in 2032.

Costs:

Estimated costs at the household level are set out in Table 4 below. The costs are for replacing a gas boiler as part of a gas central heating system. The cost of replacing an electric heating system would be considerable higher – estimated at £7,406.

Cost Type	Cost (£)
Retail Costs	875
Installation Costs	750
Ancillary Work Costs	2,000
Total:	3,625

Table 4: Estimate hydrogen boiler costs. Source: Appraisal of Domestic Hydrogen Appliances, BEIS, 2018[15]

Market barriers and opportunities:

Creating a skilled workforce is less a barrier than for a heat pump solution as hydrogen has lower training requirements as existing Gas Safe Engineers could be easily trained in using

[13] https://hydeploy.co.uk/
[14] https://www.vaillant.co.uk/for-installers/business-support/industry-drivers-and-legislation/hydrogen/
[15] https://www.gov.uk/government/publications/appraisal-of-domestic-hydrogen-appliances

hydrogen (or a blend) and installing the new boilers. The main market barrier for hydrogen is producing it at sufficient scale and low enough cost in comparison to natural gas so that it is a viable replacement and won't increase energy costs for householders, increasing levels of fuel poverty.

District heating network and retrofit

District heating is a relatively new technology in Birmingham, but district heating networks (DHNs) have been a part of city developments for a lot longer, in some cases over 100 years. Energy is often supplied by Combined Heat and Power (CHP) plants, which are more efficient than producing either heat or power, but heat networks can also use industrial waste heat directly, including heat from energy from waste (EfW) plants. Heat networks can be deployed in communal buildings such as new-build apartments and tower blocks or can be used for a cluster of homes if there is enough high-density demand in the area. Heat networks are attractive in high-density built up areas such as city centres.

As residential heat in East Birmingham is mainly generated by localised gas boilers, the total efficiency of heating can be increased by utilising a central heat source such as a combined heat and power plant (CHP). End user costs may subsequently be lower through economies of scale and since boiler acquisition, fuel and maintenance no longer need to be dealt with on an individual household level. Another benefit of district heating is that replacing combustion at the demand site by a centralised centre results in better pollution control and improved air quality in the residential areas.

District heating schemes often operate best when connected to a large variety of building types, i.e. residential, retail, and industrial demand. Heat demand of residential housing is highly seasonal and changes throughout the day, whereas industrial applications may balance out demand by providing a baseload and different peak hours. It is beneficial to include buildings with high heat demand (e.g. schools, leisure centres, care homes) into any newly developed district heating schemes.

Heat is brought into each building through a 'heat exchanger' which, for a residential connection, is about the same size as a small gas boiler. All the same heating controls are available and to the end user the central heating and hot water system works in the same way as a domestic gas-fired central heating system without the need for any combustion to take place inside the building.

As the heat loss over greater distances is significant, ideally heat production would need to happen in close proximity to customers with heat demand. For a pipe with a diameter of 250mm - which is required for a peak load of 5MW - heat loss is estimated to be 31.5 W/m. Therefore, areas of higher energy demand density, for example urban areas with a large number of apartment blocks, are ideal for district heating systems. Minimising transport losses has also led to the development of smaller energy clusters instead of large centralised systems, e.g. a housing estate connected to one CHP plant.

A challenge with the introduction of any new district heating network is the disruptiveness of construction work, which may be mitigated by combining the installation with other ongoing road work. The poor average energy performance ratings in some areas of East Birmingham indicate a need to retrofit houses before the introduction of a district heating system, which poses further disruptions. When established, however, district heating networks can result in greater comfort and cost reductions for the end user.

A potential district heating solution for East Birmingham would be to build a new energy centre and network at Washford Heath and the HS2 depot and have a branch going out to Castle Vale.

Costs:

Estimating the costs of a new districting heating network at the neighbourhood level is challenging as it depends on the location of the energy centre and the other demand on the network. Household level-cost have been estimated and are shown in Table 5 below. A methodology for estimating infrastructure costs and assigning these at the household level in a cost-benefits model is currently being developed.

CAPITAL COSTS		NON BULK SCHEMES AVERAGE	Description
Cost HIUs Dwellings (a)	£ / MWh	253	Cost of individual Hydraulic Interface Units for dwellings (not including heat meters) per annual heat demand.
Cost heat meters Dwellings (a)	£ / MWh	170	Cost of individual heat meters for individual dwelling connections per annual heat demand.
Cost internal pipework connection to HIUs (a)	£ / MWh	492	Cost of internal pipework within domestic blocks from bulk supply substation (if present) to individual dwelling connection points per annual heat demand.

Table 5: Household-level Costs of District Heating. Source: DECC, 2015[16].

Household costs are dependent on household size and average energy demand. Bigger houses have bigger costs.

Market barriers and opportunities: The IPPR calculates that if government invested £3 billion, it would leverage private investment of £22 billion, enough to supply 10% of UK heat by 2030, the target set by the Committee on Climate Change (CCC). The magnitude of investment needed will require government support to reduce the cost of capital and reduce financial risk to potential investors. Heat networks are only cost-effective to invest in if there is a contract of sufficient length to recover for private sector investors to recoup their initial investment and a reasonable rate of return on investment. There are also potential barriers

[16] https://www.gov.uk/government/publications/assessment-of-the-costs-performance-and-characteristics-of-uk-heat-networks

around planning permissions and minimising disruption to businesses and public to obtain support necessary permissions.

4.2 The Options Model

Description

An economic model has been developed that allows for an analysis of costs and benefits of different options for investment into housing retrofits. The model was created as a tool that can be applied to different neighbourhoods and scales across the region to assess the costs and impacts of differing routes to the decarbonisation of heat. The model allows inputs to be adjusted to reflect the housing, tenure, and heating type mix of the intervention area.
Further adjustments can be made for the economic conditions at the time of use (e.g. energy prices, inflation), for the anticipated split of funding between private and public sector and private individuals, and for the overall take-up (delivery) of retrofits. It is also possible to vary take-up rates and funding streams by dwelling type, tenure, and existing heating type (electric or gas) to reflect differences in ownership and energy economics. A full set of instructions is included with the model to assist the user.

A range of benefits have been considered as arising from improving the energy efficiency of homes, shifting to cleaner energy sources, and investing in improvements to the existing stock of residential properties – described in section 4.3.

Benefits appraised in the model include:

- Energy savings resulting in lower household bills;
- Employment created directly and indirectly (supply chain effects) from investment into housing retrofit;
- Health and wellbeing improvements through improved living conditions and reduced air pollution;
- Training opportunities for local residents;
- Private sector money leveraged in through public sector investment;
- Overall impact to the regional economy (GVA) taking account of economic multipliers, displacement and leakage effects, and optimism bias.

Appraisal of each option includes the calculation of net present social value, which time adjusts the net impact of costs and benefits over a 30-year time period, and also a benefit-cost ratio (BCR) which provides an indication of value-for-money on public spending. These are calculated, as far as possible, using the approach outlined in HMT's *Green Book* and BEIS' supplementary *Valuation of Energy Use and Greenhouse Gas*. This requires that costs exclude transfer payments (margins and taxes) and energy costs are based on long-run variable costs (LRVCs, which are provided by BEIS for electricity and gas). Net benefits are discounted over the analysis period by 3.5% per annum reflecting the social-time preference recommended for use in the Green Book.

To supplement the economic analysis as outline above, the effect on domestic energy bills has been calculated. This differs from the economic approach since it is based on energy prices available to consumers on the open market (i.e. includes margin and taxes). The determination of potential energy savings and length of payback to domestic consumers is a key consideration for take-up and financing. Assessing the impact on household bills also provides an indication of impact on fuel poverty.

Importantly, options are adjusted to discount effects that would have occurred anyway due to pre-existing conditions and trends. This 'business as usual' case is represented by Option 1 and the impacts of 'business as usual' have been subtracted as deadweight from Options 2 to 5.
Five options for delivering alternative heating technology have been modelled using Castle Vale as a test case.

Option 1: Business as Usual

Option 1 represents the underlying conditions and what would happen were there to be no intervention. For the purposes of demonstrating the model, it has been assumed a very low number of non-social tenure households self-elect to retrofit their homes using their own financial means, at a rate of 1% of households per annum. The economic effects, costs and benefits of this option have been subtracted from the others as 'deadweight' using Green Book terminology.

Option 2: Thermal Efficiency (TE) Retrofit

This option represents a *'do minimum'* case whereby a maximal thermal efficiency retrofit is carried out on properties (double glazing, external wall and underfloor (where applicable) insulation) but the heating type (electric or gas) is not changed. For the purposes of demonstrating the model, it has been assumed that 100% of properties in the Castle Vale area are retrofitted over a five-year period to reflect ambitions in this area. As a starting point, it has been assumed the cost of retrofitting is funded by the public sector. In practice this is likely to involve some level of private sector financing and private individual contributions, but the attractiveness to the private sector is yet to be determined in full.

Option 3: Heat Pump + TE Retrofit

Option 3 combines the benefit of a thermal efficiency retrofit (as per Option 2) with a switch in heating type to an air source heat pump. As above, for the purposes of demonstrating the model it has been assumed 100% of properties in the Castle Vale area are retrofitted over a five-year period and that the public sector provides all funding (as a starting point).

Option 4: District Heating + TE Retrofit

Option 4 combines the benefit of a thermal efficiency retrofit (as per Option 2) with a switch in heating to obtain heat from a district heat network supplied by a combined heat and power plant (CHP) using natural gas. Due to the nature of a CHP plant, the cost of producing heat energy would be subsidised/lowered through sales of electricity generated by the plant. As above, for the purposes of demonstrating the model it has been assumed 100% of properties in the Castle Vale area are retrofitted over a five-year period and that the public sector provides all funding (as a starting point).

Option 5: Hydrogen + TE Retrofit

Option 5 combines the benefit of a thermal efficiency retrofit (as per Option 2) with a switch in heating type to hydrogen using hydrogen boilers. As above, for the purposes of demonstrating the model it has been assumed 100% of properties in the Castle Vale area are retrofitted over a five-year period and that the public sector provides all funding (as a starting point).

Model Assumptions

Several assumptions have been made in the creation of the model and general input variables and inputs relating specifically to Castle Vale.

Housing stock and existing heating type

There are 4,314 households in the Castle Vale intervention area. A breakdown of dwelling types, tenure types and existing heating source is shown in Table 6 below.

			Number of Households by Tenure					No. Housholds by Existing Heating Source	
Dwelling Type	Share %	Number of Households	Private Ownership	Shared Ownership	Private Rent	Social Rent	Other Rent	Electricity	Gas
			36.9%	0.5%	4.9%	55.7%	2.00%	18%	82%
Terraced	43.6%	1,881	694	9	92	1,048	38	339	1,542
Flat	25.3%	1,091	403	5	53	608	22	196	895
Semi-detached	26.8%	1,156	427	6	57	644	23	208	948
Detached	4.3%	186	68	1	9	103	4	33	152
Bungalow	0.0%	0	0	0	0	0	0	0	0
TOTAL	**100.0%**	**4,314**	**1,592**	**22**	**211**	**2,403**	**86**	**777**	**3,537**

Table 6: Existing Housing Stock in Castle Vale

All flats are assumed to be low-rise and purpose-built.

- All properties types are assumed to be small in size.
- All non-gas heated properties are considered as electric heated, although in reality there are other heating types in existing use.

Base line energy consumption for space heating

Energy consumption for space heating for the current housing stock in Castle Vale was estimated and used as a baseline for comparison with the following assumptions:

- Electricity consumption is based on ECO7 meters and assumed to be wholly for space heating.
- Gas consumption are based on figures from BEIS' National Energy Efficiency Data-Framework: Headline Consumption Tables England and Wales 2018. It's assumed that 77% of domestic gas consumption is used for space heating.
- Average domestic energy prices for electricity and gas have been taken from the internet during desk-based research and include the standing and variable charges.

Thermal efficiency (TE) retrofit

A maximal TE retrofit option was used with following measures: double glazing, external wall insulation and underfloor insulation to one floor, except flats & bungalows where no underfloor insulation was included.

Heat pumps

- Air source heat pumps are powered by electricity, which is assumed to be priced the same rates and LRVCs as for electric heating (see Tables 9 and 10).
- No data available for heat pump energy consumption for bungalows and so has been assumed equivalent to a semi-detached house.
- Installation of upgraded radiators has been included in costs.

District heat network

- Modelling is based on a combined heat and power (CHP) plant generating heat and electricity using natural gas as feedstock.
- Domestic energy consumption based on gas properties but adjusted for lower operating efficiency of a CHP (43.3%) versus a gas boiler (assumed to be 70%).
- District heating varies widely in price and a figure has been chosen which falls within the middle of an identified range.
- The LRVC of supplying heat from a district network has been calculated by comparing the estimated OPEX of CHP (natural gas) to the OPEX for natural gas supply for gas boiler heating. The OPEX for generating heat is calculated net of sales of electricity also produced by the CHP. Future LRVCs are inflated in line with natural gas LRVCs provided by BEIS (see Table 9).

Hydrogen

- It's assumed that energy consumption in homes converted to hydrogen will be equivalent gas properties post-TE retrofit.

- Costings for electric heated properties include connection to the grid for hydrogen supply and installation of new radiators. Existing gas heated properties are assumed not to need a new connection to the grid or modification to existing radiators.
- Both gas and electric heated homes are costed to include installation of a new hydrogen boiler.
- Hydrogen LRVCs calculated based on variable costs of producing hydrogen by steam methane reformation with carbon capture and storage (SMR + CCS) and inflated for future years in line with gas LRVCs since gas is the fuel source for SMR.

Socio-economic modelling

- **Monetised costs and benefits have been modelled over a 30-year time horizon using inflated values where appropriate.** Costs and benefits have then been discounted to 'today's values' for the purpose of calculating net present values and benefit-cost-ratios. Benefits have been discounted using a rate of 3.5% as recommended in the Green Book.
- **The base year of modelling is 2021.** All input costs for supply and installation of retrofit equipment and heating technologies have been inflated to 2021 prices where required using ONS' construction output price index. Costs for future years have been inflated at a constant rate of 2% per annum.
- For the purposes of economic analysis (but not payback periods), **all costs for supply and installation of retrofit and heating equipment are calculated or assumed to be exclusive of VAT and margins**.
- As outlined above, it has been **assumed that Options 2 to 5 are delivered to the entire housing stock (i.e. 100% take-up)** in line with ambitions for decarbonisation and improving living conditions in a just manner.
- For Options 2 to 5, **delivery of retrofits is modelled over five years between 2022 and 2026**, phased as 10% of the housing stock in 2022, 20% in 2023, 30% in 2024, 30% in 2025 and 10% in 2026.
- For the purposes of demonstrating the model, and as a clear starting point, it has been **assumed that the full cost of delivering Options 2 to 5 is funded by the public sector**. Whilst this is unrealistic in practice, private sector input is required to discern an appropriate split of funding between the public and private sector and individuals and via what financing mechanisms. Business as usual retrofits (Option 1) are assumed to be self-funded by individuals without any grant funding.
- **Long run variable costs (LRVCs) exclude margins and taxes.** The LRVCs for producing and supplying domestic gas and electricity are provided by BEIS for the 30-year period. BEIS central scenarios have been used. LRVCs for heat pumps are assumed to be equal to those for electricity. LRVCs for district heating and hydrogen have been estimated using available data. Refer to Table 9 for summary of LRVCs.

- **Direct employment effects (GVA and job creation) have been calculated using an employment model that estimates the number of experienced and trainee workers required to carry out each retrofit over a specified period of time.** Employment costs include wages and fringes (employers insurance, benefits, training costs). Employment costs are assumed to increase by 2% per annum over the 30-year analysis period. The employment model **includes adjustments for displacement (workers who would be otherwise gainfully employed) and leakage (workers living outside of the East Birmingham area).** It is **assumed that 100% of trainees are recruited locally as part of a reskilling programme** and that they carry out retrofits in teams of two overseen by more experienced workers. A minority of the experienced workers have been assumed to reside outside the area (i.e. leakage).
- **Supply chain effects (GVA and indirect employment) have been calculated using economic multipliers** sourced from a peer review by Arup of a similar economic analysis proposed by the Energy Systems Catapult in 2016. Unfortunately, the original proposed analysis and detail on the derivation of multipliers are not available despite attempts to obtain them.
- **Fuel poverty impacts have been calculated using expected changes in domestic heating bills.** Baseline fuel poverty and the impacts of each option are measured using the Low-Income High-Cost (LIHC) indicator of fuel poverty although it should be noted that the UK government has recently adopted a new indicator Low-Income Low-Energy Efficiency (LILEE). **Around 10% of households in Castle Vale are estimated to be in fuel poverty representing a baseline of 434 households using the LIHC measure.** Baseline data using the new LILEE indicator was not available. The impact of the rebound effect on fuel poverty reduction is not known and has not been included.
- **Impacts on health have been monetised using research available including reducing the cost to NHS from excess cold in housing and cost of air quality damage.** Impacts on wellbeing have been quantified through Quality Adjusted Life Years (QALYs) and valued using 'willingness to pay' (£60k per QALY) as recommended in the Green Book.
- **Costs and benefits have been adjusted to account for optimism bias** using +10% on costs and -10% on benefits.

4.3 Comparing options

Identify the preferred way forward for the project – scope, solution, service delivery, implementation, and funding – together with the shortlist, against which the preferred way forward will be appraised.

Economic costs and benefits comparison

A summary of the economic benefits, costs and impacts is shown in Table B. A full summary is provided on the Summary tab in the Options Model.

The net present social value (NPSV) is calculated through the subtraction of costs at current prices from the present value of monetised benefits. A negative NPSV means that the costs exceed the benefits. Monetised benefits include net savings in the cost of energy production, GVA impact of direct and indirect job creation, and the value of health-related impacts. The latter is based on reduced cost to the NHS from excess cold in poor housing (assumed to correlated with fuel poverty), reduced costs from poor air quality, and improved quality of life measured through Quality Adjusted Life Years (QALYs). Where an option has a negative impact on health, fuel poverty or the cost of energy, the benefit is shown as a negative.

Estimated costs are for the supply and installation of thermal efficiency improvements and heating equipment (where applicable) for each option. The present value of costs is based on current prices exclusive of VAT and margins. Capital costs for the upgrade or development of new network infrastructure are excluded at this stage. Future costs for replacing or maintaining retrofit and heating equipment are not included.

	OPTION 1 No Intervention (Business as Usual)	**OPTION 2** Thermal Efficiency Retrofit	**OPTION 3** Heat Pump + Thermal Retrofit	**OPTION 4** District Heating + Thermal Retrofit	**OPTION 5** Hydrogen + Thermal Retrofit
Net present social value (NPSV) (£k) *	**-£2,927k**	**-£10,616k**	**-£74,357k**	**-£37,768k**	**-£29,949k**
Net present value of benefits (£k) *	£3,924k	£34,086k	£10,999k	£32,608k	£30,959k
Net present value of costs (£k) *	£6,851k	£44,702k	£85,356k	£70,376k	£60,908k
Benefit Cost Ratio (BCR) *	**-**	**0.56**	**0.10**	**0.36**	**0.39**
Households Retrofitted	**573**	**4,314**	**4,314**	**4,314**	**4,314**
PV of benefit per household retrofitted (£)	£6,845	£8,811	£3,459	£8,468	£8,086
PV of cost per household retrofitted (£)	£11,950	£11,950	£21,374	£17,902	£15,707
Total net new 'job years' (initial 5 years)	**24**	**1,089**	**1,201**	**1,201**	**1,201**
Net direct 'job years' created (initial 5 years)	4	198	218	218	218
Net indirect 'job years' created (initial 5 years)	20	891	982	982	982
Number of people trained	**0**	**57**	**57**	**57**	**57**
Average trainee employment period	-	3.3 years	3.3 years	3.3 years	3.3 years
Present value of total energy saving	**£322k**	**£5,042k**	**-£17,149k**	**£7,238k**	**-£4,353k**
Social Wellbeing & Health					
Households lifted out of fuel poverty	15	109	-258	-217	97
Households remaining in fuel poverty	419	324	691	651	337
Households no longer at risk of excess cold	15	109	-258	-217	97
Increase in quality life years (per annum)	0.0	0.2	-0.4	-0.4	0.2
Health Savings & Quality of Life Benefits					
Annual saving to NHS from excess cold	£11k	£85k	-£201k	-£169k	£75k
Quality Adjusted Life Years (QALYs)	£2k	£11k	-£27k	-£22k	£10k
Annual saving from air quality damage	£4k	£31k	£24k	-£29k	£136k

** NPSV and BCR for Options 2 to 5 are net of Option 1 which represents 'deadweight'.*

Table 7: Summary of economic costs and benefits.

The Benefit cost ratio (BCR) is a relative measure of value-for-money that takes the present value of benefits over costs. Since it is calculated on public sector spending only, costs are based on what the public sector would pay and therefore should include VAT and margins on the supply and installation of equipment. As noted in the limitations section, complexities around VAT mean that it has been excluded in the current BCR calculation. An assumed margin of 15% has been included where applicable. Note that both NPSV and BCR are calculated net of deadweight, which is represented by Option 1 ('business as usual').

None of the options results in a positive net present social value for society based on the benefits that have been monetised. This is on account of the relatively small energy savings and health benefits (if any) in relation to the capital cost required to carry out retrofits. However, that **the intergenerational and wider societal benefits from decarbonising heat have not been quantified or monetised** in this analysis due to complexity and unresolved questions, but should not be ignored in the round.

Option 1 is the 'business as usual' scenario whereby a small number of privately-owned properties (1% per annum) are anticipated to be retrofitted each year, either due to the energy savings on offer or because of the owner's concerns over environmental factors. This equates to **573 properties retrofitted over the 30-year period generating a total of £322k in energy savings** in present value terms (calculated using LRVCs). At a domestic level, the savings are greater for electric heated properties than gas (see Table 11).

Options 2 to 5 involve retrofits to the entire housing stock of Castle Vale (4,314 properties) and so the economic impacts are much larger than under business as usual. The impact of these options has been calculated net of those of Option 1 which represents what would happen anyway (deadweight).

Thermal efficiency retrofits (Option 2) are least costly to deliver and result in a positive energy saving of £5m (in today's money using LRVCs) over the 30-year period. This results in a **net present value that is significantly less negative than Options 3 to 5**. Given the energy savings that can be achieved, this option also has a **positive effect on reducing fuel poverty** (109 less households in fuel poverty) and generates **savings to the NHS from reduced risk of cold**, as well as **improving quality of life and air quality**. However, it should be noted that this option reduces energy usage through efficiency improvements and **does not by itself result in decarbonisation**.

Options 3 to 5 are all higher cost than thermal efficiency retrofits on account of the additional heating equipment for installation. Based on the assumptions in the employment model, **each of these options would create an estimated 1,201 job years over the 5-year delivery period including 57 trainee positions (all trainees local residents) each employed**

for an average of 3.3 years. However, the relative costs and energy savings under each of these options differs widely.

Heat pumps would be the costliest to deliver and result in the worst overall energy savings. This option would result in an increased cost of energy by £17.1m over 30 years (using LRVCs in today's money). **This option therefore has the worst BCR of all options at £0.10 in benefits for each £1 spent.** Given the increased cost of heating it could also result in a **detrimental impact to fuel poverty, pushing 258 households into poverty** as defined by the LIHC measure. There would be a **small annual benefit to health from improving air quality (£24k).** It should be noted that these results are based on assumed LRVCs and domestic energy prices equivalent to electricity from the grid (see Table 9 and 10). LRVCs and prices may be lower using disaggregated supply such as local power generation. Complexities have prevented alternate LRVCs being modelled for inclusion at this stage. A key question at this stage is how sensitive are the results to the cost of supplying and installing a heat pump. This will be explored further below.

District heating offers an opportunity to generate the highest overall energy savings totalling £7.2m (in today's money using LRVCs) and a more favourable BCR than Option 3 but slightly lower than Option 5. The operating costs (and hence LRVCs) of producing heat from a CHP plant are significantly reduced by the sale of electricity produced by the plant. However, **this is not reflected in fuel poverty which shows a large increase of 217 households based domestic energy prices higher than for gas heating** as shown in Table 8. The market for heat networks is unregulated and energy prices vary widely. A market study by the Competitions and Market Authority (CMA, 2016) found an interquartile range of 3.9p/kWh to 7.8p/kWh, mean of 6.0p/kWh and median of 4.8p/kWh across the UK heat network. The price used in this model falls within the middle of the range but the potential for variability should be recognised and is explored further below.

It is important to note that a CHP powered by natural gas would not decarbonise heat generation and is not a low carbon solution in the short-term. Over the longer-term it is envisaged that CHP plant could be powered by low carbon hydrogen or ammonia. **The use of natural gas also has a negative impact on air quality and would increase related costs by £29k per annum.**

Hydrogen would be significantly lower cost to deliver than Options 3 and 4 and result in lower domestic energy bills, and therefore reduced fuel poverty and improved quality of life. However, as shown in Table 9, calculated LRVCs for hydrogen are significantly higher than those for gas (the predominant heating type) and so **overall energy costs (using LRVCs) are estimated to increase by £4.4m over 30 years**. Note that calculated LRVCs are based on early estimates and need to be peer reviewed. Additionally, the longer-term preference is for hydrogen produced by electrolysis and LRVCs may differ to those modelled. Despite their adverse effect on the total value of benefits, the **net present value of this option still appears better (i.e. less negative) than for heat pumps or district heating and has a higher BCR (0.39) than either**. Sensitivity to changes in the price of hydrogen is shown below.

Heating Type	2021 Base Year	2026 Year 5	2031 Year 10	2036 Year 15	2041 Year 20	2046 Year 25	2051 Year 30
Electricity (£/kWh)	0.1057	0.1138	0.1074	0.1074	0.1074	0.1074	0.1074
LRVC Index	*1.000*	*1.076*	*1.016*	*1.016*	*1.016*	*1.016*	*1.016*
Gas (£/kWh)	0.0182	0.0210	0.0231	0.0231	0.0231	0.0231	0.0231
LRVC Index	*1.000*	*1.153*	*1.267*	*1.267*	*1.267*	*1.267*	*1.267*
Heat Pumps (£/kWh)	0.1057	0.1138	0.1074	0.1074	0.1074	0.1074	0.1074
LRVC Index	*1.000*	*1.076*	*1.016*	*1.016*	*1.016*	*1.016*	*1.016*
Heat Network (£/kWh	0.0149	0.0172	0.0189	0.0189	0.0189	0.0189	0.0189
LRVC Index	*1.000*	*1.153*	*1.267*	*1.267*	*1.267*	*1.267*	*1.267*
Hydrogen (£/kWh)	0.0436	0.0503	0.0553	0.0553	0.0553	0.0553	0.0553
LRVC Index	*1.000*	*1.153*	*1.267*	*1.267*	*1.267*	*1.267*	*1.267*

Table 8: Long Run Variable Costs (LRVCs).

	Electricity	Gas	Heat Pump	District Heat	Hydrogen
Standing Charge (£/day)	0.2054	0.2400	0.2054	0.0000	0.0000
Variable Charge (£/kWh)	0.1425	0.0380	0.1425	0.0689	0.0663

Table 9: Base Year Energy Prices.

Domestic Savings

A comparison of savings from the consumer perspective is shown in Table 11. The importance of domestic savings is twofold. An increase or decrease in domestic heating bills will have a direct impact on fuel poverty, disposable income, and wellbeing of households. And second, savings on heating bills will act as an incentive for individuals to invest in the retrofit of their own home or property or will provide the headroom for private sector companies to fund or finance retrofits over time. Whilst the basis of the economic model has been to assume 100% funding by the public sector, in reality this is likely to involve a combination of public, private and individual funding.

	Annual Saving / (Increase) vs. BAU (£)				Retrofit Cost per household (£)				Payback period (years)			
	Terraced	Flat	Semi-detached	Detached	Terraced	Flat	Semi-detached	Detached	Terraced	Flat	Semi-detached	Detached
Where existing heating type = ELECTRIC												
Option 1 No intervention (BAU)	-	-	-	-	£0	£0	£0	£0	-	-	-	-
Option 2 Thermal efficiency retrofit	£253	£177	£363	£507	£12,755	£8,701	£15,696	£18,881	50.4	49.1	43.3	37.2
Option 3 Heat Pump + TE retrofit	£255	£487	£371	£309	£22,834	£18,780	£25,775	£28,960	89.5	38.6	69.4	93.7
Option 4 District heating + TE retrofit	£409	£408	£379	£104	£19,443	£12,777	£23,160	£28,586	47.6	31.3	61.0	275.4
Option 5 Hydrogen + TE retrofit	£738	£609	£747	£582	£20,063	£16,008	£23,003	£26,188	27.2	26.3	30.8	45.0
Where existing heating type = GAS												
Option 1 No intervention (BAU)	-	-	-	-	£0	£0	£0	£0	-	-	-	-
Option 2 Thermal efficiency retrofit	£68	£47	£97	£135	£12,755	£8,701	£15,696	£18,881	188.9	184.2	162.3	139.5
Option 3 Heat Pump + TE retrofit	(£535)	(£113)	(£422)	(£350)	£22,834	£18,780	£25,775	£28,960	-	-	-	-
Option 4 District heating + TE retrofit	(£381)	(£192)	(£414)	(£555)	£19,443	£12,777	£23,160	£28,586	-	-	-	-
Option 5 Hydrogen + TE retrofit	(£52)	£9	(£47)	(£77)	£16,051	£11,997	£18,991	£22,176	-	1,378.3	-	-

Table 10: Domestic Energy Savings & Payback Period.

From looking at Table 10 it is clear that **all options perform poorly against existing gas heating on account of gas being a cheaper source of energy** based on domestic prices. **All options involving a shift to a new heat source (Options 3 to 5) would increase domestic energy prices for gas heated properties**. Hydrogen is the least worst of these options and the modelled price is closer to the margin, even resulting in a slight saving for purpose-built flats. Based on higher prices **the payback on retrofit cost is virtually non-existent**.

There is a more encouraging picture against electrically heated properties given the price of electricity is currently much higher than gas. **All options offer a domestic energy saving versus the status quo for electrically heated properties.** However, these **savings are relatively small** in comparison to the outlay for retrofit and **payback is over many years**. For instance, installing heat pumps into electrically heated terraced properties would take almost 90 years to payback (ignoring finance costs) and *only* 39 years for a flat. Developing a district heat network would take over 31 years to payback on a flat and much longer for other dwelling types, although as noted above and in the CMA report, heat network pricing varies widely and is explored further below.

Based on the prices modelled, **Option 5 to install hydrogen with a TE retrofit appears to be the most financially feasible with relatively attractive domestic savings for electrically heated properties and a more marginal position with regard to gas heated properties**. Sensitivity to the price of hydrogen produced heat is reviewed below.

Sensitivity Analysis

	Scenario 1: Changes in the cost of heat pump (supply & installation)						
	-50%	-25%	-10%	-5%	0%	+5%	+10%
OPTION 3: Adjusted Outcomes							
Net present social value *	(£54,030k)	(£64,193k)	(£70,291k)	(£72,324k)	(£74,357k)	(£76,390k)	(£78,422k)
Net present value of benefits *	£10,999k	£10,999k	£10,999k	£10,999k	£10,999k	£10,999k	£10,999k
Net present value of costs *	£65,029k	£75,193k	£81,291k	£83,324k	£85,356k	£87,389k	£89,422k
Benefit cost ratio *	0.13	0.11	0.11	0.10	0.10	0.10	0.10
Households retrofitted	4,314	4,314	4,314	4,314	4,314	4,314	4,314
Total net new job years (initial 5 years)	1,201	1,201	1,201	1,201	1,201	1,201	1,201
Number of people trained	57	57	57	57	57	57	57
Present value of energy saving (LRVCs)	(£17,149k)	(£17,149k)	(£17,149k)	(£17,149k)	(£17,149k)	(£17,149k)	(£17,149k)
Households lifted out of fuel poverty	-258	-258	-258	-258	-258	-258	-258
Housholds remaining in fuel poverty	691	691	691	691	691	691	691
Households no longer at risk of cold	-258	-258	-258	-258	-258	-258	-258
Increase in quality life years (per annum)	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
Annualised health & quality of life benefit	(£203k)	(£203k)	(£203k)	(£203k)	(£203k)	(£203k)	(£203k)
Adjusted savings for terraced property							
Annual energy saving per home - Electric	£255	£255	£255	£255	£255	£255	£255
Annual energy saving per home - Gas	-£535	-£535	-£535	-£535	-£535	-£535	-£535
Household payback period - Electric	69.7yrs	79.6yrs	85.6yrs	87.5yrs	89.5yrs	91.5yrs	93.5yrs
Household payback period - Gas	-	-	-	-	-	-	-

** NPSV and BCR are net of Option 1 which represents 'deadweight'.*

Table 11: Option 3 Sensitivity to Changes in the Cost of a Heat Pump.

Table 11 demonstrates that **even with a 50% reduction in the cost for supplying and installing a heat pump the economic cost remains high (£65m), net social value significantly negative (-£54m), and the BCR very low (0.13)**. Additionally**, a reduction in the cost of installing a heat pump does not reduce either the LRVC of electricity required to power the pump, nor the domestic energy price**. Energy costs and domestic bills would therefore remain higher for existing gas heated properties which are the predominant type in the Castle Vale area.

	Scenario 2: Changes in unit price (tariff) for district heating						
	-50%	-25%	-10%	0%	+10%	+25%	+50%
OPTION 4: Adjusted Outcomes							
Net present social value *	(£30,961k)	(£34,364k)	(£36,407k)	(£37,768k)	(£39,129k)	(£41,171k)	(£44,575k)
Net present value of benefits *	£39,415k	£36,011k	£33,969k	£32,608k	£31,247k	£29,204k	£25,801k
Net present value of costs *	£70,376k	£70,376k	£70,376k	£70,376k	£70,376k	£70,376k	£70,376k
Benefit cost ratio *	0.43	0.40	0.37	0.36	0.34	0.32	0.28
Households retrofitted	4,314	4,314	4,314	4,314	4,314	4,314	4,314
Total net new job years (initial 5 years)	1,201	1,201	1,201	1,201	1,201	1,201	1,201
Number of people trained	57	57	57	57	57	57	57
Present value of energy saving (LRVCs)	£7,238k	£7,238k	£7,238k	£7,238k	£7,238k	£7,238k	£7,238k
Households lifted out of fuel poverty	171	-23	-140	-217	-295	-411	-605
Housholds remaining in fuel poverty	263	457	573	651	728	845	1,039
Households no longer at risk of cold	171	-23	-140	-217	-295	-411	-605
Increase in quality life years (per annum)	0.3	0.0	-0.2	-0.4	-0.5	-0.7	-1.0
Annualised health & quality of life benefit	£122k	(£49k)	(£152k)	(£220k)	(£289k)	(£392k)	(£563k)
Adjusted savings for terraced property							
Annual energy saving per home - Electric	£816	£612	£490	£409	£327	£205	£2
Annual energy saving per home - Gas	£26	-£178	-£300	-£381	-£462	-£585	-£788
Household payback period - Electric	23.8yrs	31.8yrs	39.7yrs	47.6yrs	59.4yrs	94.7yrs	10,579.6yrs
Household payback period - Gas	750.5 yrs	-	-	-	-	-	-

** NPSV and BCR are net of Option 1 which represents 'deadweight'.*

Table 12: Option 4 Sensitivity to Changes in the Energy Price for District Heat

As noted above, pricing within the district heat market varies widely across the nation. Table 12 provides a sensitivity analysis in economic impacts to changes in the price of district heat +/- 50% from the modelled price. Higher prices have the expected effect of worsening the present value of benefits, impact on fuel poverty and domestic bills.

A near 50% reduction in price would make the conversion of gas heated properties to district heating more feasible from a consumer perspective (based on a terraced property). The cross-over point is estimated to be at a price point 47% lower than that modelled (based on terraced properties) and beyond this would start to generate a payback for the conversion of gas heated properties. The payback on electric heated terraced properties is a relatively reasonable 23.8 years. Whilst this seems like a very large necessary reduction in price, the CMA report found an interquartile range starting at 3.9p/kWh and median price of 4.8p/kWh in 2016. The modelled price is 6.89p/kWh in the base year (2021).

Beyond the cross-over point on gas heated properties, **the impact on fuel poverty reduction, health and wellbeing becomes positive and the BCR improves.** At a 50% reduction in price the BCR would be 0.43, higher than for hydrogen and heat pumps.

	Scenario 3: Changes in unit price (tariff) for hydrogen heating						
	-50%	-25%	-10%	0%	+10%	+25%	+50%
OPTION 5: Adjusted Outcomes							
Net present social value *	(£25,896k)	(£27,923k)	(£29,139k)	(£29,949k)	(£30,760k)	(£31,976k)	(£34,003k)
Net present value of benefits *	£35,012k	£32,986k	£31,770k	£30,959k	£30,148k	£28,932k	£26,906k
Net present value of costs *	£60,908k	£60,908k	£60,908k	£60,908k	£60,908k	£60,908k	£60,908k
Benefit cost ratio *	0.44	0.41	0.40	0.39	0.38	0.36	0.34
Households retrofitted	4,314	4,314	4,314	4,314	4,314	4,314	4,314
Total net new job years (initial 5 years)	1,201	1,201	1,201	1,201	1,201	1,201	1,201
Number of people trained	57	57	57	57	57	57	57
Present value of energy saving (LRVCs)	(£4,353k)	(£4,353k)	(£4,353k)	(£4,353k)	(£4,353k)	(£4,353k)	(£4,353k)
Households lifted out of fuel poverty	328	212	143	97	50	-19	-134
Housholds remaining in fuel poverty	106	221	291	337	383	452	568
Households no longer at risk of cold	328	212	143	97	50	-19	-134
Increase in quality life years (per annum)	0.6	0.4	0.2	0.2	0.1	0.0	-0.2
Annualised health & quality of life benefit	£426k	£324k	£263k	£222k	£181k	£120k	£18k
Adjusted savings for terraced property							
Annual energy saving per home - Electric	£980	£859	£787	£738	£690	£617	£496
Annual energy saving per home - Gas	£191	£69	-£3	-£52	-£100	-£173	-£294
Household payback period - Electric	20.5yrs	23.4yrs	25.5yrs	27.2yrs	29.1yrs	32.5yrs	40.5yrs
Household payback period - Gas	84.2 yrs	231.4 yrs	-	-	-	-	-

** NPSV and BCR are net of Option 1 which represents 'deadweight'.*

Table 13: Option 5 Sensitivity to Changes in the Energy Price for Hydrogen Heat.

As performed for district heating, a sensitivity analysis is provided for hydrogen heat in Table 13. Hydrogen heating already offers a less costly and/or fastest payback from a domestic perspective based on the price modelled. However, the impact on energy bills for gas heated properties is still unfavourable. **The sensitivity analysis shows a cross-over point for gas heated terraced properties where the hydrogen price is 11% lower than that modelled.** The feasibility of achieving a 11% reduction in the price of hydrogen against that modelled is not clear but it may be assumed as achievable as technology develops over time. This would likely be associated with a fall in the LRVC of hydrogen which would also improve the benefits and overall net social value.

Limitations

The model has been developed as a tool that can be applied to different geographical areas by adjusting inputs for the existing housing stock. This is the first iteration of the model that has been developed for the Castle Vale pilot and as such it is subject to several limitations as outlined here.

CO_2 emissions have not been quantified due to complexity and unknown conditions. As the model is developed, a main intention is to add these since they represent a major strategic objective of decarbonisation and a cost saving from mitigating the future impacts of climate change.

The model does not include any costs associated with the development of network infrastructure to support alternative types of space heating. For instance, large scale installation of heat pumps may require upgrades to the electricity grid, use of hydrogen upgrades to the gas grid, and district heating an entire new network or extension to an existing network. This would likely involve large sums of capital investment which may affect the costs and prices of energy supply.

The maintenance and replacement of heating equipment (e.g. boilers, pipes, etc.) has also not been included since the operational cycle for each option is not known. This would have an effect on costs and payback periods.

Several assumptions and estimations have been made relating to costs, energy prices, energy consumption, housing stock and retrofit measures. A more detailed and thorough review of these is required and missing or incorrect elements added or replaced. In particular, it has been assumed heat pumps are powered by electricity at grid prices which may not be the case with disaggregated and/or community led energy supply systems in the future. In addition, LRVCs for hydrogen are based on early estimates for production by SMR + CCS and have not been peer reviewed. The longer-term preference is for hydrogen produced by electrolysis. The list of energy consumption and retrofit costings could be more comprehensive covering a broader array of dwelling types, sizes and 'configurations'.

There are also limitations in the estimations of socio-economic benefits of the different options. The employment model is based on initial assumptions around worker and skill requirements and cost to employ, and needs to be technically and commercial qualified. In addition, direct and Indirect employment effects use multipliers and leakage variables taken from Arup's 'Peer Review of Proposed Approach for Socio-economic Assessment of EnergyPath Networks' (p.16). The original report is unavailable and the figures need further review for applicability.

The calculation of health and wellbeing benefits is oversimplified. For instance, fuel poverty is unweighted for tenure and dwelling type despite the fact that instances of fuel poverty are higher for certain tenures. The air quality impact on health and associated cost are unquantified for district heating and hydrogen. They have been assumed to be zero for the purposes of the model. However, for district heating air quality impact would depend on the feedstock for the CHP system. For hydrogen, there will be an air quality impact as with gas boilers produce NOx gas. Quantifying this impact will be a focus of future work to develop the model.

A flat rate of 2% inflation has been used for energy prices, capital costs and wages. Official forecasts could be used instead.

- Costs should be modelled fully including and excluding VAT and margins for a complete analysis. This has only been done partially at this stage due to data availability and to maintain a level of simplicity, particularly in relation to VAT.
- Project phasing assumes retrofits are delivered at the same rate for all housing and tenure types which may not necessarily be the case.
- Financing and funding of retrofits involving the private sector has not been fully considered and would require private sector input.

4.4 Summary of the Analysis

The present analysis, though limited in scope (the model and its inputs are subject to the limitations outlined in the section above) provides some important learning. For the 4,000 homes which were part of the programme a thermal retrofit programme would cost approximately £45m, with an estimated benefit cost ratio of 0.6, meaning that the cost outweighs significantly the benefits of the retrofit, but there is a positive impact of 25% reduction in fuel poverty. As such thermal efficiency retrofits offer the least costly and highest value-for-money option of reducing energy consumption in the Castle Vale area. However, thermal efficiency retrofits do not achieve decarbonisation of domestic heat, they just lower the amount of heat used.

The low-carbon heating solutions including the retrofit are estimated to raise the costs for the 4,000 homes to between at least £60-85m. Different options provide different costs and benefits. Heat pumps, district heat and hydrogen all offer job creation potential but differ on cost to deliver and on overall benefits and impacts on domestic energy bills. They also differ in terms of their potential impact on carbon reduction. The number of jobs created locally will be important and the activity is seen to support 1,200 job years over the 5 years of a heat installation programme. At present grid electricity is not zero carbon, district heating is not zero carbon and there is uncertainty around the carbon intensity of hydrogen and the availability of green hydrogen. The three options reveal:

- **Heat pumps appear to be the least favourable option being both costly to install and significantly increasing energy bills for gas heated properties.** A 50% reduction in the cost of installing heat pumps would not change this conclusion and would still offer poor value-for-money. Energy costs for powering heat pumps should be explored further, as should options around behind the meter generation, e.g. solar to offset the costs.
- **District heating could provide the greatest energy savings based on LRVCs that are reduced by electricity generation and sale from a CHP plant.** However, this form of

heating would only be feasible from a domestic and social wellbeing perspective if the lower OPEX for district heat was reflected in lower energy prices which is likely possible but not certain in the UK's unregulated heat network market. This route does not offer a low carbon solution in the short-term since it uses natural gas.

- **Hydrogen offers a relatively low-cost approach to decarbonising heat, however, is held back by energy prices and LRVCs that are higher than for natural gas.** If hydrogen prices fall by around 11% then the conversion of gas heated properties to hydrogen heating becomes more financially feasible. Further work is required to establish appropriate LRVCs and prices for hydrogen energy using different production methods (SMR + CCS / electrolysis).

The introduction of the low-carbon heating on top of the thermal efficiency improvements clearly has no further impact on energy consumption, but has the effect of adding cost and driving down the cost benefit ratio to closer to between 0.1 and 0.4. The additional £15-40m thus is the cost of the overhead of delivering a low carbon solution.

The **move from a low-cost to high cost fuel, natural gas to electricity or green/blue hydrogen means that there is a corresponding increase in household bills potentially resulting in a much greater number of households being plunged into fuel poverty** by 60%. This is a crucial point often missed, and demonstrates that any heat retrofit and low-carbon heating programme needs to be accompanied by a set of support measures which recognise that the cost of fuel bills will go up and not down and that the thermal efficiency measures are not enough to compensate.

The analysis demonstrates that **even with the aggregated benefits associated with the jobs and improvements to health that the is not parity in terms of the costs and benefits**. What is presently missing from the present calculations and analysis is a recognition of the benefits and costs of the avoided carbon emissions.

The Committee on Climate Change estimates[17] that direct emissions from homes were 64 million tonnes (Mt) CO_2 in 2017. This is broadly consistent with the analysis of a UK household's carbon footprint[18] which suggests 2.5 tonnes of CO_2 per year is on average associated with the gas consumption of a home. Carbon prices are expected to rise from £50/tonne to £75/tonne by 2030. Thus for a housing sample such as the 4,300 homes considered that the annual avoided cost associated with a zero carbon solution is £0.8m. For a capital cost of a low carbon heating solution of £15m (the lower end of what was explored here) this suggests that the investment is repaid alone in terms of the avoided carbon costs is a period of less than 20 years.

[17] https://www.theccc.org.uk/wp-content/uploads/2019/02/UK-housing-Fit-for-the-future-CCC-2019.pdf
[18] http://ftp.iza.org/dp7204.pdf

This indicates that the value of the carbon savings need to be an important ingredient to the benefits in the evaluation of the cost benefit ratio and if there were mechanisms for capturing this cost there could be potential benefits which justify the public sector investment.

5. Recommendations and next steps

5.1 Case for Investment: Castle Vale

The current analysis provides a baseline understanding of the scale of the investment that will be required for an estate of the size and nature of Castle Vale. For a low-carbon, energy efficient solution an investment of over £60-85m would be required. This neglects the cost of the upgrades and installation of infrastructure to supply the heat, electricity or hydrogen. The capital cost of these will depend on the location of the energy centre, existing grid infrastructure and injection point into a hydrogen gas network and the cost of the plant to generate the hydrogen.

The analysis highlights some of the potential impacts for communities such as Castle Vale that go beyond the inconvenience and challenge of delivering a retrofit programme. The potential increased energy costs and associated increases in levels of fuel poverty make most of the options involving new heating technologies too risky for anchor institutes such as the Pioneer Housing Group if they are to avoid becoming expensive guinea pigs. A change to how householders pay for energy is needed that promotes lower/zero carbon technologies over a business as usual or retrofit only approach.

There are potentially significant employment and skills benefits for first mover communities as the number of jobs and job years created, even for a small programme, are significant. For the communities that move first, those skills will be in high demand elsewhere regionally and nationally. For Castle Vale there would be the chance to replace some of the local employment opportunities and jobs lost through automation of heavy industry. However, the initial engagement we have had with Castle Vale and the Pioneer Housing Group identified the need to think about the impacts on the end user in more detail. These economic benefits alone will not be enough to de-risk a proposition for Castle Vale for those delivering the works needed to the community.

The conclusions from this work and development of a baseline economic model provide the foundations for a neighbourhood-level model for developing neighbourhood level housing and heating retrofit solutions for East Birmingham. The East Birmingham Community Heat Test and Learn project will develop the baseline model as well as establishing a platform for further engagement with Castle Vale and other communities which will inform the costs-benefit analysis and ensure solutions are of benefit to communities and have the buy-in of key stakeholders.

There are some key elements where further work is needed. Firstly, building a better understanding of the costs and benefits of heating decarbonisation solutions and how to mitigate the potential issue of higher energy costs when replacing exiting heating systems. This can be done either by ensuring the economic, social and environmental benefits increase household income and reduce the relative costs of energy for householders. Or alternatively, by identifying investment models that leverage the potential economic, social and environmental benefits of low and zero carbon heating solutions to subsidise the increased cost to householders. Input is needed, particular from the energy infrastructure sector, to develop more accurate costings for the different technical options and to develop business cases for delivering infrastructure upgrades and household retrofits. We also need to work with partners to explore the options around how different types of project could be financed.

Secondly, **the benefits of avoided carbon emissions need to be monetised and included in the model so that heat decarbonisation solutions are more competitive in comparison with BAU and retrofit only options, where emission reductions are minimal**. Connected to this, we also need to develop methodologies for quantifying the economic benefit of neighbourhood renewal and improved community cohesion, as well as exploring how the benefits of building new energy infrastructure can be put back into the local economy, rather than providing benefit outside of the region.

5.2 Developing the options model for other neighbourhoods

The present model provides a basis for evaluating the costs of different neighbourhoods across East Birmingham. A linked set of heat and retrofit interventions would reduce the cost per community of the infrastructure development and deliver greater value for money. It is therefore necessary to ensure that neighbouring communities have consistent requirements in terms of infrastructure and that the development of infrastructure recognises existing assets located locally.

Castle Vale estate is a relatively simple community to model with comparatively large number of homes managed through the Pioneer Group, there is also a relatively high standard of energy efficiency. Other areas of East Birmingham have more challenging housing types for retrofit and have higher levels of unemployment and deprivation. It is likely that the cost benefit ratios vary significantly from one community to another and that in turn will impact the balance between public and private finance that will be required. There are also areas which will fall into the category of “able to pay”. Here the financing approach is likely to be based around green mortgages where, for example, home buyers commit to the low-carbon heat and retrofit on purchase in exchange for a discounted mortgage rate. The Green Finance Institute have developed a number of financing approaches which can be examined.

Further engagement with the Castle Vale community and housing group, as well as a wider group of asset managers and industry stakeholders, is planned. This will help develop the model and increase the robustness of the calculations of costs and benefits in the following areas:

- Household energy consumption and energy savings pre and post low carbon heating interventions.

- Environmental benefits of different options in terms of reduction of air pollution and CO_2 emissions, warmer and healthier housing, any subsequent impact on health and wellbeing and the economic benefit/cost saving.
- Economic benefits of wider neighbourhood renewal through low carbon heating programme delivery

The deeper engagement around Castle Vale will also support development of a financing module to sit alongside the baseline cost-benefit options model, to identify public/private investment business models and new ways of paying for housing retrofit and low carbon heating solutions and post-retrofit energy consumption. A key next step of the present programme is to analyse and work with other communities across East Birmingham to develop a broader understanding of the range of issues that will be faced as projects are developed.

5.3 Recommendations and Next Steps for East Birmingham Community Heat Taskforce

The following are the key next steps required to build on the present work through the East Birmingham Community Heat Taskforce:

- Establish a working group to develop the associated infrastructure costings and refine the energy and emission calculations.
- Establish a proper basis for evaluating the avoided carbon emissions and the associated savings.
- Develop methodologies for costing wider societal benefits from neighbourhood renewal - including social cost of carbon.
- Convene a working group to develop financing solutions for retrofit and paying for energy consumption.
- Embed the East Birmingham Test and Learn Project (funded by Cadent Foundation) which will
    - Establish a Community Learning Platform
    - Further develop the baseline economic model for Castle Vale and then other East Birmingham neighbourhoods.
    - Develop different modules for the Excel based options model.

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Appendix A: Castle Vale and East Birmingham Full Data Tables.

Castle Vale	LSOA Name	Total	029A	029B	029C	029D	029E	029F
	LSOA Code		E01009096	E01009097	E01009099	E01009101	E01009103	E01009106
Population	All ages	**9,812**	1,627	2,040	1,851	1,584	1,488	1,222
Properties	Number of properties	**4,314**	795	790	825	656	652	596
Electricity Consumption	Total number of domestic electricity meters	**4,096**	728	778	724	633	644	589
	Total domestic electricity consumption (kWh)	**14,095,233**	2,588,491	2,712,958	2,279,924	2,192,359	2,339,527	1,981,974
	Mean domestic electricity consumption (kWh per meter)	**3,441**	3,556	3,487	3,149	3,463	3,633	3,365
	Median domestic electricity consumption (kWh per meter)		2,948	3,141	2,636	2,862	3,075	2,798
	Per Capita	**1,437**	264	276	232	223	238	202

	Per Household	**3,267**		600	629	528	508	542	459
Gas Consumption	Total number of domestic gas meters	**4,074**		696	800	742	653	596	587
	Total domestic gas consumption (kWh)	**41,843,021**		7,216,238	8,636,919	6,745,074	6,910,642	5,872,222	6,461,925
	Mean domestic gas consumption (kWh per meter)	**10,271**		10,368	10,796	9,090	10,583	9,853	11,008
	Median domestic gas consumption (kWh per meter)			9,940	10,129	8,516	9,845	9,721	10,720
	Per Capita	**4,264**		735	880	687	704	598	659
	Per Household	**9,699**		1,673	2,002	1,564	1,602	1,361	1,498
Non-gas Properties	non_gas_properties_%	*18.13%*		28%	19%	21%	15%	13%	8%
	total_off_grid	**782**	*18.13%*	226	153	174	101	82	46
	heating_fuel_electric	**242**	*30.95%*	74	29	34	18	73	14
	heating_fuel_multiple	**180**	*23.02%*	24	33	40	31	32	20
	heating_fuel_none	**44**	*5.63%*	9	7	6	12	4	6

	heating_fuel_oil	**2**	*0.26%*	0	1	1	0	0	0
	heating_fuel_other	**181**	*23.15%*	38	32	34	32	17	28
	heating_fuel_solid	**0**	*0.00%*	0	0	0	0	0	0
FiT Installed Capacity (kW)	All technologies	**733**		65.86 *8.98%*	62.21 *8.49%*	106.47 *14.53%*	397.38 *54.21%*	25.1 *3.42%*	75.92 *10.36%*
Technology Type (kW)	Anaerobic digestion	**0**	*0.00%*	0	0	0	0	0	0
	Hydro	**0**	*0.00%*	0	0	0	0	0	0
	Photovoltaic	**733**	*100.00%*	65.86	62.21	106.47	397.38	25.1	75.92
	Wind	**0**	*0.00%*	0	0	0	0	0	0
	Micro CHP	**0**	*0.00%*	0	0	0	0	0	0
Export Status (kW)	No Export	**165**	*22.48%*	0	0	49.8	115	0	0
	Export (Negotiated Tariff)	**0**	*0.00%*	0	0	0	0	0	0
	Export (Standard Tariff)	**250**	*34.08%*	0	0	0	249.75	0	0
	Export (Deemed)	**318**	*43.44%*	65.86	62.21	56.67	32.63	25.1	75.92
	No Export (Off-Grid)	**0**	*0.00%*	0	0	0	0	0	0
Installation Type (kW)	Domestic	**288**	*39.35%*	65.86	32.23	56.67	32.63	25.1	75.92
	Non Domestic (Commercial)	**365**	*49.77%*	0	0	0	364.75	0	0
	Community	**80**	*10.88%*	0	29.98	49.8	0	0	0
	Non Domestic (Industrial)	**0**	*0.00%*	0	0	0	0	0	0
Population	All ages	**9,812**		1,627	2,040	1,851	1,584	1,488	1,222
Properties	Number of properties	**4,314**		795	790	825	656	652	596
Housing Type	House - Detached	**177**	*4.31%*	34	44	31	38	20	10
	House - Semi-Detached	**1,102**	*26.83%*	112	268	113	216	169	224

	House - Terraced	**1,786**	*43.48%*	362	308	335	277	279	225
	Flat - Purpose-built	**1,005**	*24.46%*	273	172	331	92		137
	Flat - Converted	**24**	*0.58%*	9	4	4	2	4	1
	Flat - Commercial	**11**	*0.27%*	0	3	6	2	0	0
	Shared dwelling	**2**	*0.05%*	1	0	1	0	0	0
	Caravan Temp	**1**	*0.02%*	0	0	0	1	0	0
Housing Build Period	BP_PRE_1900	**1**	*0.02%*	1	0	0	0	0	0
	BP_1900_1918	**0**	*0.00%*	0	0	0	0	0	0
	BP_1919_1929	**21**	*0.49%*	1	0	0	20	0	0
	BP_1930_1939	**1**	*0.02%*	1	0	0	0	0	0
	BP_1945_1954	**0**	*0.00%*	0	0	0	0	0	0
	BP_1955_1964	**330**	*7.68%*	110	70	80	40	20	10
	BP_1965_1972	**2,290**	*53.32%*	540	340	180	270	410	550
	BP_1973_1982	**81**	*1.89%*	1	0	20	50	10	0
	BP_1983_1992	**20**	*0.47%*	20	0	0	0	0	0
	BP_1993_1999	**820**	*19.09%*	20	90	350	170	170	20
	BP_2000_2009	**700**	*16.30%*	80	300	180	90	40	10
	BP_2010_2015	**31**	*0.72%*	1	0	20	10	0	0
Tenure Type	Owned Outright	**722**	*17.00%*	135	117	61	118	87	204
	Owned Mortgage	**846**	*19.92%*	167	109	113	151	94	212
	Owned Shared	**20**	*0.47%*	2	2	4	3	6	3
	Living Rent Free	**62**	*1.46%*	14	12	11	8	8	9
	Rented Private	**208**	*4.90%*	42	30	56	23	27	30
	Rented Council	**207**	*4.87%*	40	48	39	35	30	15
	Other Social Rent	**2,161**	*50.88%*	370	470	523	286	403	109

	Rented Other	**21**	*0.49%*	4	4	4	2	2	5
Energy Performance Ratings	A	**9**	*0.62%*	3	0	3	1	2	0
	B	**130**	*8.92%*	16	13	72	10	8	11
	C	**789**	*54.12%*	119	144	210	130	112	74
	D	**428**	*29.36%*	0	95	70	104	51	108
	E	**87**	*5.97%*	15	14	4	21	5	28
	F	**14**	*0.96%*	2	3	1	2	3	3
	G and below	**1**	*0.07%*	0	0	0	0	1	0
Fuel Poverty	Number of Households	**4,496**		819	844	850	663	696	624
	Number of Households in Fuel Poverty	**452**		78	97	72	75	75	55
	Proportion of Households Fuel Poor	*10.05%*		*9.50%*	*11.50%*	*8.50%*	*11.30%*	*10.80%*	*8.80%*

			Rank	Decile	Rank	Decile	Rank	Decile	Rank	Decile	Rank	Decile	Rank	Decile
Indices of Multiple Deprivation	Index of Multiple Deprivation		1540	1	952	1	414	1	2518	1	877	1	6632	3
	Income		1824	1	1450	1	707	1	3999	2	1078	1	8488	3
	Employment		1529	1	1184	1	604	1	2771	1	1441	1	6704	3
	Education, Skills and Training		2717	1	282	1	329	1	2445	1	298	1	3961	2
	Health Deprivation and Disability		1079	1	1221	1	449	1	1427	1	899	1	4737	2
	Crime		7579	3	12777	4	7534	3	10071	4	9259	3	17867	6

	Barriers to Housing and Services		4325	2	3479	2	4176	2	5665	2	8432	3	8519	3
	Living Environment		15114	5	18882	6	19669	6	9658	3	11335	4	11821	4

East Birmingham			
Population	All ages	247,943	
Properties	Number of properties	86,378	
Electricity Consumption	Total number of domestic electricity meters	85,388.00	
	Total domestic electricity consumption (kWh)	279,496,726.12	
	Mean domestic electricity consumption (kWh per meter)	3,273.26	
	Per Capita	1,127.26	
	Per Household	3,235.74	
Gas Consumption	Total number of domestic gas meters	81,334.00	
	Total domestic gas consumption (kWh)	1,126,326,611.54	
	Mean domestic gas consumption (kWh per meter)	13,848.16	
	Per Capita	4,542.68	
	Per Household	13,039.51	
Non-gas Properties	non_gas_properties_%	*16.04%*	
	total_off_grid	13855	
	heating_fuel_electric	5,276	*38.08%*
	heating_fuel_multiple	4,507	*32.53%*
	heating_fuel_none	3,455	*24.94%*
	heating_fuel_oil	39	*0.28%*
	heating_fuel_other	3,944	*28.47%*
	heating_fuel_solid	28	*0.20%*
Housing Type	House - Detached	5,626	*6.51%*
	House - Semi-Detached	32,331	*37.43%*

	House - Terraced	**30,170**	*34.93%*
	Flat - Purpose-built	**13,690**	*15.85%*
	Flat - Converted	**1,837**	*2.13%*
	Flat - Commercial	**1,075**	*1.24%*
	Shared dwelling	**57**	*0.07%*
	Caravan Temp	**17**	*0.02%*
Housing Build Period	BP_PRE_1900	**9,029**	*8.85%*
	BP_1900_1918	**8,347**	*8.19%*
	BP_1919_1929	**12,131**	*11.90%*
	BP_1930_1939	**17,868**	*17.52%*
	BP_1945_1954	**10,483**	*10.28%*
	BP_1955_1964	**4,750**	*4.66%*
	BP_1965_1972	**8,965**	*8.79%*
	BP_1973_1982	**3,801**	*3.73%*
	BP_1983_1992	**2,434**	*2.39%*
	BP_1993_1999	**3,509**	*3.44%*
	BP_2000_2009	**2,595**	*2.54%*
	BP_2010_2015	**1,205**	*1.18%*
Tenure Type	Owned Outright	**20,249**	*23.44%*
	Owned Mortgage	**23,227**	*26.89%*
	Owned Shared	**726**	*0.84%*
	Living Rent Free	**1,678**	*1.94%*
	Rented Private	**11,032**	*12.77%*
	Rented Council	**16,541**	*19.15%*
	Other Social Rent	**7,993**	*9.25%*
	Rented Other	**939**	*1.09%*
Energy Performance Ratings*	A	**91**	*0.21%*
	B	**1703**	*3.89%*
	C	**8801**	*20.10%*
	D	**19577**	*44.72%*
	E	**10945**	*25.00%*
	F	**1945**	*4.44%*
	G and below	**717**	*1.64%*
Fuel Poverty	Number of Households	**87,239**	
	Number of Households in Fuel Poverty	**15,073**	
	Proportion of Households Fuel Poor	*17%*	

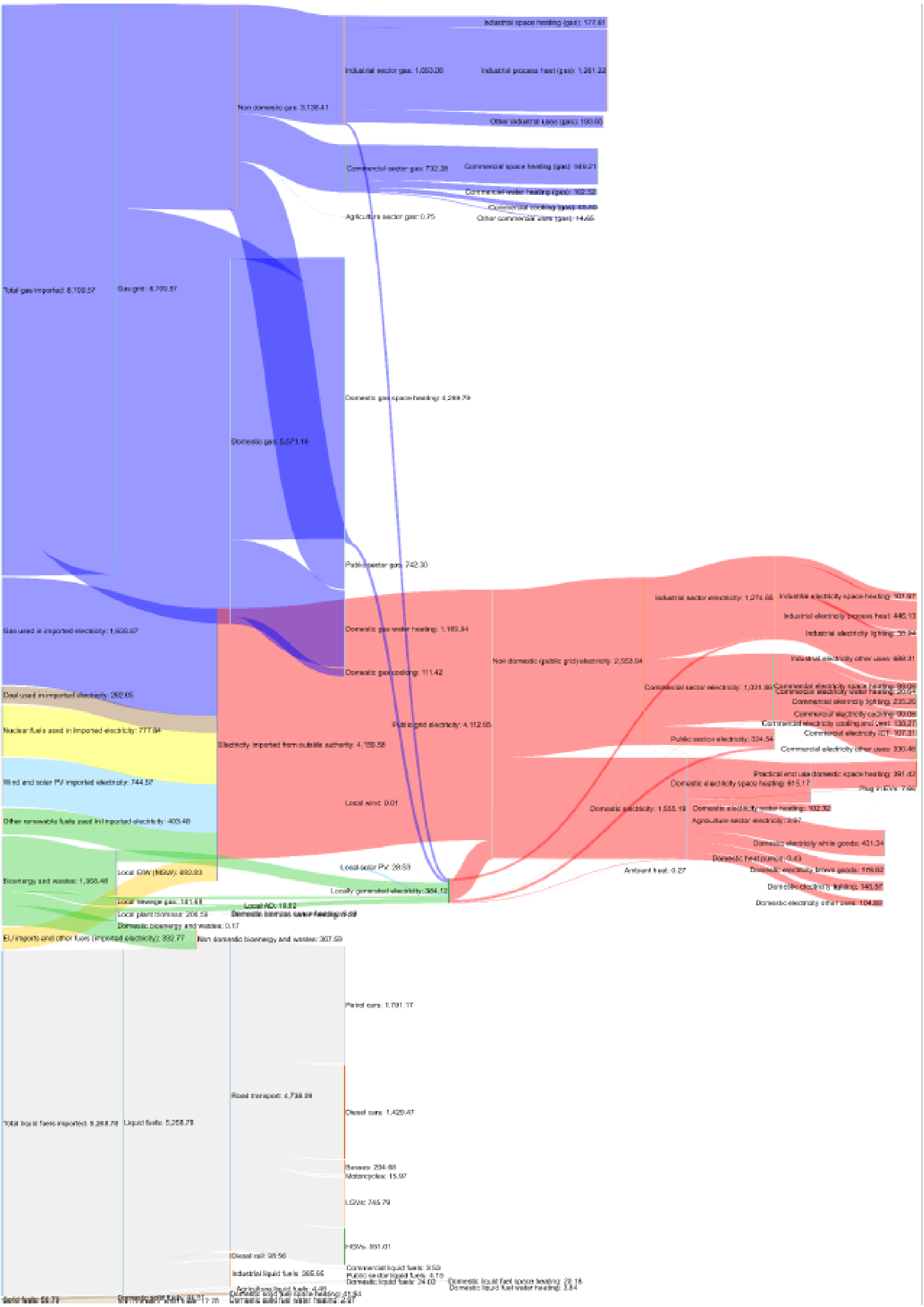
Appendix B: Options Model Data Sources & Use

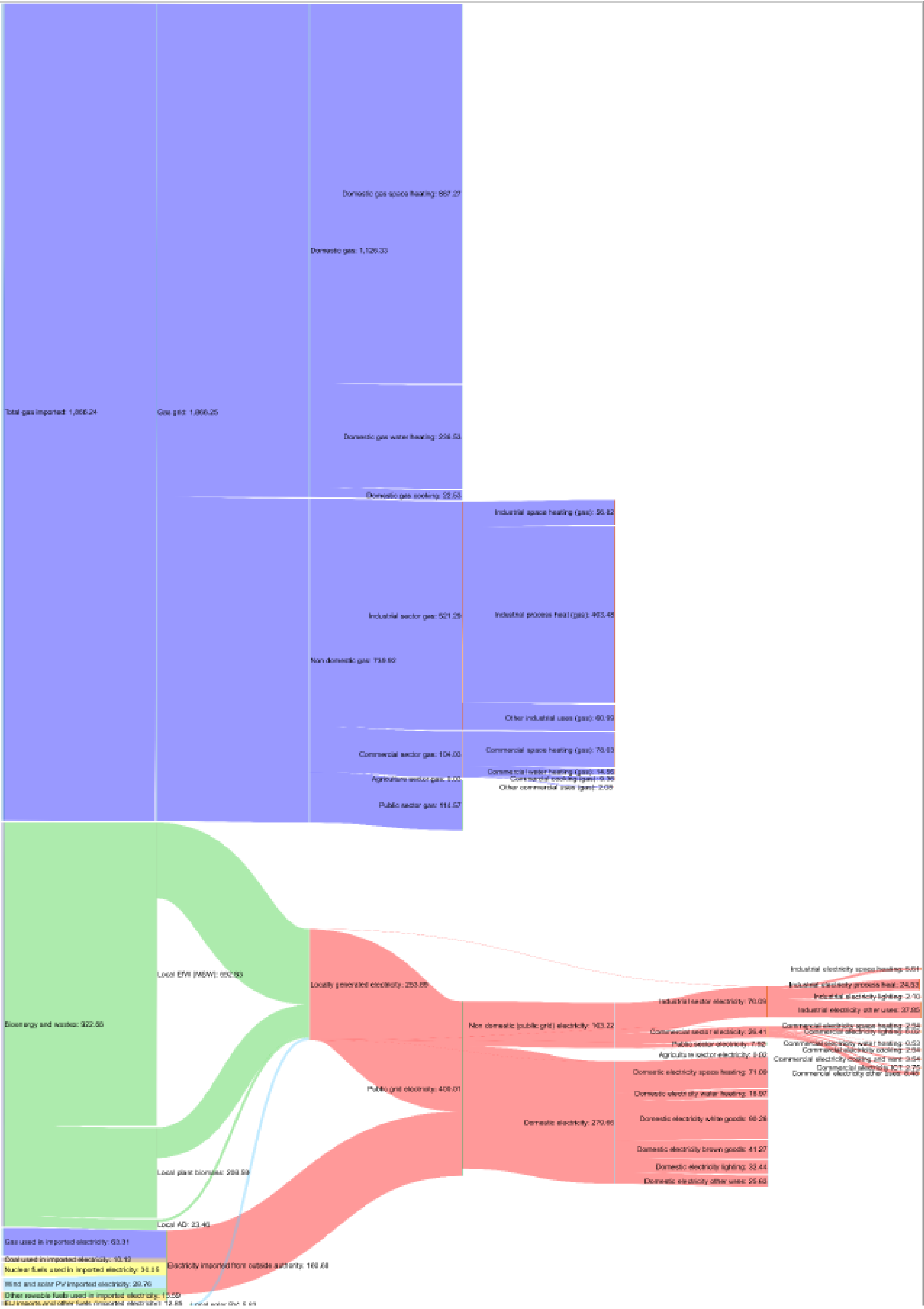
Data Source	Application
Arup (2016) Peer Review of Proposed Approach for Socio-economic Assessment of EnergyPath Networks [link]	Leakage and multipliers for employment model.
Bauchinger, S. & Beskid, D., Heat Decarbonisation Summer Placement Report	Used to establish maximal thermal efficiency retrofit measures: double glazing, external wall insulation and underfloor insulation (except flats & bungalows).
BEIS (2017) What Does it Cost to Retrofit Homes? Updating the cost assumptions for BEIS' energy efficiency modelling [link]	Used for deriving cost of maximal thermal efficiency retrofits. Costs based on mid-range values. Assumed that provided costs include a 15% margin which was subtracted for cost-benefit analysis.
BEIS (2018) Appraisal of Domestic Hydrogen Appliances [link]	Cost of hydrogen boiler supply & installation based on mid-range estimates for combi-boiler. Adjusted to excluded VAT at an assumed rate of 20%. Assumed that provided costs include a 15% margin which was subtracted.
BEIS (2020) Annual Fuel Poverty Statistics in England (2018 statistics) [link]	West Midlands (NUTS2) regional average fuel poverty gap (£) measured using LIHC indicator.
BEIS (2020) Cost of domestic heating measures: data underpinning report [link]	Cost for connecting a non-gas property to the grid for hydrogen supply.
BEIS (2020) National Energy Efficiency Data-Framework (NEED): Headline consumption tables England and Wales 2018 [link]	Used to estimate domestic gas consumption. Heating type is not specified but assumed to be gas in line with national norms. It is assumed 77% of domestic gas is used for space heating.
BEIS (2020) National Energy Efficiency Data-Framework (NEED): Multiple attributes table 2018 [link]	Electricity consumption based on ECO7 meters. Assumed to be wholly for space heating.
BEIS (2020) Sub-regional fuel poverty 2018 data [link]	Fuel poverty of Castle Vale LSOAs based on LIHC indicator.
BEIS (2020) Valuation of energy use and greenhouse gas emissions for appraisal: Data tables 9 & 10 [link]	Used Long-Run Variable Costs (LRVC) of domestic electricity and gas supply based on central scenario from supporting tables 9 & 10.

BEIS (2020) Valuation of Energy Use and Greenhouse Gas: Data Table 15 [link]	Air quality damage costs for electricity (0.5p/kWh) and gas (0.34p/kWh).
BEIS (2021) Part 2: A guide to CHP Technologies [link]	District heat generation efficiency assumed to be 43.3% based on larger CHP plant (gas engine).
British Gas, SEDBUK ratings for gas boiler efficiency [link]	Gas boiler efficiency assumed to be 70% on average (low band F).
Calderon et al., An area-based modelling approach for planning heating electrification [link]	Used to calculate energy consumption of air source heat pumps.
Castle Vale Data 25032021	Castle Vale housing stock by dwelling type, tenure, and existing heating type.
CMA (2018) Heat networks market study - final report [link]	Heat Network LRVC calculated by comparing the estimated OPEX of a CHP (natural gas) heat network to the OPEX for natural gas supply for gas boiler heating.
DECC (2012) Household electricity survey [link]	77% of domestic gas is used for space heating.
DECC (2015) Assessment of the Costs, Performance, and Characteristics of UK Heat Networks [link]	Used to establish district heating installation costs at the domestic/household level. Provided costs have been assumed to exclude VAT but has not been confirmed by BEIS. Assumed that provided costs include a 15% margin which was subtracted for cost-benefit analysis. District heat energy pricing based on non-bulk mean average at 2014 prices, inflated to 2021 prices using domestic gas LRVCs (central scenario).
Nicol, Roys & Garrett (2015) The cost of poor housing to the NHS (BRE Briefing Paper) [link]	Average cost of £640/dwelling (assumed to be 2011 figure and adjusted for inflation by 2% per annum until 2021).
Kiwa (draft 2020) Hydrogen hubs for heat and motive power feasibility study TEP – technologies, modelling and costing report (DRAFT)	Hydrogen LRVC calculated from variable cost of 6.3p/kWh (2019) for producing hydrogen using SMR + CCS method. Inflated to 2021 prices using domestic gas LRVCs since gas is the feedstock for SMR production. Hydrogen energy pricing based on using SMR+CCS hydrogen heat network cost of 7.2p / kWh at 2019 prices, inflated to 2021 prices using domestic gas LRVCs.

HMT (2020) Green Book [link]	Appraisal methodology. 3.5% social discount factor. Willingness to Pay (WTP) value of one QALY of £60k.
Non-gas map - LSOAs in Birmingham City Council [link]	Data for 'flats' is based on purpose-built flats. Majority of flats in Castle Vale are purpose-built according to non-gas map.
OECD (2021) GDP long-term forecast [link]	Long-term GDP forecast for UK 2016-2060 (as at 26.05.21), used to inflate future health related benefits as per Green Book methodology.
ONS (2020) Construction output price indices, UK statistical bulletins [link]	Indices for all construction used to inflate costs to 2021 prices where necessary.
The Carbon Trust (2020) Heat Pump Retrofit in London [link]	Cost of air source heat pumps, adjusted to exclude VAT of 20% on equipment and 5% on installation. Assumed that provided costs include a 15% margin which was subtracted.
UCL (2020) Analysis work to refine fabric energy efficiency assumptions for use in developing the Sixth Carbon Budget [link]	Used for thermal efficiency retrofit energy savings.
UKPower, compare energy prices per kWh [link]	Energy prices (standing charge and variable rate) for gas and electricity. These have been taken for the West Midlands where possible. It is assumed these rates are up to date for 2021. Electricity: £0.2054/day + £0.1425/kWh. Gas: £0.24/day + £0.038/kWh.

Appendix C: Sankey diagrams for Birmingham and East Birmingham




Total gas imported: 1,866.24
Gas grid: 1,866.25
Domestic gas: 1,128.33
Domestic gas space heating: 867.27
Domestic gas water heating: 238.53
Domestic gas cooking: 22.53
Non domestic gas: 738.93
Industrial sector gas: 521.28
Industrial space heating (gas): 56.82
Industrial process heat (gas): 403.48
Other industrial uses (gas): 60.99
Commercial sector gas: 104.00
Commercial space heating (gas): 76.83
Commercial water heating (gas): 14.56
Agriculture sector gas: 0.00
Public sector gas: 114.57
Bioenergy and wastes: 922.88
Local EfW (MSW): 652.83
Local plant biomass: 268.59
Local AD: 23.40
Locally generated electricity: 253.85
Public grid electricity: 408.01
Non domestic (public grid) electricity: 103.22
Industrial sector electricity: 70.09
Commercial sector electricity: 26.41
Public sector electricity: 7.52
Agriculture sector electricity: 0.00
Domestic electricity: 279.66
Domestic electricity space heating: 71.09
Domestic electricity water heating: 18.57
Domestic electricity white goods: 66.28
Domestic electricity brown goods: 41.27
Domestic electricity lighting: 32.44
Domestic electricity other uses: 25.65
Industrial electricity space heating: 5.61
Industrial electricity process heat: 24.53
Industrial electricity lighting: 2.10
Industrial electricity other uses: 37.85
Commercial electricity space heating: 2.54
Commercial electricity water heating: 0.52
Commercial electricity cooking: 2.54
Commercial electricity ICT: 2.75
Gas used in imported electricity: 63.31
Coal used in imported electricity: 10.12
Nuclear fuels used in imported electricity: 36.15
Wind and solar PV imported electricity: 20.76
Other reewable fuels used in imported electricity: 15.59
Electricity imported from outside authority: 169.68
Local solar PV: 5.63