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Ross-On-Wye High Level Heat Network Potential Study

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EXECUTIVE SUMMARY

This report details the findings of the Ross-on-Wye High Level Study assessing the potential heat supply solutions for the Land to the East of Ross-on-Wye development, identified in the upcoming Local Plan. The study was supported and funded by Herefordshire Council (the council).

Land to the East of Ross-on-Wye sets out plans for approximately 1,000 new homes, 33 hectares of employment space, a new primary school, and associated infrastructure including a new outer distribution road, small scale retail, and a community facility. As part of the assessment, key information and documentation was provided by the team at the council including the Draft Local Plan and supporting documentation.

Heat Demand Assessment

Using information provided in the Draft Local Plan, Future Homes Standard Consultation, local planning applications, and similar developments, a heat demand assessment for the site was completed. A summary of the site wide heat demands is shown in the table below. The assessment was based on the high level information currently available for the site and heat demands should be reassessed when development plans are progressed.

Building type	Total area, m^2	Heat demand, MWh	Peak demand MW
Residential	95,930	6,121	2.54
Industrial	62,843	1,670	2.51
Commercial	3,775	359	0.15
Total	**162,548**	**8,150**	**5.2**

Heat Supply Assessment

As a result of a long list appraisal, four potentially viable low carbon solutions were shortlisted for further consideration.

- Centralised anaerobic digestion (AD) district heat network (DHN)
- Centralised air source heat pump (ASHP) DHN
- Closed loop ground water source heat pump (WSHP) Ambient Network for the residential sites and individual ASHPs for the employment sites
- Individual ASHPs for all buildings

For the DHN options, an energy centre location was assumed to be to the north of the site, near the M50 and A449. St Mary's Garden Village (an area located next to the Land East of A40 Development) was used to generate heat benchmarks for the residential properties while the Model Farm development was used to generate benchmarks for the commercial buildings.

Options Assessment

Each of the four shortlisted options were assessed against economics, CO_2e, benefits and opportunities, and risks and issues. A high level estimate of the layout of the development site was based on the neighbouring St Mary's Garden Village and other similar development sites.

Economic and CO_2e Assessment

A summary of the economic assessment results for the shortlisted options is shown below; the savings identified for the AD DHN, ASHP DHN and Ambient Network are calculated against the individual ASHPs solution which is also the counterfactual solution for this assessment i.e. the low carbon heating solution that would be installed if a heat network is not viable. Based on current assumptions, the AD DHN is the only economically viable option that provides a return on investment (although it excludes the cost of investment for the AD plant itself). However, this could change if different assumptions were used. For example, the layout of the development could be designed to reduce the length of the network pipework, this would reduce capital costs for the DHN and Ambient Network options and reduce losses for the DHN schemes. The CO_2e emissions of the ASHP DHN option are significantly higher than the other solutions due to the high network losses and the heat generated from peak and reserve gas boilers.

	AD DHN	ASHP DHN	Ambient Network	Individual ASHPs
Capital costs	£8,147,069	£14,060,566	£11,052,885	£9,898,000
Net present cost (40 years)	£14,397,681	£29,277,840	£26,691,911	£37,898,644
IRR (40 years)	26.98%	-6.77%	-1.36%	N/A
CO_2e intensity (year 1), gCO_2e/kWh	17.78	63.24	35.76	41.05
Total CO_2e emissions (40 years), tCO_2e	886	10,111	1,755	2,017

Benefits and Risks

The table below summarises the key benefits and risks of each of the shortlisted options.

	Benefits	Risks
AD DHN	• Highest economic returns • Utilises waste heat streams that are currently causing pollution of the River Wye or other waste streams such as agricultural wastes • Energy supply company will operate and maintain the scheme, ensuring optimal operation and higher efficiencies are achieved • Lowest CO_2e option • Lower electrical grid capacity required	• Security of supply, reliability of waste streams, requirements for deliveries • Reliant on AD plant being developed on site • Private investment from AD developer and heat network developer required • Heat generation profile could be inconsistent with the demand profile from connections • Visual impacts and odour of AD plant • Commercial negotiations required with AD operator • Coordination required between heat network developer and site developer
ASHP DHN	• Not dependent on accessing ground water or negotiating supply agreement with AD plant operator • Energy supply company will operate and maintain the scheme, ensuring optimal operation and higher efficiencies are achieved • Lower electrical grid capacity required compared with ambient network and individual ASHP options	• Project is not economically viable • High network heat losses • Highest CO_2e option • Visual and noise impacts of energy centre • Coordination required between heat network developer and site developer
Ambient Network	• Network can expand in line with the development – additional boreholes can be drilled as new homes are brought forward • Very low heat losses through distribution of low grade heat • Constant temperature of ground results in consistent and higher heat pump efficiency than individual ASHPs • No requirement for a large energy centre	• Higher electricity grid capacity required for individual heat pumps • Heat energy available from the ground is dependent on ground temperatures and replacement of energy • Project is not economically viable under current assumptions due to high network lengths • Heat pumps will require space in dwellings

	Benefits	Risks
Individual ASHPs	• Not dependent on timing of development – delays to build out will not impact the viability • Simple solution • No heat losses • Not dependent on accessing ground water or negotiating heat supply agreement • No requirement for a large energy centre	• Highest electricity grid capacity required • Low efficiency heat pumps during cold periods • May result in highest cost to developers and residents • Noise and visual impacts of the ASHPs • ASHPs will require internal and external space at dwellings

Summary

Each of the network options have been assessed based on high level information for a mixed use development near Ross on Wye. High level assumptions have been made for this analysis including the layout of the site, which has been estimated based on discussion with the council's planning team and plans for the adjacent residential development St Marys Garden Village, and other similar developments across the country.

Based on the assumptions in this study, all options with the exception of the ASHP DHN offer the potential for cost effective, efficient, and low carbon heat supply for the development site (depending on the assumptions used as the basis for the assessment). The AD DHN results in the most economic scheme but comes with significant risk. Should a developer of an AD plant come forward, this is likely to be the preferred solution for the site. However, a separate study should be commissioned to assess the potential case for an AD on the site, including assessment of the capital costs of a scheme. Planning policy should state that any AD plant proposed in the area is required to be combined heat and power (CHP) ready, to supply heat to nearby sites. The counterfactual of individual ASHPs provides the simplest solution for the site but will result in higher costs to residents and developers as well as noise and visual impacts for residents. The Ambient Network does not provide economic returns under the assumptions made in this study, however, a reduction in network pipe length, connection charges from developers, and standing charge from residents could result in an economic network.

For both the Ambient Network and individual ASHP options, a reduction in heat demand from dwellings will reduce the cost of heat to residents and will not impact the economic viability of the scheme. If possible in future, more stringent requirements than the proposed Future Homes Standard Building Regulations could be proposed through planning policy. Although this will negatively impact the economic viability of the DHN options, it is recommended for the development site as it will result in lower CO_2e emissions, cost of heat to residents, and electricity grid requirements.

Key Recommendations for Planning Policy

Key recommendations for planning policy include:

- Developers should show due consideration to the layout of the development site, ensuring it does not impede the development of a heat network
- Development of any AD plant should be CHP ready and required to connect to a DHN if in proximity to an existing or planned network

Next Steps

The proposed next steps for this project include:

- Undertake a further study to assess the technical and economic feasibility of an AD plant at the Land East of Ross-on-Wye – 3-6 month study within the next 12 months
- Ensure planning policy requires the development of any AD plant to be CHP ready

- Ensure developers consider connection to heat network in their development plans, ensuring connection points are located at the front of properties to minimise network pipe length – initial requirements to be set out within the Local Plan and continued engagement with developers once identified
- Support the coordination of multi-utility approach across the site – initial requirements to be set out within the Local Plan and continued engagement with developers once identified
- Undertake a detailed techno-economic feasibility to assess the potential for a heat network when development plans are progressed and further detail is available – 3-6 month study to be procured following identification of developer and a masterplan for the site has been developed
- Initial soft market testing with heat network developers to identify preferred scheme and minimum development scale – initial discussions could be held immediately to inform the next steps for the site, engagement should continue periodically to ensure any plans for the site are attractive to the market

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ABBREVIATIONS

ASHP	Air source heat pump
AD	Anaerobic digestion
CHP	Combined heat and power
CO_2e	Carbon dioxide equivalent
DESNZ	Department for Energy Security and Net Zero
DHN	District heat network
DHW	Domestic hot water
GIS	Geographic Information System
LTHW	Low temperature hot water
SEL	Sustainable Energy Limited
WSHP	Water source heat pump

1 INTRODUCTION

This report presents the findings of the Ross-on-Wye High Level Study (2024). The project is funded and informed by Herefordshire Council (the council). The purpose of the project is to identify and evaluate opportunities to develop an energy network in the Ross-on-Wye area, adding to the evidence base which will inform the council's update to their Local Plan.

1.1 Project Scope

SEL were commissioned to undertake a high level study for the council. The scope of the study comprised:

- Heat demand assessment including energy modelling using benchmarks, in line with the nature and scale of the proposed developments
- Heat supply assessment including but not limited to energy from waste (EfW) plants, industrial waste heat, geothermal, and water source heat opportunities
- Provide a high level examination of energy distribution systems and infrastructure, identifying opportunities and major constraints and barriers
- Undertake a high level options appraisal including high level assessment of costs and revenue streams
- Provide recommendations based on the high level feasibility of low carbon heating solutions including technical, environmental, economic, and other planning considerations (such as layout and density)

1.2 Project Background

In 2015, the council adopted their Local Plan Core Strategy (2011-2031), which sets out a strategic planning framework for the county's future development needs. A 2019 review concluded that due to changes in local and national policy, an update to the local plan was required. The Draft Local Plan includes approximately 16,100 homes and 182 hectares of employment land, and details the infrastructure requirements to support the new development. The distribution of this development is focused on Hereford and the county's five market towns, including Ross-on-Wye which has identified an area for development into primarily residential and commercial use. With the declaration of a Climate and Ecological Emergency, the Council has a target of the county becoming carbon neutral by 2031.

Several previous studies have been carried out to assess heat loads and heat sources in the county. In 2016, a heat mapping and masterplanning exercise was carried out to assess the domestic and non-domestic heat loads in Herefordshire. In 2010, a renewable energy study identified large biomass sources and the potential for use as fuels with appropriate technologies. The availability of waste biomass sources in the area was assessed in greater detail as part of the 2023 Minerals & Waste Local Plan study which also showed significant amounts of biomass which could potentially be integrated into an energy strategy.

1.2.1 Land to the East of Ross-on-Wye

Several developments are taking place in the Ross-on-Wye area, the developments that are either under construction or have been granted planning permission include: "Model Farm", "Land East of A40" and "Land at Hildersley Farm". The largest development in the area is the "Land to the East of Ross-on-Wye", details of these developments are discussed further in section 2.1.

The Ross-on-Wye local plan urban extension supports approximately 1,000 new homes and 33 hectares of employment space. Following discussion with the council, it has been assumed that the employment sites will be primarily light industrial and storage and distribution. This study assesses the potential for the development of a heat network as part of the energy strategy for the site. The findings of the study will inform the evidence base for the local plan update and if feasible may form part of the Council's adopted planning policy framework and other strategies.

At the time of this study, the size and layout of the site were unknown so findings are presented as indicative results for a potential development layout. While these findings are sufficient to inform the Local Plan update, further assessment will be required to assess the viability of a heat network once the development layout is confirmed.

1.3 Local Context

The Land to the East of Ross-on-Wye development is located within the setting of a National Landscape area and therefore the development and any heating solution identified for the site will need to ensure that there is no adverse impact to the wider area. The development will also require the construction of a new road to connect the Traveller's Rest roundabout to the north, to the A40 at the south of the site to alleviate congestion.

A large concern for Herefordshire is the significant animal waste streams from farms within the county. Runoff from these sites has resulted in heavy pollution of the River Wye.

1.4 Project Drivers

With the declaration of a Climate and Ecological Emergency, the council has a target for the county to become carbon neutral by 2031. Some of the Council's other key drivers for investigating heat networks include:

- Reducing carbon emissions
- Sustainable economic growth and investment opportunities
- Improving energy security through local generation

2 DATA COLLECTION

A data collection exercise was undertaken to enable detailed energy mapping of existing and future energy demands as well as potential energy sources, barriers, and constraints. As part of this process, the energy demand assessment area was reviewed, as discussed in section 3.

2.1 Planned Developments

All known planned developments within and surrounding the energy demand assessment area were identified and assessed. Details of identified planned developments are shown in Figure 1 and Table 1.

Figure 1: Planned developments

Table 1: Current information for planned developments

Development area	Details of development	Status
Land to the East of Ross-on-Wye	• 1,000 dwellings at 35 dwellings per hectare • 33 hectares of employment land • No current development plans	Proposed Local Plan site allocation
St Mary's Garden Village	• 365 dwellings developed across 4 phases • Phase 4A currently under development • Future homes and building standards	Under construction
Model Farm	• 8 hectares of land • Building area 15,200 m^2 of building area • Future buildings standards	Approved
Land at Hildersley Farm	• 200 homes • 36 dwellings per hectare	Under construction – nearing completion

Development area	Details of development	Status
	• Future homes standards	

2.2 Document Review

Key information and documentation were provided by the project team at Herefordshire Council and reviewed to inform the study. Documents reviewed include:

- Waste Need Assessment (2021) Annex (June 2022)
- Provision of Employment Land Requirements (2022)
- Draft Local Plan Strategic Policies (2024)
- Minerals and Waste Plan(2024)
- Green and Blue Infrastructure Strategy (2023)
- Renewable Energy Survey Report (2023)
- Ross on Wye Investment Plan (2021)
- Local Heritage Impact Assessment (2023)
- Housing Market Area Needs Assessment (2021)
- Provision of Employment Land Requirements (2022)
- Planning portal

2.3 Similar Developments

Other developments of a similar scale were reviewed to identify common estimates and assumptions that could be made when assessing the Land to the East of Ross-on-Wye. All sites identified are new garden village schemes. St Mary's Garden Village was also included in this analysis as the site is likely to be indicative of the form and density that will be approved by planning officers for the Land to the East of Ross-on-Wye. Details for these sites are shown in Table 2 and in Appendix 1: Similar Planned Development Sites.

Table 2: Details of similar scale and nearby developments

	Welborne	Handforth	Seaham	Halsnead	West Carclaze	St Mary's	Land to the East of Ross-on-Wye
No. dwellings	6,000	1,500	1,500	1,600	1,500	365	1,000
Dwellings per hectare	27	35	35	37	45	17[1]	35
Network length per dwelling, m/dwelling	15.3	17.5	11.9	-	-	-	Unknown
Industrial space, m^2	75,000	11,250	-	225,000	-	-	333,000
No. primary schools	3	1	1	1	1	-	1
Dedicated green space	18%	42%	45%	37%	37%	40%	Unknown
Percentage industrial	2%	1%	-	13%	-	-	21%

Based on this assessment, it has been determined that the assumptions for the residential sites can be based on the average of the similar developments identified. However, the assumptions for the industrial sites are not applicable

[1] Dwellings per hectare for St Mary's Garden Village calculated based on the area of the development boundary and the total number of dwellings

as the scale and form vary significantly across the developments. Assumptions for the employment sites within the Land to the East of Ross-on-Wye will be based on the nearby Model Farm site, due to its proximity to the development.

3 HEAT DEMAND ASSESSMENT

Following the data collection exercise, heat demands were assessed for the buildings within the Land to the East of Ross-on-Wye. The methodology for estimating energy demands and hourly energy profiles is discussed below.

Due to the lack of existing buildings in the study area or the surrounding planned developments, no half hourly data was available for the development of energy profiles. In line with best practice (Objective 2.2 of the Code of Practice), hourly annual energy demand profiles were generated using in-house modelling software which apportions demands to hourly loads over the year, considering degree day data, building use and occupancy. All significant energy loads were then identified and categorised.

The Future Homes Standard Consultation document was also considered when developing heat demands for the residential developments as all of the planned developments will be constructed after 2025. It is expected that energy demands will decrease in the future as building fabric improves and policy requires higher standards from new builds.

Hourly profiles for heating and domestic hot water demand were modelled and normalised against degree day data from the nearest weather monitoring station (Hereford). Profiles were developed using in-house software and considered building plans, site measurements, building construction and operating parameters. Peak, base load, seasonal and annual heat demands were identified.

St Mary's Garden Village (an area located within the Land East of A40 Development) was used to generate heat benchmarks for the residential properties while the Model Farm development was used to generate benchmarks for the commercial buildings. The heat demand model considers building fabric U-values, and heat gains from solar, electrical appliances, and occupancy.

For each building type, the hourly heat demand model was used to identify the average, maximum and minimum hourly demand throughout the year.

3.1 Residential Demands

Heat benchmarks were generated by heat demand models of housing in St Mary's Garden Village. A summary of the U-values used is shown in Appendix 2: Key Parameters and Assumptions. A summary of the residential demands is shown in Table 3.

Table 3: Heat demand in residential dwellings

Residential type	Number of dwellings	Total area, m^2	Heat benchmark, kWh/m^2	Heat demand, MWh
Flats	40	2,020	79.9	161
Semi-detached	350	24,530	63.0	1,545
Detached	610	69,380	63.6	4,415
Total	**1,000**	**95,930**	**-**	**6,121**

The average maximum and minimum profiles are shown in Figure 2 and Figure 3 for semi-detached and detached dwellings.

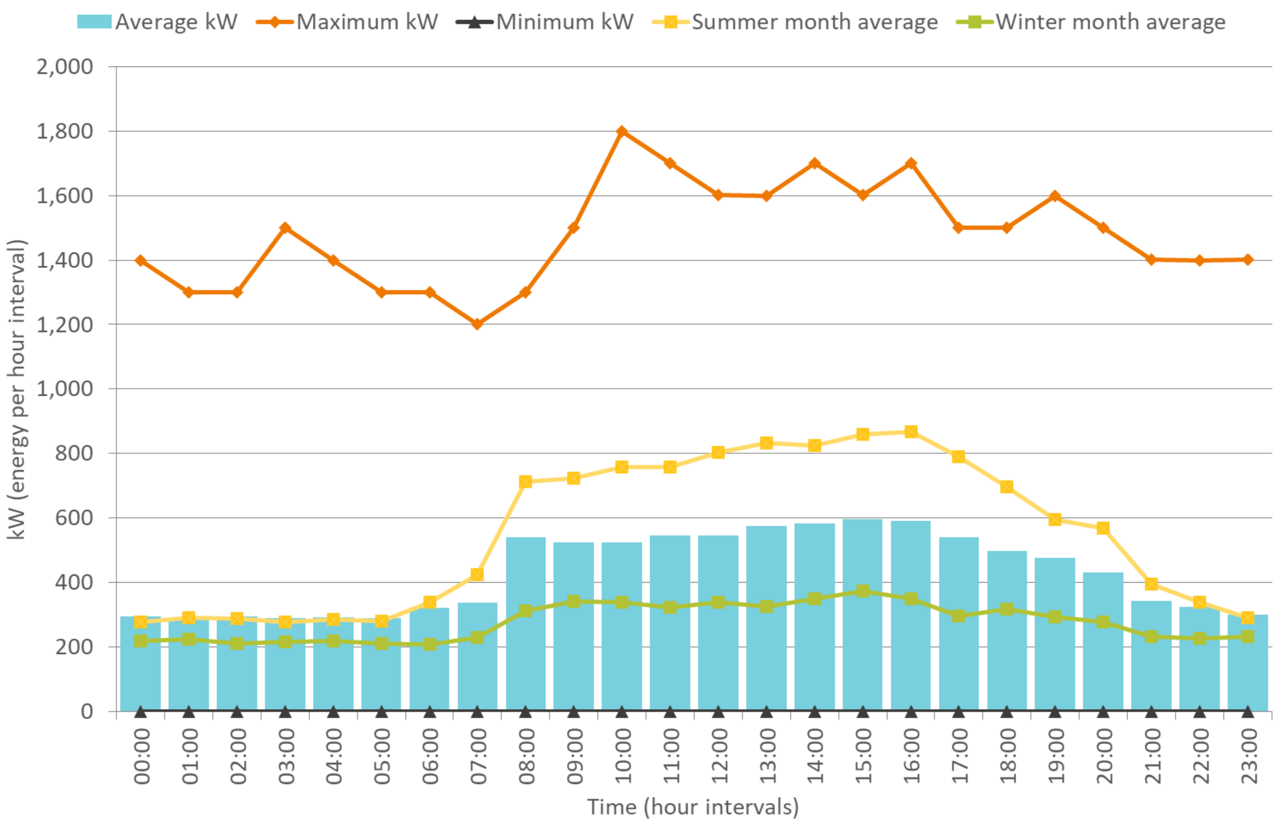

Figure 2: Average, minimum and maximum heat demand profiles for a semi-detached house

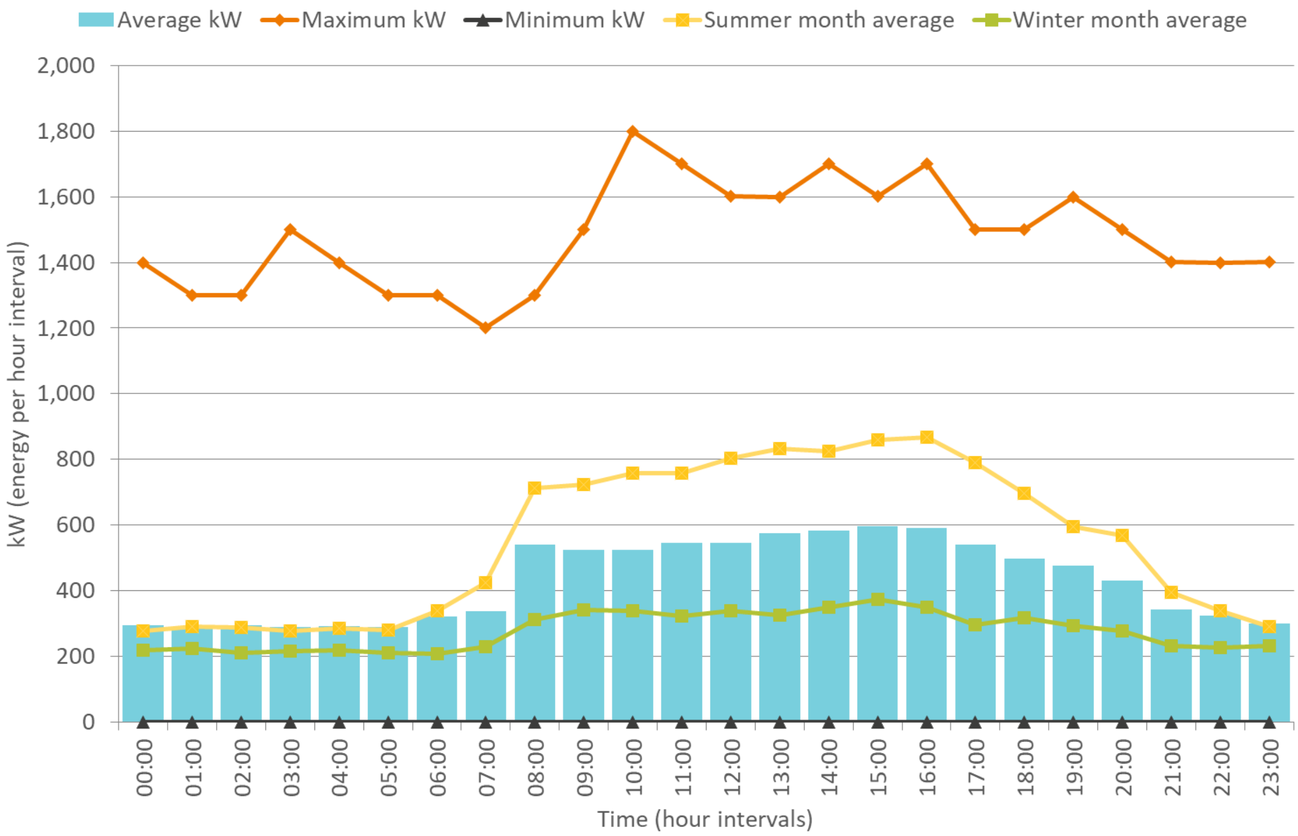

Figure 3: Average, minimum and maximum heat demand profiles for a detached house

3.2 Non-Residential Demands

A summary of the non-residential demands is shown in Table 4. Heat benchmarks for the employment sites were generated based on the development of heat demand models for buildings in the Model Farm development. Heat demands for industrial use are very site and use specific and therefore, they should be reassessed as more information becomes available for the site. For other commercial buildings, benchmarks based on similar sized developments were used to estimate the floor area of each building use and their respective heat demands.

A summary of the U-values is shown in Appendix 2: Key Parameters and Assumptions.

Table 4: Heat demand of non-residential buildings

Building type	Total area, m^2	Heat benchmark, kWh/m^2	Heat demand, MWh
Offices	12,569	46.5	584
Light industrial	25,137	21.6	543
Warehouses	25,137	21.6	543
Primary school	2,725	105	286
Shops	400	69.6	28
Restaurant / café	350	69.6	24
Pub	300	69.6	21
Total	**66,620**	**-**	**2,030**

3.3 Summary

The majority of the heat demand for the network comes from the residential dwellings. The residential heat demands have been based on the Future Homes Standard Consultation as the development will come forward after 2025. The industrial demands have been based on high level figures from similar developments and building regulations. The assumptions and heat demands should be reassessed and updated as more information becomes available for the development.

Table 5: Heat demands summary

Building type	Total area, m^2	Heat demand, MWh	Peak demand MW
Residential	95,930	6,121	2.54
Industrial	62,843	1,670	2.51
Commercial	3,775	359	0.15
Total	**162,548**	**8,150**	**5.2**

4 HEAT SUPPLY ASSESSMENT

Potential low carbon or renewable energy sources that are within or near the assessment area were assessed to identify any that may have the potential to supply a heat network. No existing heat generation technologies were identified within, or near the Ross-on-Wye area which were significant enough to supply a potential network.

4.1 Long List of Technologies

Potential heat sources are shown in Figure 4.

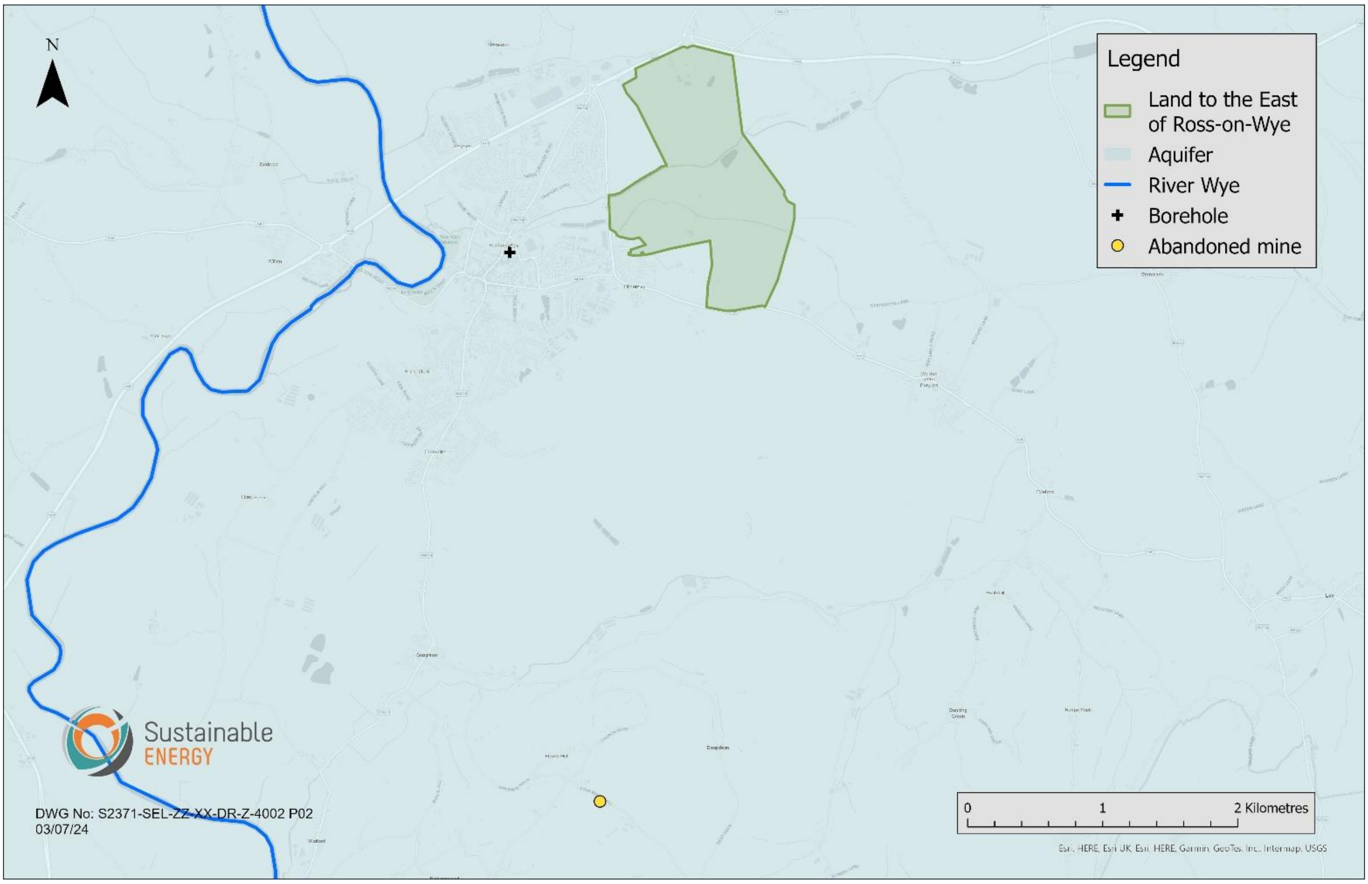

Figure 4: Potential heat sources

A long list appraisal of all potential low carbon heat sources to supply the Land to the East of Ross-on-Wye was undertaken and is shown in Table 6.

Table 6: Long list options for potential heat sources

Technology		High level technical viability considerations	Considered further?
Anaerobic digestion (AD)		• Good economics against low carbon counterfactual • 22 t of input material a day needed • Potentially a large footprint required • Very low capital costs for heat generation • Security of supply vulnerabilities around a fault in the AD plant or disruptions in waste supply lines • Third party negotiations required to secure low cost of heat	Yes, shortlisted option
Open loop heat pump	Boreholes utilising aquifer	• Record for existing borehole near the site does not state pumping rates or water resting levels, which may indicate limited amounts of water • Test well required to determine capacity • Higher capital costs due to boreholes than ASHPs	No
	Deep geothermal	• Significant space requirements • Potentially economic against low carbon counterfactual • Higher temperatures of source available • High capital costs associated with deep drilling	No
	Open water	• River Wye is a significant distance from the assessment area • Environmental risks and regulations required to utilise the river as a heat source • Abstraction plant/structure and water filtration and treatment equipment increases capital costs	No
	Mine water source heat pump	• No mine resource close to the Land to the East of Ross-on-Wye area • Potentially lower operating cost due to higher CoP compared to ASHP • Third party negotiations that may impact the cost of heat required	No
Closed loop bore field		• Suitable for an ambient loop solution • Requires a large area of land • Lower risk than open loop boreholes • Significant capital costs associated with borefield • May have a cooling effect on local ground condition if not designed correctly	Yes, shortlisted option
Centralised air source heat pump (ASHP)		• Lower initial capital costs than WSHP, however higher operating costs due to lower CoP • ASHP at large scale may have a cooling effect on local environment • Planning, visual and noise restrictions close to residential buildings • Not dependent on accessing ground water • More familiarity with developers compared to other low carbon technologies	Yes, shortlisted option
Individual ASHP		• No losses from heat network • Space required at each building / dwelling • Visual and noise impacts for residents • Lower SPF for smaller heat pumps	Yes, shortlisted option

Technology	High level technical viability considerations	Considered further?
	• Heat demand is not diversified, and significantly greater heat pump capacity required, increasing strain on local grid	
Gas CHP	• Higher carbon emissions compared to other technologies • Local air quality considerations • Private wire revenue can significantly improve project economics • Not eligible for grant funding	No
Electric boilers	• Compact footprint • No impact on air quality • Expensive to generate heat, particularly during peak electricity usage times • Potential electricity grid capacity constraints and costs • Electricity grid carbon intensity is likely to be high at times of peak heat demand due to greater generation from combined cycle gas turbines (CCGT) • Possible reduction in price in future • Potential to take advantage of demand side response schemes if these become available	Yes, only as peak and reserve
Gas boilers	• High CO_2e intensity • Current government policy is to ban the sale of new gas boilers by 2035 • Lower OPEX than electric boilers • Proven and reliable technology	Yes, only as peak and reserve
Biomass CHP/ biomass boiler	• Lower carbon in earlier years (better than heat pumps until grid is sufficiently decarbonised) • Requires sustainable source of fuel, none identified in the immediate area • Air quality considerations • Fuel costs may be equal or lower than gas and electricity • Requires space for solid fuel delivery and storage • Environmental impact of haulage of fuel due to frequency of fuel deliveries • Potential to provide energy source resilience as part of larger energy system	No
Hydrogen fuel cell CHP	• Economics of hydrogen-based CHP very uncertain • Security of fuel supply issues • Requires significant space for fuel cell • No local hydrogen generation • Fuel will need to be transported by road • Fuel cell market not developed	No
Energy from waste (EfW)	• At the time of this study there are no planned energy from waste sites planned within a feasible distance • Changing public perception of EfW as ‘green’ technology option • Significant negotiations required with plant operator to access heat	No

Technology	High level technical viability considerations	Considered further?
Solar thermal	• Significant initial capital costs • Significant land required for collector arrays	No

4.2 Short List Options

As a result of the long list assessment, four potentially viable solutions were shortlisted for further consideration. These technologies have the potential to meet the client's key priorities by providing affordable low carbon/renewable energy. A short list appraisal of each option was then undertaken to consider possible risks, benefits, and disbenefits. The following options have been shortlisted and are explained in further detail in this section:

- Centralised ASHP district heat network
- Centralised AD network
- Closed loop ground WSHP ambient network for residential, ASHPs for employmentIndividual ASHPs at buildings

4.2.1 Centralised Anaerobic Digestion DHN

Anaerobic digestion (AD) is a process that produces natural bio-gases from organic waste, predominantly methane. This methane can be used in a combined heat and power (CHP) engine to provide heat to a network. The key considerations for an AD solution are the availability of organic waste and space for the AD plant, storage of feedstock, CHP and back up plant. The solution will require easy access to transport links, such as the M50 to allow for feedstock deliveries. As the operator of the AD plant will have multiple revenue streams, there is the potential for a low price of heat offtake from the CHP by the network operator. An AD plant on this site would meet the councils aims to locate AD within industrial sites and utilise animal waste streams that are currently causing pollution problems in the River Wye. Figure 5 shows an example of utilising waste process heat (AD in this instance) to supply a heat network.

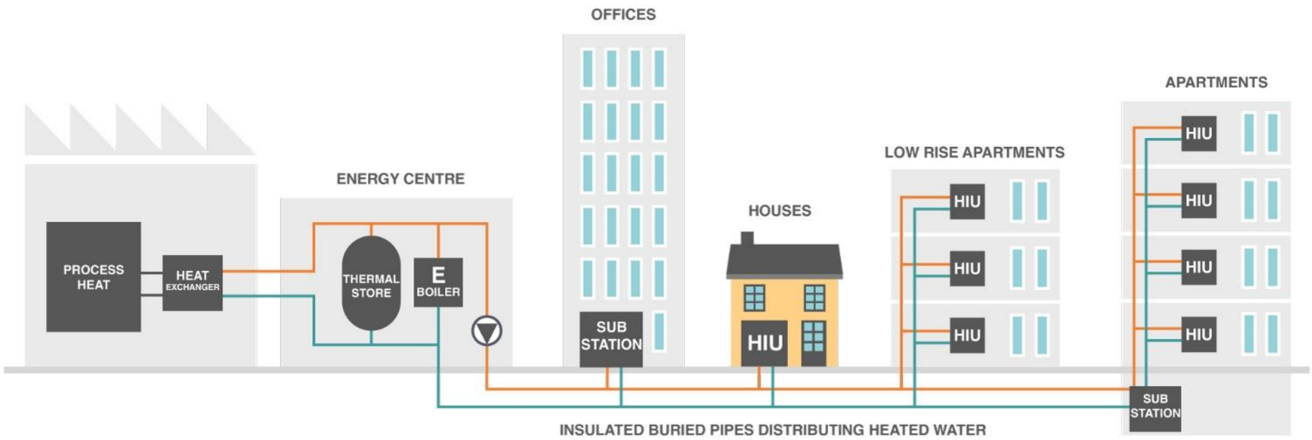

Figure 5: Indicative arrangement for a heat network utilising waste heat from an AD plant

This option is dependent on constant supplies of feedstock to meet the network heat demand. An energy centre for the network will also be required on site to house the back up generation equipment (gas or electric boilers), and associated plant (e.g. pumps, controls, thermal storage etc.). Should there be a failure in the AD plant or a shortfall of feedstock, the back up plant will generate heat to serve the network. However, this heat is likely to have a higher CO_2e intensity and result in higher operating costs.

The land required for an AD plant on site could vary depending on the technology type, waste streams used, storage required on site with a high level estimate ranging from 5,000 m^2 to 10,000 m^2. However, further assessment is required to confirm the land required and the technical and economic feasibility for an AD plant at this location.

For this assessment it has been assumed that an independent AD scheme could be developed on site and a heat network operator could negotiate a heat offtake agreement with the site to supply a heat network. This study will not assess the viability of an AD scheme at this site and will not include that capital costs of the plant. Only back up boilers and infrastructure associated directly with the heat network are included in this assessment.

4.2.2 Centralised ASHP DHN

ASHP systems utilise external heat exchangers to facilitate the exchange of heat between the ambient air and the heating medium. Key considerations for an ASHP solution are the space available for the installation of external heat exchangers, noise, visual, and cooling impacts on the local environment. Figure 6 illustrates an ASHP energy centre supplying a heat network.

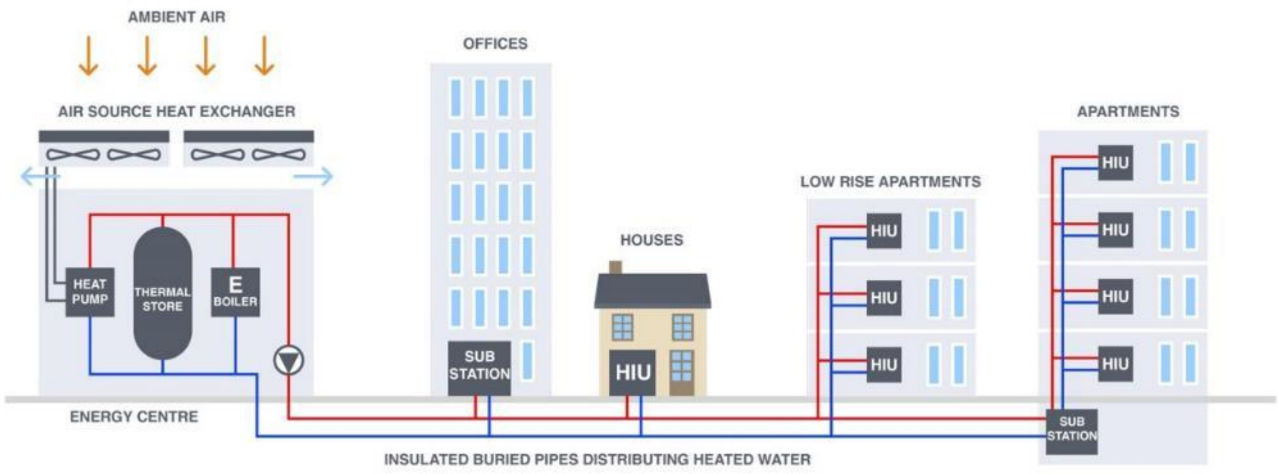

Figure 6: Indicative arrangement for an ASHP energy centre supplying a heat network

ASHPs can be beneficial in areas where there are no alternative and more efficient heat sources. ASHPs can also be a cost effective solution as no drilling or abstraction equipment is required to supply the heat pumps.

A single centralised heat pump option (with larger heat pumps) has advantages over smaller heat pumps at building level and these include:

- Potentially higher SPF than smaller heat pumps
- Economy of scale capital and operating cost benefits
- Significantly reduced space requirements within planned development buildings
- Potential to purchase electricity more competitively
- Thermal storage, control strategy and multiple heat sources enable smart operation
- Potential for grant funding
- A more diversified heat demand and so the centralised heat pump capacity is far lower than at the building level
- It is more practical to utilise low or zero GWP working fluids such in large heat pumps

However, ASHPs will be less efficient than ground WSHPs, therefore operating temperatures will be important. ASHP efficiency will vary with external air temperature; it will be less efficient in winter and have lower output. The lower seasonal performance factor (SPF) will impact project economics, CO_2e savings and potentially grant funding (where CO_2e savings are a key criteria). ASHPs can also have a cooling “cold plume” effect on their environment and nearby buildings as they extract heat from the air.

4.2.3 Closed Loop Ground WSHP Ambient Network

A closed loop heat pump system includes a thermal fluid that exchanges heat between the ground and the heating system. It does not rely on the abstraction and discharge of water and therefore has lower maintenance costs compared to open loop systems as there is no requirement for filtration. In a closed loop ground WSHP system, vertically drilled boreholes (collectively known as a bore field) allow heat to be exchanged with the ground.

In an ambient network, a fluid at ambient temperature is supplied to the connecting buildings and from this, heat is generated locally at the individual connections. Figure 7 shows the closed loop boreholes supplying an ambient network with heat pumps located at each building connection. Two major advantages of an ambient network are the low network losses due to the use of ambient temperatures and the ability to provide cooling to the network connections. The network is also able to expand in line with development build out, with the addition of more boreholes throughout the delivery of the site.

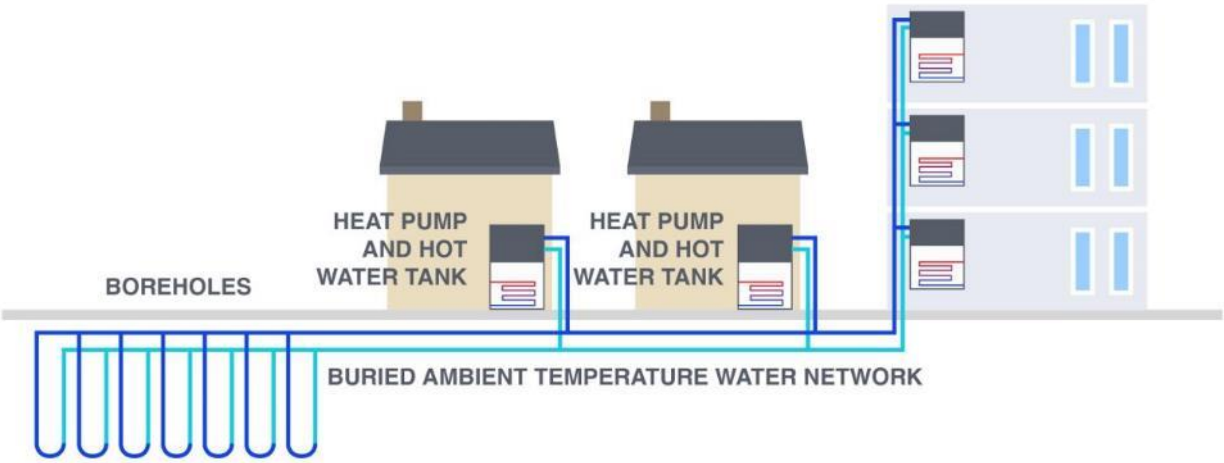

Figure 7: Indicative arrangement of closed loop ground WSHP Ambient Network

While an ambient network is potentially viable to serve the residential buildings, due to the unknown size and heating requirements of the industrial units, an ambient network solution may not be suitable for these connections. For this assessment, it has been assumed that an ambient network could serve the residential developments while the employment sites are served by individual ASHPs.

For this network 33 boreholes will be required to serve the 1,000 dwellings planned at the site.

4.2.4 Individual ASHPs

Individual ASHPs at the building level are typically the preferred low carbon heat source for buildings, where a heat network is not viable. As with centralised ASHPs, individual ASHPs can be beneficial in areas where there is no alternative, more efficient heat source as they are not dependent on accessing a heat source such as ground water.

However, individual ASHPs are often less efficient than larger scale heat pumps, resulting in higher operating costs. As individual ASHPs must be sized to meet the peak demand of each building, the overall installed heat pump capacity will be much higher than a centralised option. This will result in greater electricity grid connection requirements that could lead to expensive grid reinforcement. Individual ASHPs will also require rooftop plant rooms on each commercial and industrial building to house the air heat exchangers and heat pumps. For the residential sites, garden space for the heat pumps and internal space for the water tanks and other ancillary equipment will be required. An indicative arrangement of individual ASHPs supplying heat to different building types is shown in Figure 8.

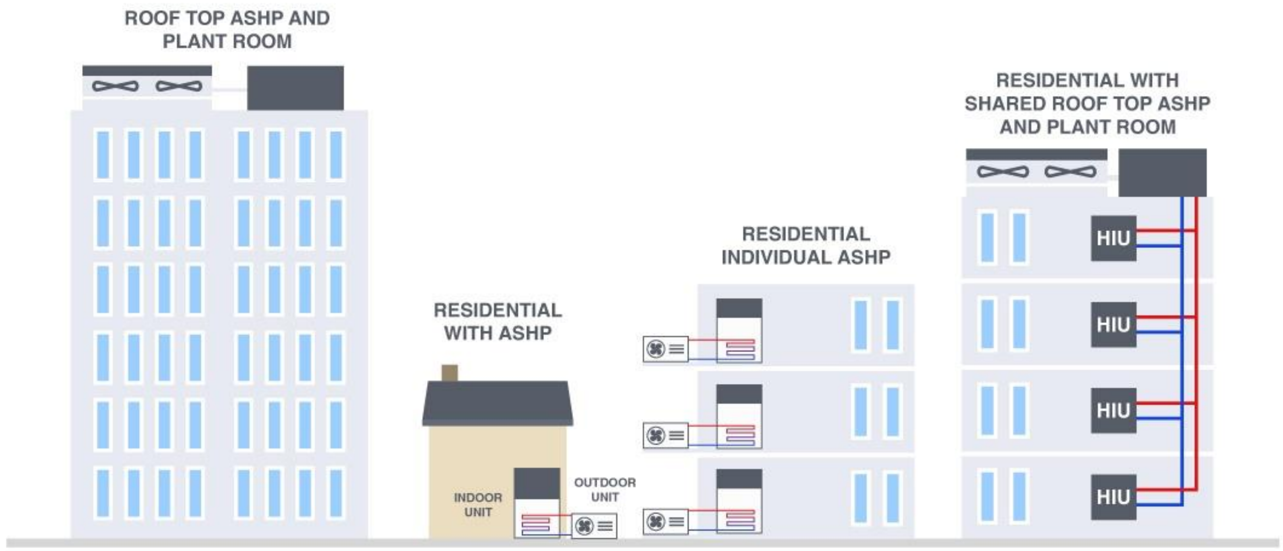

Figure 8: Indicative arrangement of individual ASHPs supplying different building types

4.3 Energy Centre

For the district heat network options, a centralised energy centre will be required that will house the heat generation plant and ancillary equipment. The location of the energy centre for this assessment has been assumed to be towards the north of the development site, within the employment area and near to the existing road network of the M50 and A449. This location will allow for ease of access for deliveries of fuel for an anaerobic digestion plant and minimise visual and noise impacts to the residential development areas. However, there are also risks to this location including the increased height of the land at the north of the site which will result in higher visual impacts from the neighbouring roads as well as increased pipe sizing of the network. Should the heat network solutions be identified as viable, the preferred location of an energy centre should be further assessed once more details are available for the development site.

4.4 Network Assessment

The network route assessment for the residential areas is based on the network length for similar development sites, as shown in Table 7. The average length of pipe per dwelling for Handforth Garden Village was used in the base case, as the layout and density of the site was the most similar to other developments in the Ross area.

Table 7: Residential network assumptions

	Welborne	Handforth	Seaham	Land to the East of Ross-on-Wye
No. dwellings	6,000	1,500	1,500	1,000
Dwellings per hectare	27	35	35	35
Network length per dwelling, m/dwelling	15.3	17.5	11.9	Assumed: 17.5

The assumptions for the employment areas have been based on the neighbouring Model Farm Development. A high level route was identified for this site and a corresponding length per connection was used.

4.5 Summary

The shortlisted heat supply solutions include AD and ASHP heat networks, an Ambient Network (with a residential ambient network served by closed loop ground WSHPs, employment sites served by individual ASHPs), and individual ASHPs for all buildings.

The energy centre for the DHN options is assumed to be to the north of the site near the M50 and A449. The network route assessment is based on the average length of network for planned developments with similar density of dwellings. The network route for the employment sites is based on the layout of the neighbouring Model Farm Development.

All assumptions should be reassessed as development plans for the site are progressed.

5 OPTIONS ASSESSMENT

Each of the four short listed options have been assessed with respect to project economics, CO_2e, benefits and opportunities, and risks and issues. The key underlying assumptions for the economic and CO_2e assessments are detailed in section 5.1, with full details provided in Appendix 2: Key Parameters and Assumptions.

5.1 Key Assumptions

5.1.1 Energy Price Projections

To assess the impact of expected future energy price changes on the financial outputs, the 2023 DESNZ central scenario price projections for natural gas and electricity have been used. The projected changes in prices for electricity and natural gas for residential, commercial and industrial are illustrated in Figure 9. The projected price variations have been applied to the calculated heat sale tariffs.

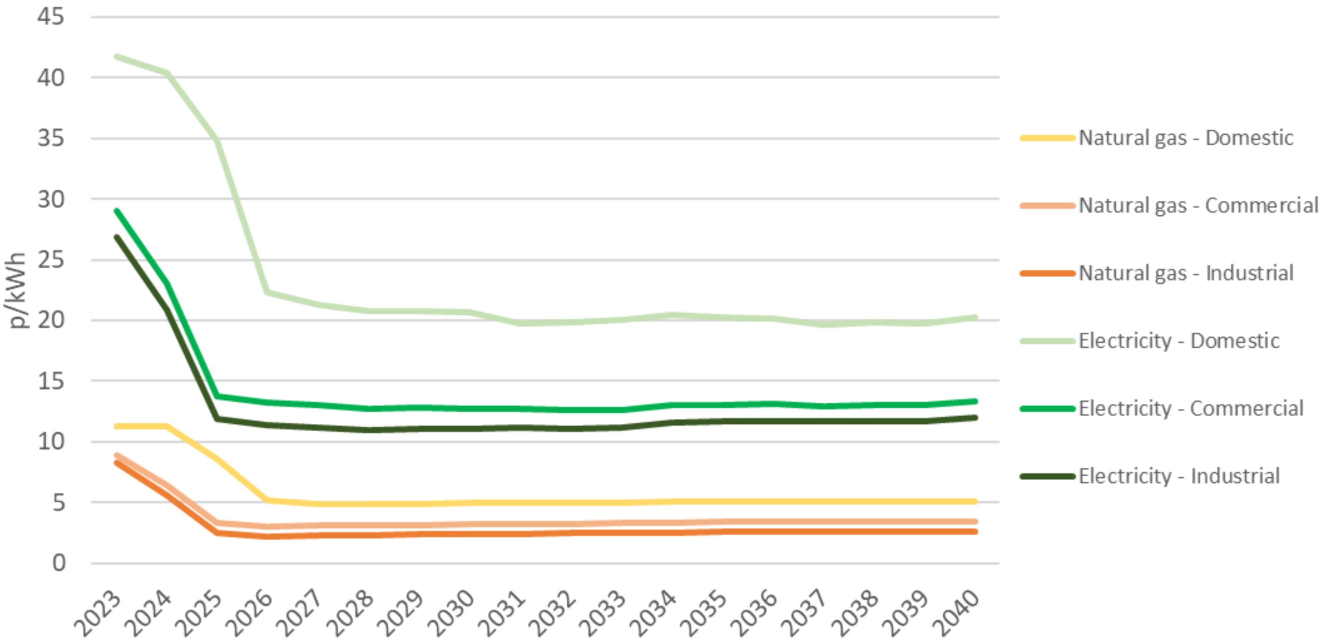

Figure 9: DESNZ[2] price projections – central scenario, updated 2023

The above projections indicate that, in the long term, energy prices will stabilise beyond 2026. Additionally, the projected trend may be affected by policy changes over time, such as modifications to the electricity market from market balancing or the Review of the Electricity Market Arrangements (REMA) initiative.

5.1.2 Heat Sales Tariffs

The heat sale tariffs were developed for the network connections based on the levelised cost of heat from the DESNZ zoning pilot programme study for Sunderland. The heat sale tariffs comprise two elements - a variable tariff and a daily fixed charge. The DESNZ 'central scenario' energy price projections are applied to the heat tariffs to account for the variance in electricity prices over the project lifetime. The detailed calculations for the heat sales tariffs used in the assessment are shown in Appendix 2: Key Parameters and Assumptions.

[2] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal - GOV.UK (www.gov.uk)

5.1.3 Ambient Network Standing Charge

An annual standing charge of £250 per dwelling was assumed for the Ambient Network solution. This was calculated based on the annual cost to residents to maintain individual ASHPs in the counterfactual scenario.

5.1.4 Energy Centre Tariffs

Electricity purchase tariffs used for the energy centre have been based on the predicted commercial gas and electricity tariffs for 2030 (assumed phase 1 start date) using DESNZ price projections.

5.1.5 AD Heat Purchase Price

A heat purchase price from the AD operator of 4 p/kWh has been assumed for the assessment. This is based on a Z factor of 7. The Z factor is a ratio of heat generation to lost power generation and is used to determine the loss in revenue for the AD operator from electricity sales.

5.1.6 Initial Capital and Replacement Costs

Technology replacement costs are modelled on an annualised basis and consider the capital costs, expected lifetime, fractional repairs, and the length of the business term. Details of expected equipment lifetime are shown in Appendix 2: Key Parameters and Assumptions.

Capital costs for the scheme are based on a combination of previous project experience, quotations for recent similar works and soft market testing and budget quotes. To develop an estimate of the heat network costs, the proposed network length has been multiplied by the average rates taken from numerous recent quotations obtained for similar work. Estimated capital costs for key plant items (such as heat pumps, thermal storage tanks, boilers, etc.) have been obtained from the respective suppliers. A breakdown of capital costs for each scenario is shown in Appendix 2: Key Parameters and Assumptions.

5.1.7 Connection Costs and Connection Charges

It has been assumed that the network operator will cover the connection cost, and customers will contribute to these costs through a connection charge when connecting to the network. Connection charges for all residential network connections have been included in the base case assessment and are assumed to be £6,500 based on the counterfactual cost of individual ASHPs. For commercial connections, connection charges are assumed to be £600 /kW in line with recent similar projects.

5.1.8 CO_2e Emissions

CO_2e intensity projections for grid electricity and natural gas are shown in Figure 10. The CO_2e emissions for the electricity grid are expected to reduce over time due to the increase in wind, solar, and nuclear power and the closure of coal power stations.

Two CO_2e projections for grid electricity have been used in the techno-economic modelling[3]:

- Long run marginal figure (commercial)
- Long run marginal figures (residential)

The long run marginal emissions factors consider the marginal plant for electricity generation. The projections are based on assumptions of future economic growth, fossil fuel prices, electricity generation costs, UK population, and

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[3] https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal

other key variables which are regularly updated. They also give an indication of the impact of the uncertainty around some of these input assumptions. Each set of projections takes account of climate change policies where funding has been agreed and where decisions on policy design are sufficiently advanced to allow robust estimates of policy impacts to be made. These figures have been used for all electricity imported from the grid (i.e., for heat pump electricity demand). The long run marginal figures for grid electricity and the natural gas figure[4] have been used for the counterfactual CO_2e emissions.

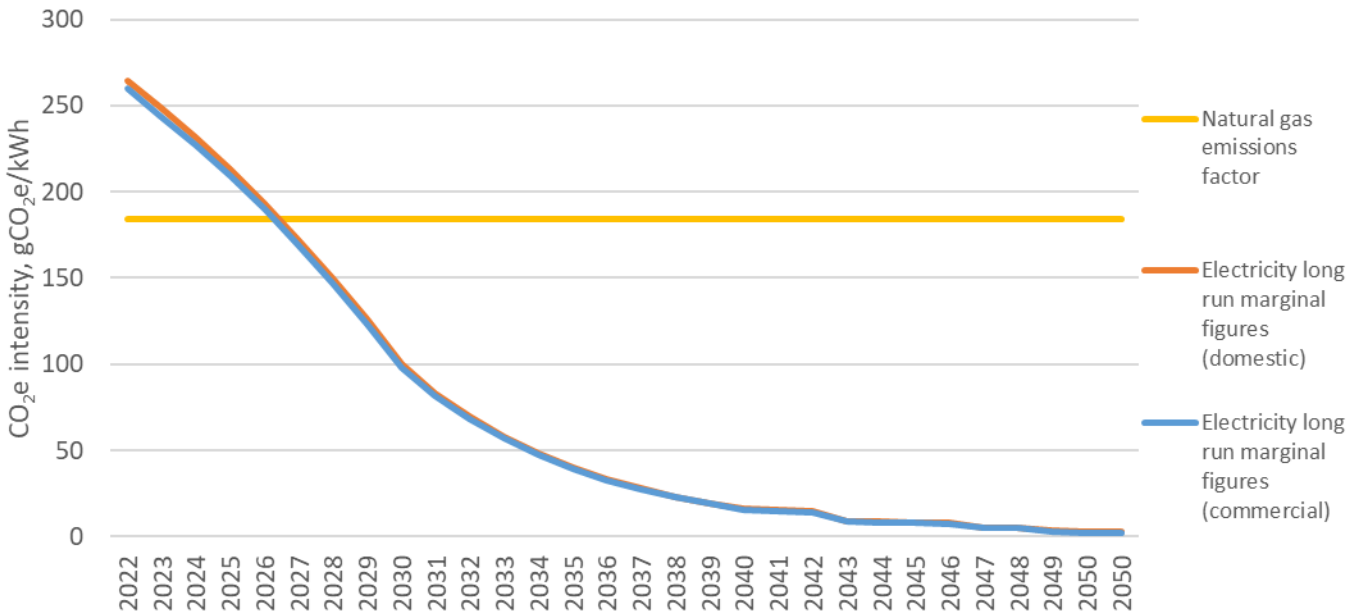


Figure 10: CO_2e intensity projections for grid electricity and natural gas

5.2 Technical Assessment

Table 8 shows details of the technology capacity required for each of the network options and individual ASHPs. The DHN options have a higher overall heat demand due to the heat losses in the network pipework. These losses are high due to the very low linear heat density of the site. Pipework with higher insulation can be used to minimise losses, however, this would increase the capital cost of the network. However, this will also lead to a reduction in operating costs that could cover the increased capital cost. This should be assessed further when more detailed plans for the development become available.

For the DHN options, peak and reserve boilers will be installed within the energy centre. This ensures scheme resilience and more economic sizing of the low carbon heating plant. Gas boilers have been assumed in the base case, due to lower operating costs. However, electric boilers could be installed in their place to reduce the CO_2e emissions.

Table 8: Technology options assessment

	AD DHN	ASHP DHN	Ambient Network	Individual ASHPs
Total heat demand, MWh	8,150	8,150	8,150	8,150
Network trench length, m	22,428	22,428	17,468	N/A

[4] https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2022

	AD DHN	ASHP DHN	Ambient Network	Individual ASHPs
Network linear heat density, MWh/m	0.36	0.36	N/A	N/A
Network losses, MWh	783	783	0.0	N/A
Total heat pump / low carbon capacity, MW	N/A	2.5	5.2	5.2
Back up boiler capacity, MW	4.0	4.0	N/A	N/A
Heat demand met by low carbon technology	100%	90%	100%	100%

5.3 Economic and CO_2e Assessment

The results of the economic assessment for the shortlisted options are shown in Table 9. Based on current assumptions, the AD DHN is the only economically viable option that results in a return on investment. However, this could change if different assumptions were used. For example, the layout of the development could be designed to reduce the length of the network pipework, this would reduce capital costs for the DHN and Ambient Network options and reduce losses for the DHN schemes.

Table 9: Economic assessment of options

	AD DHN	ASHP DHN	Ambient Network	Individual ASHPs
Capital costs	£8,147,069	£14,060,566	£11,052,885	£9,898,000
Net present cost (40 years)	£14,397,681	£29,277,840	£26,691,911	£37,898,644
Levelised cost of heat (40 years)	12.68	17.03	15.97	22.68
IRR (40 years)	26.98%	-6.77%	-1.36%	N/A
NPV (40 years)	£7,147,172	-£7,506,601	-£3,841,270	N/A
Annual cost to resident	£643	£643	£662	£1,081
Cost to developer, £	£8,099,000	£8,099,000	£9,589,855	£9,898,000
CO_2e intensity (year 1), gCO_2e/kWh	17.78	63.24	35.76	41.05
Total CO_2e emissions (40 years), tCO_2e	886	10,111	1,755	2,017

Figure 11 shows the net present cost and CO_2e emissions for the shortlisted options. The closer the option is to the zero axis, the lower the cost and carbon of the solution. The CO_2e emissions of the ASHP DHN option are significantly higher than the other solutions due to the high network losses and peak and reserve heat generated by the gas boilers.

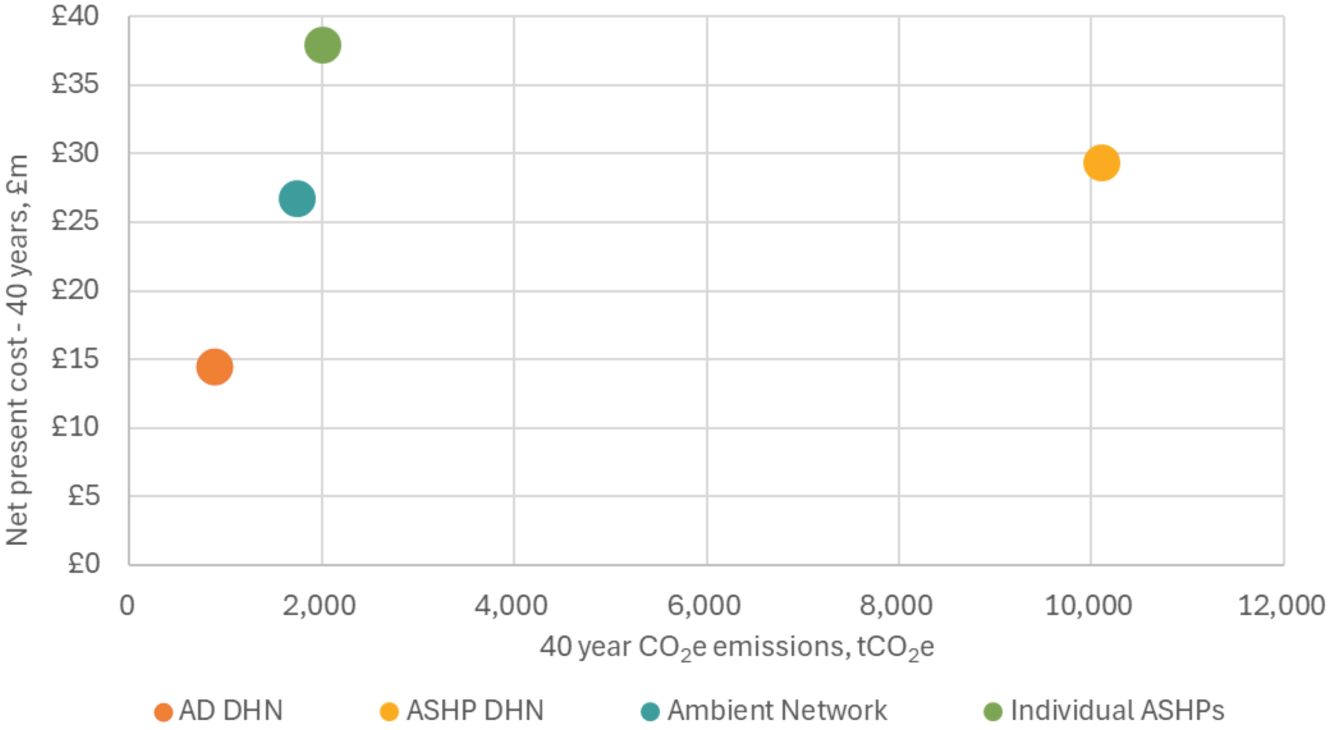


Figure 11: Net present cost and CO_2e emissions of options

The 40 year CO_2e intensity for each option is shown in Figure 12. All heat pump options decarbonise as the grid decarbonises. The ASHP DHN option has the highest CO_2e intensity due to the inclusion of gas peak and reserve boilers. The CO_2e intensity of this option would be reduced with the installation of electric peak and reserve boilers, however scheme operating costs would increase.

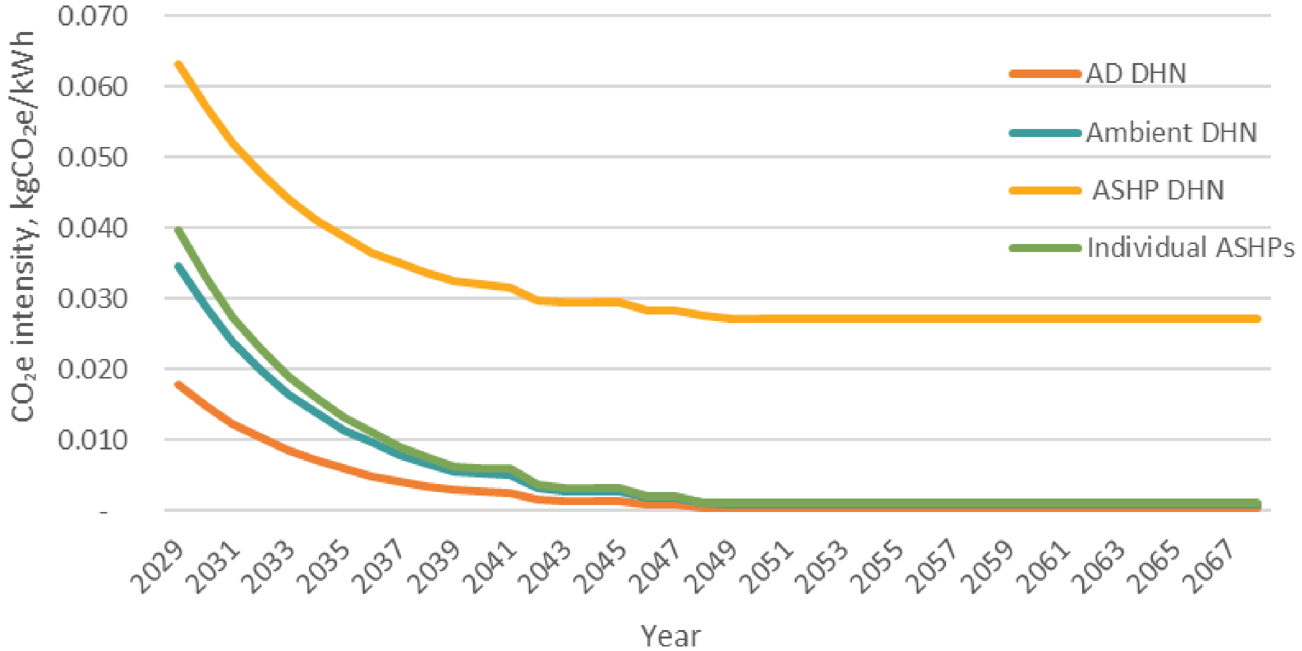


Figure 12: 40 year CO_2e intensity of options

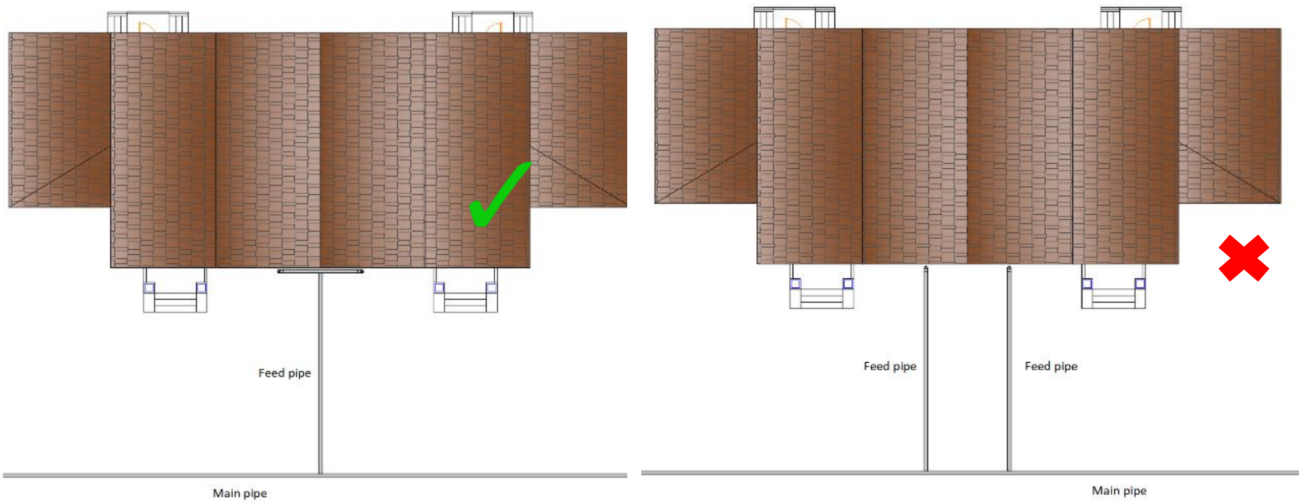
5.4 Network Length Sensitivity

In the base case assessment, a network length of 17.5 m per dwelling was assumed for the residential areas, which is a slightly conservative estimate. Table 10 shows the effect of a decrease and an increase in network length on the network economics. While the economics of each option improve with a reduction in network length, and decrease with a longer network, the variance in the network length does not result in a significant change in the economic returns of the options. The capital costs of the Ambient Network are predominately related to the heat pumps in at each connection and the drilling of the borefield.

Table 10: Sensitivity assessment of variance in network length

	Economics	AD DHN	ASHP DHN	Ambient Network
Base case: 17.5 m/dwelling	Capital costs	£8,147,069	£14,060,566	£11,052,885
	Net present cost (40 years)	£14,397,681	£29,277,840	£26,691,911
	IRR (40 years)	26.98%	-6.77%	-1.36%
12 m/dwelling	Capital costs	£6,926,383	£12,839,880	£9,959,285
	Net present cost (40 years)	£12,300,244	£27,180,403	£7,677,222
	IRR (40 years)	803.46%	-4.07%	0.17%
20 m/dwelling	Capital costs	£8,712,317	£14,625,914	£11,559,285
	Net present cost (40 years)	£15,368,915	£30,249,075	£9,990,783
	IRR (40 years)	17.97%	-8.46%	-1.96%

Examples of how network pipe length can be minimised for the residential sites is shown in Figure 13. For any social housing sites, network length can be reduced through a shared feed pipe that branches off to feed both properties, as shown in the first figures. The location of the connection point within the dwellings is another key consideration to minimising the network length, as shown in the second figure. If the connection point is at the front of the dwelling, a significant amount of pipework can be reduced across the site.



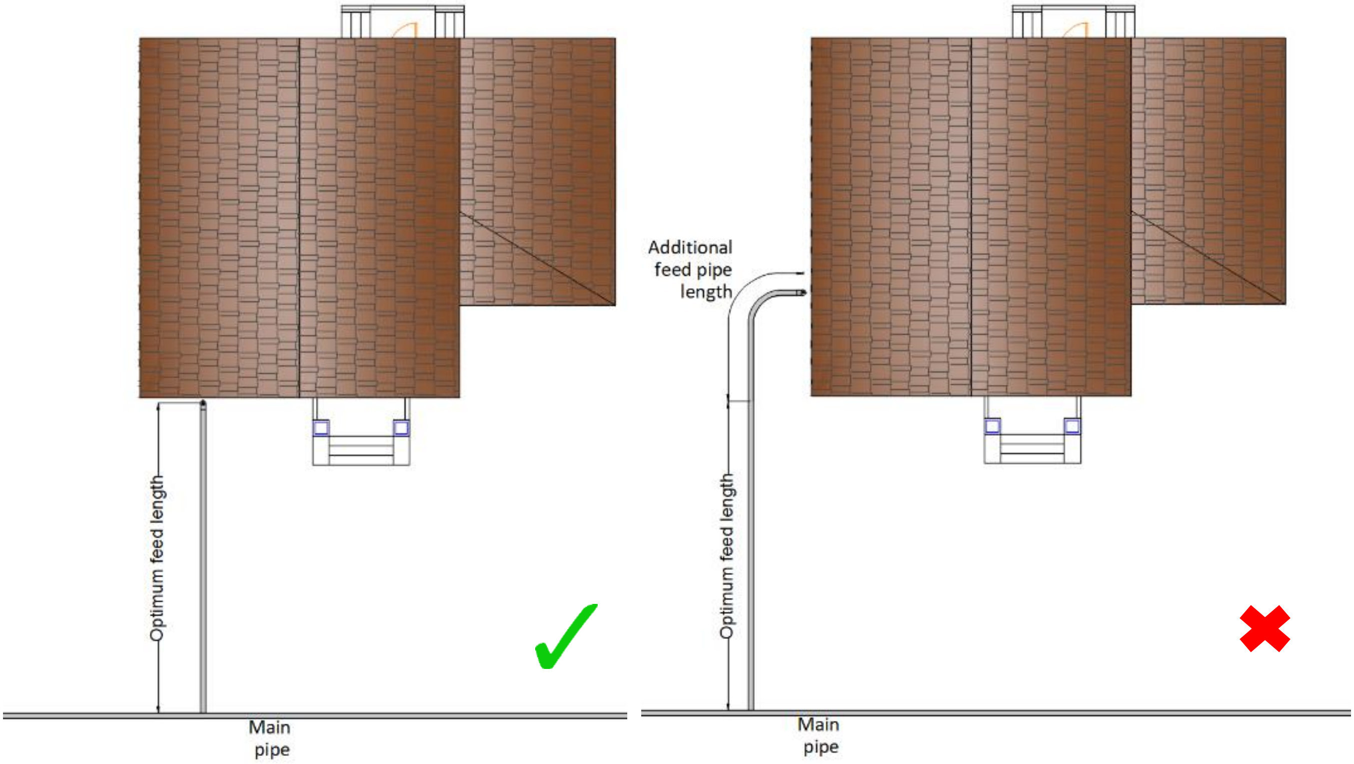


Figure 13: Examples of minimising pipe lengths

Additional capital cost savings can be made through utilising multi-utility trenches throughout the development, as shown in Figure 14. Laying all utilities within a single trench while the development is under construction can significantly reduce civils and excavation costs. However, this will require coordination with all utility companies.

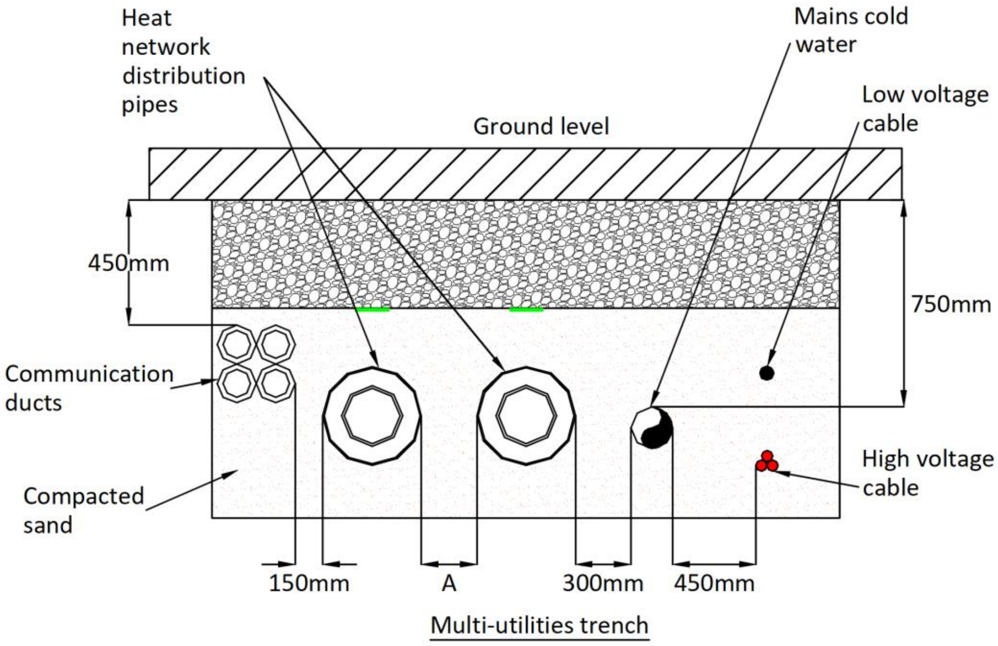


Figure 14: Multi-utility trench

5.5 Benefits and Opportunities

The benefits and opportunities for each option are detailed in Table 11.

Table 11: Benefits and opportunities of all heat supply options

AD DHN	ASHP DHN	Ambient Network	Individual ASHPs
• Highest economic returns • Lowest cost of heat to residents • Utilises waste heat streams that are currently causing pollution of the River Wye • Energy supply company would operate and maintain the scheme, ensuring optimal operation and higher efficiencies are achieved • Lowest CO_2e option • Potentially lowest cost for developers • Low cost of heat from AD plant • Low capital cost for heat generation • Lower electrical grid capacity required	• Not dependent on accessing ground water or negotiating supply agreement with AD plant • Energy supply company will operate and maintain the scheme, ensuring optimal operation and higher efficiencies are achieved • Lower electrical grid capacity required compared with Ambient Network and individual ASHP options	• Network can expand in line with the development – additional boreholes can be drilled as new homes are brought forward • Very low heat losses through distribution of low grade heat • Network operator owns and maintains the heat pump plant ensuring efficient operation • Constant temperature of ground results in consistent and higher heat pump efficiency than individual ASHPs • No requirement for a large energy centre • Slightly lower electrical grid capacity required compared with individual ASHP option	• Not dependent on timing of development – delays to build out will not impact the viability • Simple solution • No heat losses • Not dependent on accessing ground water or negotiating heat supply agreement with AD plant • No requirement for a large energy centre

5.6 Risks and Issues

The main risks and issues for the shortlisted options have been considered and assessed. Table 13, Table 14, Table 15, and Table 16 outline key potential risks and issues that apply the AD DHN, ASHP DHN, Ambient Network, and Individual ASHP options respectively, including both current risk and re-scored values.

Risk ratings are the product of impact and likelihood. The impact measures the effect of the risk being realised, and the likelihood measures the probability of the risk being realised. The current risk rating is the level of risk present if no further action is taken, and the re-scored risk rating is a measure of the risk present following mitigating measures.

A key showing the level of risk is shown in Table 12.

Table 12: Risk level key

Impact	1	Insignificant
	2	Minor
	3	Moderate
	4	Major
	5	Catastrophic
Likelihood	1	Highly unlikely, but may occur in exceptional circumstances
	2	Not expected, but a slight possibility it may occur
	3	Might occur at some time
	4	There is a strong possibility of occurrence
	5	Very likely, expected to occur
Risk rating	0-5	**Low risk**
	6-14	**Medium risk**
	15-25	**High risk**

Table 13: Risk register – AD DHN

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Technical	**T1.1** Security of supply and delivery of waste streams	Risk rating			An average of approximately 22 t of feedstock will be required daily for the AD plant to serve the network heat demand. A delay in deliveries or a failure in the AD plant will result in insufficient heat supply to the network.	Back up boiler plant (electric or gas) will be required on site to ensure constant supply of heat, during times of planned maintenance, failure in the AD plant or any issues with delivery of feedstock. The AD plant should be designed to allow various waste streams (animal, food, industry effluent, sewage sludge), to minimise the dependency on any in particular. Additional storage on site for feedstock could reduce the risk of a delay in deliveries. However, significant land area will be required. A further study is required to assess the technical and economic feasibility of an AD plant at the site and confirm the land requirements.
		5	4	**20**		
		Mitigated risk rating				
		5	3	**15**		
	T1.2 Significant land requirements for AD plant, back up plant, and storage.	Risk rating			Potential large footprint required for AD plant, onsite storage, and back up boilers (high level estimate ranges from 5,000 m^2 to 10,000 m^2. The AD plant will also require sufficient space for delivery vehicles to offload waste streams. This will reduce the land available for employment development sites.	Any loss in revenue from a reduction in land availability for employment development could be recouped through charges to the AD site developer. A further study is required to assess the technical and economic feasibility of an AD plant at the site and confirm the land requirements.
		2	5	**10**		
		Mitigated risk rating				
		2	5	**10**		
	T1.3 AD plant is not developed on site	Risk rating			Network option is reliant on AD plant being developed on site and utilizing the waste heat for a heat network. If an AD plant is not developed, a heat network will not be viable.	The council's planning officers should encourage the development of AD plant on site to supply low cost heat to the development site.
		5	4	**20**		
		Mitigated risk rating				
		5	4	**20**		
	T1.4 Inconsistent heat supply	Risk rating			The heat generation profile from the AD plant could be inconsistent with the demand profile from the connections.	The back up boiler plant will be required to serve more of the network heat demand if the AD plant does not generate heat when needed by the connections. This will result in a higher CO_2e intensity network and a higher cost of heat.
		4	4	**16**		
		Mitigated risk rating				
		4	4	**16**		

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Economic	**Ec1.1** Reduction in site heat demand	Risk rating			A reduction in heat demand from the development will decrease the potential heat sales for the network and therefore reduce the economics of the scheme.	Heat demands for the site have been estimated using heat demand models and u-values from the proposed Future Homes Standard. A reduction in site heat demand will result in spare available capacity within the energy centre plant. This will allow further expansion of the network and connection of additional sites. Should connecting additional sites not be viable, an increase in heat sales tariffs may be required to ensure economic viability of the network.
		3	4	12		
		Mitigated risk rating				
		3	3	9		
Environmental	**En1.1** Visual impacts and odour of AD plant	Risk rating			The assessment area is within the setting of a National Landscape and any development will need to ensure there are no adverse impacts to the wider area. The assumed energy centre location at the north of the site is at a higher level than the rest of the development site and may result in greater visual impacts. Consideration will be required for the potential odour of the AD plant on the surrounding area including nearby residential sites. There may also be a visual and noise impact from the delivery lorries to the neighbouring residential areas, as well as impacts to the highway network capacity.	The assumed energy centre location has been selected based on its proximity to existing road infrastructure and its distance from the planned residential areas. This will minimise the visual and odour impacts of the site. Discussion with planning officers will be needed to ensure the scale and location of an AD plant and energy centre complies with planning policy and does not result in adverse impacts. Further assessment of the optimal energy centre location will be required as development plans are progressed.
		5	4	20		
		Mitigated risk rating				
		5	3	15		
Commercial	**C1.1** Commercial negotiations with AD operator	Risk rating			The AD operator will be responsible for the delivery of low carbon heat to the development. The negotiation of a fair price of heat from the operator will determine the economic viability of the heat network.	The price of heat from the AD plant will be calculated based on the loss of revenue from the export of electricity generated by the plant. The assumed price of heat for this study is 4 p/kWh, estimated based on previous project experience at similar sites. The council can encourage the development of an AD plant and support the negotiation of contract terms.
		5	4	20		
		Mitigated risk rating				
		5	3	15		

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
	C1.2 Effect on development	Risk rating			The timing of this solution is highly dependent on the development of an AD plant. A delay in the development of the heat network or AD plant will result in the requirement for temporary energy centre(s) to serve connections in the short term, negatively impacting project economics.	The timing of the development of the heat network must be coordinated with the development of the housing and employment sites. Engagement with the AD operator/developer, heat network developer, and site developer will be critical to ensure delivery of the scheme.
		4	5	**20**		
		Mitigated risk rating				
		4	3	**12**		

Table 14: Risk register – ASHP DHN

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Technical	**T2.1** High network heat losses	Risk rating			The low heat demands and density of housing results in very high network heat losses (~20% of network heat demand). This results in higher energy costs due to generating additional heat.	The heat losses in the base case are based on standard Series 2 pre-insulated pipes. These could be reduced with higher levels of insulation. However, this will result in higher capital costs.
		4	5	**20**		
		Mitigated risk rating				
		4	3	**12**		
Economic	**Ec2.1** Project is not economically viable	Risk rating			High project capital costs and high heat losses due to low heat density in the development results in a network that is not economically viable. The cost of heat to residents would need to be very high to cover the costs of the scheme.	The network could potentially be economically viable if the development layout was designed to minimise pipe lengths resulting in lower capital costs. Higher heat sales tariffs and connection charges could also improve project economics. However, this would significantly increase the cost of heat to residents and likely become unaffordable.
		5	5	**25**		
		Mitigated risk rating				
		5	5	**25**		
Economic	**Ec2.2** Reduction in site heat demand	Risk rating			A reduction in heat demand from the development will decrease the potential heat sales for the network and therefore reduce the economics of the scheme. The network economics of the base case are very low and a reduction in heat demand would further reduce its viability.	Heat demands for the site have been estimated using heat demand models and u-values from the proposed Future Homes Standard. A reduction in site heat demand will result in spare available capacity within the energy centre plant. This will allow further expansion of the network and connection of additional sites. Should connecting additional sites not be viable, an increase in heat sales tariffs may be required to ensure economic viability of the network.
		5	4	**20**		
		Mitigated risk rating				
		5	3	**15**		
Environmental	**Env2.1** Highest CO_2e intensity option	Risk rating			The high network heat losses and the peak and reserve gas boilers installed within the energy centre result in the highest CO_2e emissions of all network options.	Higher insulation on network pipework will reduce the network losses and resulting CO_2e emissions. Gas peak and reserve boilers have been assumed in the base case assessment due to lower operating costs. Alternatively, electric boilers could be installed in the energy centre. A fully electric energy centre will decarbonize in line with the decarbonization of the grid.
		3	5	**15**		
		Mitigated risk rating				
		3	2	**6**		

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Environmental	**En2.2** Visual impacts and noise impacts of energy centre	Risk rating			The assessment area is within the setting of a National Landscape and any development will need to ensure there are no adverse impacts to the wider area. The assumed energy centre location at the north of the site is at a higher level than the rest of the development site and may result in greater visual impacts. Noise impacts from ASHP may require attenuation which will increase capital costs. A large ASHP installation could result in a visible cold plume effect due to the cooler air around the plant	The assumed energy centre location has been selected based on its proximity to existing road infrastructure and its distance from the planned residential areas. This will minimise the visual and noise impacts of the site. Discussion with planning officers will be needed to ensure the scale and location energy centre complies with planning policy and does not result in adverse impacts. Further assessment of the optimal energy centre location will be required as development plans are progressed.
		5	3	**15**		
		Mitigated risk rating				
		5	2	**10**		
Commercial	**C1.2** Effect on development	Risk rating			A delay in the development of the heat network will result in the requirement for temporary energy centre(s) to serve connections in the short term, negatively impacting project economics.	The timing of the development of the heat network must be coordinated with the development of the housing and employment sites. Heat network developer, and site developer will be critical to ensure delivery of the scheme.
		5	4	**20**		
		Mitigated risk rating				
		5	2	**10**		

Table 15: Risk register – Ambient Network

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Technical	Electricity grid capacity restrictions	Risk rating			Heat pumps will be installed at all connections and therefore a greater overall capacity of heat pumps (and electricity connection) will be required as there will be no diversity in the network. A higher capacity electricity grid connection may result in the requirement for additional grid infrastructure upgrades and higher capital costs.	Grid infrastructure upgrades are likely to be required for the development site and all heating options. The cost of upgrading infrastructure is likely to be small in relation to the wider costs of the scheme and the development.
		4	4	**16**		
		Mitigated risk rating				
		4	4	**16**		
	T3.2 Efficiency of heat pumps	Risk rating			The efficiency of heat pumps and the resulting cost of heat to residents will be dependent on how the individual resident operates and controls the heat pump. Should the residents operate the heat pump inefficiently, the resulting cost of heat will be higher.	Guidance should be provided to all residents on the appropriate and effective operation and control of the heat pumps. Regular maintenance and servicing of heat pumps will be undertaken by the Ambient Network operator ensuring greater efficiencies and a longer life for the plant.
		3	4	**12**		
		Mitigated risk rating				
		3	3	**9**		
	T3.3 Thermal availability of boreholes	Risk rating			The heat energy available from the ground is dependent on the ground temperatures and replacement of energy.	A conservative estimate of thermal energy from a borehole has been used and is based on experience of ground source heat pumps in a variety of locations. A trial borehole will be required to determine the thermal response of the local area.
		5	4	**20**		
		Mitigated risk rating				
		5	3	**15**		
Economic	**Ec3.1** Capital costs of borehole drilling is higher than estimated	Risk rating			A large number of boreholes will be required on site to serve the ambient scheme. An increase in capital costs of the boreholes will significantly impact overall project economics.	Capital costs have been estimated based on previous project experience and soft market testing. The drilling of boreholes throughout a development site offers cost savings.
		5	4	**20**		
		Mitigated risk rating				
		5	3	**15**		

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Economic	**Ec3.2** Project may not be economically viable	Risk rating			The economics of the scheme are marginal and will likely require grant funding. If the economics are not improved, private sector developers will not invest in an Ambient Network at the site.	The Ambient Network technology type and scale will likely be eligible for grant funding, under current eligibility criteria for the Green Heat Network Fund. If grant funding is no longer available due to the timing of the development, network economics could be improved through increased connection charges from developers and standing charges from residents.
		5	4	20		
		Mitigated risk rating				
		5	3	15		
Environmental	**En3.1** Long term performance of boreholes	Risk rating			If the scheme and layout of boreholes is not designed and modelled correctly, too much heat could be removed from the ground resulting in negative impact on the environment.	Ensure through procurement that the developer of the Ambient Network solution adheres to all environmental regulations to design the boreholes to allow for a stable and sustainable heat resource.
		4	3	12		
		Mitigated risk rating				
		4	1	4		
Commercial	**C3.1** Heat pumps will require space in dwellings	Risk rating			The heat pumps will be installed within the dwellings and will take up more space than an HIU connected to a heat network. This loss of space within dwellings could negatively impact the price of houses.	The water source heat pumps within dwellings are likely to be a similar size to a combi boiler. Therefore, are unlikely to have a significant impact on the price of the property. While the installation of a more efficient (compared to ASHP), low carbon heat pump may in fact increase the attractiveness of the property.
		3	2	6		
		Mitigated risk rating				
		3	1	3		
	C3.2 Energy supply company will be required to deliver the network	Risk rating			An energy supply company will be required to deliver the Ambient Network as developer for the housing site is unlikely to do so. However, the economics of the base case assessment are not viable.	In order to attract an energy supply company to deliver the network, a higher standing charge from residents will be required to improve the economics of the scheme. An annual charge of £250 per dwelling has been assumed in the base case. This would need to increase to £430 to be viable. The network economics could also improve if the housing development and layout were designed to minimize pipe lengths as this would reduce network capital costs.
		3	2	6		
		Mitigated risk rating				
		3	1	3		

Table 16: Risk register – Individual ASHPs

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Technical	**T4.1** Electricity grid capacity restrictions	Risk rating			Heat pumps will be installed at all connections and therefore a greater overall capacity of heat pumps (and electricity connection) will be required as there will be no diversity in the network. A higher capacity electricity grid connection may result in the requirement for additional grid infrastructure upgrades and higher capital costs.	Grid infrastructure upgrades are likely to be required for the development site and all heating options. The cost of upgrading infrastructure is likely to be small in relation to the wider costs of the scheme and the development.
		4	5	20		
		Mitigated risk rating				
		4	5	20		
Technical	**T4.2** Efficiency of heat pumps	Risk rating			The efficiency of heat pumps and the resulting cost of heat to residents will be dependent on how the individual resident operates and controls the heat pump. Should the residents operate the heat pump inefficiently, the resulting cost of heat will be higher. This is a slightly greater risk for individual ASHPs as the average efficiency of the heat pump is lower than water source heat pumps.	Guidance should be provided to all residents on the appropriate and effective operation and control of the heat pumps.
		3	4	12		
		Mitigated risk rating				
		3	3	9		
Technical	**T4.3** Low efficiency during cold periods	Risk rating			The efficiency of an ASHP varies in line with external air temperature. When outside temperatures are at their lowest, the efficiency of the heat pump is also at its lowest. This will result in a higher cost of heat to connections during these times.	As efficiency varies in line with air temperature, the efficiency of the heat pump during the summer months is very high. Therefore, on average throughout the year, the efficiency of the ASHP is only slightly lower than the water source heat pump.
		3	5	15		
		Mitigated risk rating				
		3	3	9		
Economic	**Ec4.1** ASHPs may result in the highest cost to developers and residents	Risk rating			The individual ASHP solution results in higher cost of heat to residents and higher cost to developers.	The cost of heat to residents could be lower than other solutions if assumptions vary. For example, an increase in the standing charge (for ambient option) or the heat sale tariff (for ASHP DHN option) to achieve market level returns on investment would make these options higher cost for residents.
		3	4	12		
		Mitigated risk rating				
		3	3	9		
Environmen	**En4.1** Noise and visual impact of the ASHPs	Risk rating			ASHPs will be located outside of the dwellings and may result in noise and visual impacts to the residents.	The ASHPs should be installed in a location at dwellings to reduce the visual and noise impact of the unit. Acoustic attenuation can also be installed to ensure the noise impact is minimal. However, this will increase the capital costs of the unit.
		3	4	12		
		Mitigated risk rating				
		3	2	6		

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Commercial	**C4.1** Heat pumps and associated plant will require internal and external space at dwellings	Risk rating			The heat pumps will be installed in the gardens of the dwellings but will also require internal space for other associated equipment including buffer tank, pumps, and controls. This loss of space within dwellings could negatively impact the price of houses.	The ASHPs should be installed in a location at dwellings to reduce the visual and noise impact of the unit. The internal equipment will require a similar space to a typical combi boiler and will therefore, be unlikely to have a significant impact to the price of the property.
		3	3	**9**		
		Mitigated risk rating				
		3	2	**6**		

6 SUMMARY AND CONCLUSIONS

This report details the findings of the Ross-on-Wye High Level Study assessing the potential heat supply solutions for the Land to the East of Ross-on-Wye development, identified in the upcoming Local Plan. The Land to the East of Ross-on-Wye has plans for approximately 1,000 new homes, 33 hectares of employment space, and a new primary school. As part of the assessment, key information and documentation was provided by the team at the council including the Draft Local Plan and supporting documentation.

Heat Demand Assessment

Using information provided in the Draft Local Plan, Future Homes Standard Consultation, local planning applications, and similar developments, a heat demand assessment for the site was completed. A summary of the site wide heat demands are shown in Table 17. The assessment was based on the high level information currently available for the site and heat demands should be reassessed when development plans are progressed. The assumptions and heat demands should be reassessed and updated as more information becomes available for the development.

Table 17: Heat demand assessment summary

Building type	Total area, m^2	Heat demand, MWh	Peak demand MW
Residential	95,930	6,121	2.54
Industrial	62,843	1,670	2.51
Commercial	3,775	359	0.15
Total	**162,548**	**8,150**	**5.2**

Heat Supply Assessment

As a result of a long list appraisal, four potentially viable low carbon solutions were shortlisted for further consideration.

- Centralised AD DHN
- Centralised ASHP DHN
- Closed loop ground WSHP Ambient Network for the residential and individual ASHPs for the employment sites
- Individual ASHPs for all buildings

An energy centre location was assumed at the north of the site, near the M50 and A449 for the DHN options. The land required for an energy centre would likely be in the range of 250-400 m^2. The network assessment was based on the nearby Model Farm Development for the employment sites, and similar housing developments for the residential sites.

Options Assessment

Each of the four shortlisted options were assessed with respect to project economics, CO_2e, benefits and opportunities, and risks and issues.

Economic and CO_2e Assessment

A summary of the economic assessment results for the shortlisted options are shown in Table 18. Based on current assumptions, the AD DHN is the only economically viable option that results in a return on investment. However, this could change if different assumptions were used. As only high level information is currently available for the site, the development plans are likely to vary from the assumptions used in this assessment. Therefore, three heating solutions of AD DHN, Ambient Network, and Individual ASHPs should be further considered and assessed as more detailed plans become available for the site.

Table 18: Economic assessment of options summary

	AD DHN	ASHP DHN	Ambient Network	Individual ASHPs
Capital costs	£8,147,069	£14,060,566	£11,052,885	£9,898,000
Net present cost (40 years)	£14,397,681	£29,277,840	£26,691,911	£37,898,644
IRR (40 years)	26.98%	-6.77%	-1.36%	N/A
CO_2e intensity (year 1), gCO_2e/kWh	17.78	63.24	35.76	41.05
Total CO_2e emissions (40 years), tCO_2e	886	10,111	1,755	2,017

Summary

Each of the network options have been assessed against the counterfactual option of individual ASHPs, based on high level information for a mixed use development near Ross on Wye. High level assumptions have been made, including the layout of the site, which has been estimated based on discussions with the council's planning team and plans for the adjacent residential development St Marys Garden Village, and other similar developments across the country.

Based on these assumptions, the AD DHN is the most economically viable solution. This option also benefits from utilising waste streams within the county, including animal waste which is currently causing pollution of the River Wye; however, there are several significant risks for this option. Technical risks include the dependency on an AD plant operator developing a plant at this location. Other technical risks include the security of heat supply from waste streams and the generation profile of the heat. This assessment assumes a price of heat from the AD plant of 4 p/kWh based on the avoided revenue from electricity generation, however, this will require further assessment. The AD plant and vehicular deliveries, and the heat network energy centre may also result in visual, odour, and noise impacts to the wider area that would need to be further considered as development plans are progressed.

Under the base case assumptions, the ASHP DHN is not economically viable. This is due to the low linear heat density of the network and high heat losses. This results in high capital and operating costs and limited improvements in efficiency compared to the ambient network and individual ASHP options. This network would become more viable with increased connection charges from developers and increased heat sales tariffs from connections.

The Ambient Network option can be developed and expanded as the development site is built. As the heat pumps are installed in the dwellings, additional boreholes can be drilled, reducing the complexity of coordination between network development and housing development. The Ambient Network also results in the lowest visual and noise impacts of all options and does not emit any odours. However, it does not provide an economic return to investors under current assumptions. The standing charge from residents would need to be increased to achieve an economic return. A trial borehole will also be required to confirm the thermal conductivity of the ground and the potential resource available. Further assessment of the grid constraints in the area will be required to confirm sufficient capacity for individual heat pumps at connections. Electrical infrastructure upgrades are likely to be required for the development and the cost of these may be shared across the schemes.

All network options will require an energy supply company to deliver the heat supply solutions and will require market level returns on investment to do so. However, under current assumptions, only the AD DHN option is economically viable. However, if the planned development was designed specifically to reduce the costs of heat network development, including minimising pipe lengths through the layout of housing and / or increase housing density, economics of all network options would be improved. All options should be considered further and reassessed as development plans for the site are progressed.

Based on the assumptions in this study, all options with the exception of the ASHP DHN offer the potential for cost effective, efficient, and low carbon heat supply for the development site (depending on the assumptions used for the assessment). The AD DHN results in the most economic scheme but comes with significant risk. Should a developer of an AD plant come forward on this site, this is likely to be the preferred solution. Planning policy should state that any AD plant proposed in the area must be CHP ready, and supply heat to nearby sites. The counterfactual of individual ASHPs provides the simplest solution for the site but will result in higher costs to residents and developers as well as noise and visual impacts for residents. The Ambient Network does not provide economic returns under the assumptions made in this study, however, a change in development layout, connection charges from developers, and standing charge from residents could result in an economic network.

For both the Ambient Network and individual ASHP options, a reduction in heat demand from dwellings would reduce the cost of heat to residents and will not impact the economic viability of the scheme. If possible in future, more stringent requirements than the proposed Future Homes Standard Building Regulations could be proposed through planning policy. Although this would negatively impact the economic viability of the ASHP DHN and AD DHN options, it will result in lower CO_2e emissions, cost of heat to residents, and electricity grid requirements.

Key Recommendations for Planning Policy

Based on the assessment of heat supply options for the site, key recommendations for planning policy regarding the Land to the East of Ross-on-Wye development include:

- Developers should show due consideration to the layout of the development site, ensuring it does not impede the development of a heat network
- Development of any AD plant should be CHP ready and be required to connect to a DHN if in proximity to an existing or planned network
- Site heat demand should be reassessed when more detailed development plans are available

Next Steps

The proposed next steps for this project include:

- Undertake a further study to assess the technical and economic feasibility of an AD plant at the Land East of Ross-on-Wye – 3-6 month study within the next 12 months
- Ensure planning policy requires the development of any AD plant to be CHP ready
- Ensure developers consider connection to heat network in their development plans, ensuring connection points are located at the front of properties to minimise network pipe length – initial requirements to be set out within the Local Plan and continued engagement with developers once identified
- Support the coordination of multi-utility approach across the site – initial requirements to be set out within the Local Plan and continued engagement with developers once identified
- Undertake a detailed techno-economic feasibility to assess the potential for a heat network when development plans are progressed and further detail is available – 3-6 month study to be procured following identification of developer and a masterplan for the site has been developed
- Initial soft market testing with heat network developers to identify preferred scheme and minimum development scale – initial discussions could be held immediately to inform the next steps for the site, engagement should continue periodically to ensure any plans for the site are attractive to the market

APPENDIX 1: SIMILAR PLANNED DEVELOPMENT SITES

Further details of the development plans used as the basis for assessments in this study are shown below.

Welbourne Garden Village

Welborne Garden Village is a development consisting of 6,000 new homes and approximately 140,000 m^2 of non-residential sites (site plan shown in Figure 15). The energy strategy at the site encourages housing developers to provide:

- Secure energy supply, maximizing low carbon technologies including to a heat network
- Achieve high levels of energy efficiency including 10% of housing to meet Passivhaus standards

The council have supported the installation of a DHN in the village centre, allowing both the connection of existing buildings and planned developments. Low carbon technologies will be installed on buildings where appropriate, including heat pumps and solar thermal.

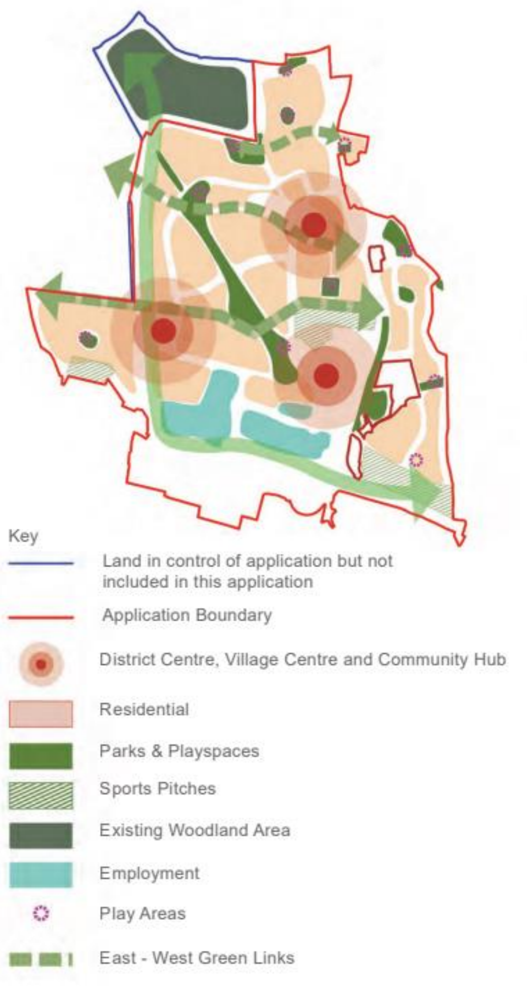


Figure 15: Welborne Garden Village

Handforth Garden Village

The garden village development consists of 1,500 new homes and approximately 120,000 m^2 of non-residential sites. The council aims for it to be an “exemplar sustainable” development, with the energy strategy for the site. A heat network for the development was identified utilizing open loop ground WSHPs following feasibility and detailed project development studies. The project has also achieved a successful GHNF application. Details for the site are shown in Figure 16.

Figure 16: Handforth Garden Village

Seaham Garden Village

Seaham Garden Village is a development of 1,500 homes and village centre amenities. A heat network under development for the site, utilizing mine WSHPs. The scheme has completed feasibility, detailed project development, and commercialization stages, as well as receiving Heat Network Investment Programme grant funding. The site is shown in Figure 17.

Figure 17: Seaham Garden Village

Halsnead Garden Village

Halsnead is a garden village development of 1,600 new homes and approximately 22.5 hectares of employment land.

Figure 18: Halsnead Garden Village

West Carclaze Garden Village

The West Carclaze Garden Village in Cornwall is a development of 1,500 homes and industrial space. The energy study for the area identified the potential for a DHN served by an energy from waste plant. There is also the potential for biofuels, geothermal and large amounts of solar on the site. Figure 19 shows the development plans.

Figure 19: West Carclaze Garden Village

St Mary's Garden Village

St Mary's Garden Village is a housing development of 365 homes and neighbours the Land to the East of Ross-on-Wye development area. It is likely that the proposed housing development will follow a similar scale and density to the St Mary's site. Plans for the site are shown in Figure 20.

Figure 20: St Mary's Garden Village

Model Farm

Plans for the Model Farm development were used as the basis for the assumptions for the industrial employment sites within the Land to the East of Ross-on-Wye .

Figure 21: Model Farm development plan

APPENDIX 2: KEY PARAMETERS AND ASSUMPTIONS

U-Values

U-values used for the heat demand assessments are shown in Table 19.

Table 19: U-values for development sites

	Future homes and buildings standards (U values (W/m²K))		
	Semi detached house	Detached house	Light industrial
		0.15	0.26
		0.80	1.60
		0.11	0.18
		0.11	0.22
		1.00	1.40

Energy Tariffs

The heat sales tariffs used in assessments are shown in Table 20.

Table 20: Heat sales tariffs

Tariff type	ASHP DHN	AD DHN	Ambient DHN	Individual ASHPs
Fixed charge	£90.0/kW/year	£90.0/kW/year	£250/dwelling/year	N/A
Variable charge	6.97 p/kWh	6.97 p/kWh	N/A	N/A

Key Technology Parameters

Key technology parameters for the network are shown in Table 21.

Table 21: Technical inputs

Parameter	ASHP DHN	AD DHN	Ambient DHN	Source of data / assumption
Average COP for heat pump	2.8	N/A	N/A	Calculated based on previous experience on similar projects.
Peak and reserve boiler efficiency	80%	80%	N/A	Expected efficiency of new gas boilers based on experience of operating plant.
Network losses, kW	10%		0%	Calculated based on previous experience on similar projects.
Heat pump capacity, MW	2.5	N/A	N/A	The heat pump has been sized using experience on similar projects.

Parameter	ASHP DHN	AD DHN	Ambient DHN	Source of data / assumption
	1%			

Financial Assessment

The Financial Assessment is shown in Table 22.

Table 22: Financial assessment

Key parameter	Source of data / assumption
Discount rate	Treasury Green Book
Inflation	Not included in the base case assessment.
XNPV	XNPV calculation used on an annual basis (31st December each year).
Project term	40 years
Simple payback	Simple payback calculation takes into account initial capital costs in network year 0. It does not take into account additional capital costs (i.e. for later phases).
Prices	All prices in this model are 2024 prices.
Capital investment	Initial capital investment is taken in year 0 as a single payment. Capital investment for later phases is taken a year before revenue from energy sales for that phase is received. The phase start year (which can be varied on the 'Dashboard' tab, is the first year of energy supply and energy sales for the network).

OPEX

The operating expenditure projections for different scenarios shown in Table 23.

Table 23: Operating expenditure

	ASHP DHN	AD DHN	Ambient DHN
Import electricity costs for heat pump, energy centre and network pumps	£374,000	£22,000	£8,000
Cost of heat from AD plant	N/A	£344,000	N/A
Heat network operation monitoring and maintenance (including pipework, energy centre and HIUs/substations)	£184,000	£137,000	£35,000
Staff costs	£28,000	£28,000	£10,000
Metering and billing	£19,000	£19,000	N/A

Insurance costs assumed to be 0.1% of the capital costs for all scenarios.

Capital Costs

The capital expenditure projections are shown in Table 24.

Table 24: Capital expenditure

	ASHP DHN	AD DHN	Ambient DHN	Individual ASHPs
Energy centre (including any				

Table 25: Revenue

	ASHP DHN	AD DHN	Ambient DHN
		£469,000	£250,000
		£105,000	N/A
Variable heat tariff revenue –		£418,000	N/A
Variable heat tariff revenue -		£23,000	N/A
		£8,099,000	£6,500,000

Energy Price Indexation

The energy price indexation used in the economic assessments are shown in Table 26. Figures are shown in p/kWh.

Table 26: Energy price indexing

Year	Industrial	Residential	Commercial	Year	Industrial	Residential	Commercial
2023	26.8	41.7	29	2037	11.7	19.6	12.9
2024	20.9	40.3	23	2038	11.7	19.9	13
2025	11.9	34.8	13.8	2039	11.7	19.7	13
2026	11.3	22.3	13.2	2040	12	20.2	13.3
2027	11.2	21.3	13	2041	11.8	19.9	13.1
2028	10.9	20.7	12.7	2042	11.8	19.9	13.1
2029	11.1	20.7	12.8	2043	26.8	19.9	13.1
2030	11.1	20.6	12.7	2044	20.9	19.9	13.1
2031	11.2	19.7	12.7	2045	11.9	19.9	13.1
2032	11.1	19.8	12.6	2046	11.3	19.9	13.1
2033	11.2	20.1	12.6	2047	11.2	19.9	13.1
2034	11.6	20.4	13	2048	10.9	19.9	13.1
2035	11.7	20.2	13.1	2049	11.1	19.9	13.1
2036	11.7	20.2	13.1	2050	11.1	19.9	13.1

CO_2e Emissions Factors

The electricity grid CO_2e emissions figures used in assessments are shown in Table 27. The long run marginal figures have been used for the electricity grid. These have been used for all electricity imported from the grid for the heat pumps and parasitic load. Figures taken from "Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal":

Table 27: Electricity grid CO_2e emissions industrial

	Long run marginal, gCO_2e/kWh				Long run marginal, gCO_2e/kWh		
Year	**Commercial**	**Domestic**	**Industrial**	**Year**	**Commercial**	**Domestic**	**Industrial**
2030	98	100	96	2050	2	3	2
2031	82	83	80	2051	2	3	2
2032	68	69	67	2052	2	3	2
2033	57	58	56	2053	2	3	2
2034	47	48	46	2054	2	3	2
2035	39	40	39	2055	2	3	2
2036	33	33	32	2056	2	3	2
2037	27	28	27	2057	2	3	2
2038	23	23	22	2058	2	3	2
2039	19	19	19	2059	2	3	2
2040	16	16	15	2060	2	3	2
2041	15	15	15	2061	2	3	2
2042	14	15	14	2062	2	3	2
2043	9	9	9	2063	2	3	2
2044	8	8	8	2064	2	3	2
2045	8	8	8	2065	2	3	2
2046	8	8	7	2066	2	3	2
2047	5	5	5	2067	2	3	2
2048	5	5	5	2068	2	3	2
2049	3	3	3	2069	2	3	2