Welborne Garden Village
Heat Network Feasibility Study

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Prepared for: Buckland Development and Fareham Borough Council

Prepared by: Lee Evans

Matthew Crawford

Alexis Ciunek

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Contents

List of Figures

Sustainable ENERGY

List of Tables

List of Abbreviations

ASHP	Air source heat pump
AQMA	Air Quality Management Area
BAU	Business As Usual
BEIS	Department for Business, Energy and Industrial Strategy
BGS	British Geological Survey
CAPEX	Capital expenditure
CHP	Combined heat and power
CoP	Coefficient of Performance
CO_2e	Carbon dioxide equivalent
DEFRA	Department for Environment, Food and Rural Affairs
DHN	District heating network
DHW	Domestic hot water
Dph	Dwellings per hectare
EA	Environment Agency
EC	Energy centre
FBC	Fareham Borough Council
FHS	Future Homes Standard
GA	General Arrangement drawing
GIS	Geographic Information System
GHNF	Green Heat Network Fund
GSHP	Ground source heat pump
HIU	Heat interface unit
HNCoP	Heat Networks Code of Practice
HNDU	Heat Network Delivery Unit
IAG	Interdepartmental Analysts Group
IRR	Internal Rate of Return
LCP	Lane Clark and Peacock
LHD	Liner heat density
LTHW	Low temperature hot water
NOx	Nitrogen oxides
NPV	Net Present Value
OPEX	Operational expenditure
PFD	Process Flow Diagram
PV	Photovoltaics
RFI	Request for information
SuDS	Sustainable Drainage Systems
SPF	Seasonal performance factor
TEM	Techno-economic model
WSHP	Water source heat pump

Glossary

Distribution Network	The circulation pipework (with flow and return) between the Energy Centre and the Substations
District heating	The provision of heat to a group of buildings, district or whole city usually in the form of piped hot water from one or more centralised heat source
Energy centre	The building or room housing the heat and / or power generation technologies, network distribution pumps and all ancillary items
Energy demand	The heat / electricity / cooling demand of a building or site, usually shown as an annual figure in megawatt hours (MWh) or kilowatt hours (kWh)
Combined heat and power	The generation of electricity and heat simultaneously in a single process to improve primary energy efficiency compared to the separate generation of electricity (from power stations) and heat (from boilers)
Green Heat Network Fund	The £270m capital grant funding programme for heat networks announced by Government that is expected to open on 1 April 2022
Heat clusters	Buildings / sites grouped based on heat demand, location, barriers, ownership and risk
Heat exchanger	A device in which heat is transferred from one fluid stream to another without mixing - there must be a temperature difference between the streams for heat exchange to occur
Heat Interface Unit	Defined point of technical and contractual separation between the Distribution Network and a heat user
Heat network	The flow and return pipes that convey the heat from energy centre to the customers – pipes are usually buried but may be above ground or within buildings
Heat offtake opportunity	An opportunity to utilise waste heat from an industrial process including EfW plants using heat exchangers
Heat pump	A technology that transfers heat from a heat source to heat sink using electricity (heat sources can include air, water, ground, waste heat, mine water)
Hurdle rate	The minimum internal rate or return that is required for a network to be deemed financially viable
HNDU	The Heat Network Delivery Unit within BEIS
Internal Rate of Return	Defined as the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero, and used to evaluate the attractiveness of a project or investment
Linear heat density	Total heat demand divided by indicative pipe trench length - it provides a high level indicator for the potential viability of network options and phases
Peak and reserve plant	Boilers which produce heat to supply the network at times when heat demand is greater than can be supplied by the renewable or low carbon technology or when the renewable or low carbon technology is undergoing maintenance (also called auxiliary boilers)
Phases	Construction phases in which it is proposed the Heat Network will be delivered

Private wire	Electricity generated by a CHP that is supplied to network connections as part of private wire arrangements where underground cables connect the buildings to the energy centre
Project IRR	Internal rate of return (IRR) of a project
Services Provider	Party who will deliver the operational and maintenance services including metering and billing
Social NPV	Social net present value
Substation	A defined point on the property boundary of the heat user, comprising a heat exchanger, up to which the heat network is responsible for the heat supply
Thermal store	Storage of heat, typically in an insulated tank as hot water to provide a buffer against peak demand

EXECUTIVE SUMMARY

The Welborne Garden Village Heat Network Feasibility Study is funded by HNDU, Buckland Development and the project partners are Fareham Borough Council

The main driver for this project is to help ensure Welborne Garden Village becomes a sustainable community development, delivering low / zero carbon and energy efficiency to the village. This project should form a key part of the overall carbon reduction and heating strategy for the Welborne Garden Village.

The Future Homes Standard sets out the commitment that fossil fuel heating systems will not be installed in new homes from 2025. The aim of the study is to identify the preferred option to deliver renewable heating to all new homes in a way that is technically and economically viable and maximises environmental and social benefits.

Two network options have been identified that could provide affordable low carbon heating to the Welborne Garden Village development. The first of these is a centralised low temperature hot water network utilising large scale Air Source Heat Pumps and electric peak and reserve boilers (LTHW ASHP network). The second option is to develop a series of smaller ambient loop clusters utilising closed loop boreholes to serve individual heat pumps within each property (Ambient Cluster network). These network options have been compared to the counterfactual of individual ASHPs in each property.

These options can satisfy the site heat demands and the closed loop borehole clusters have the added advantage of potentially being able to provide cooling to each property as well.

Energy Demand and Supply

Most of the heat demand comes from the planned 6,000 domestic dwellings. These account for 78% of the estimated 34 GWh of heat demand and 86% of the estimated 2.9 GWh of cooling demand. The commercial energy demand assessment has been performed using high level of information and will be subject to change.

The heat demand of the houses will be determined by the master developer requirements and the FHS coming into effect in 2025. The heat demand assessment has used notional values from the FHS. As more information is available from the house builders, the heat demand assessment should be re-visited.

Heat pump (air, ground, water), energy from waste, geothermal, waste heat, biomass and gas CHP technologies were assessed as options to supply heat network options. Potential water sources identified for water source heat pumps (WSHPs) were the three Portsmouth Water reservoirs located to the Northeast of the development.

In discussions with the development team, it was agreed that an energy centre utilising air source heat pumps and electric peak and reserve boilers could be located to the northeast of the development. This would be subject to a local planning application which could have a significant impact on the network timing and project CAPEX.

The ambient loop option assessed an open loop connection to Portsmouth Water Hoads Hill reservoirs and a closed loop ground source clustered option which would use a series of closed loop boreholes. The closed loop cluster model was deemed as potentially the most beneficial as it would allow the networks to be built to correspond with the build-out rate of the site.

Options Assessment

A sitewide energy network and a cluster based network were both assessed.

LTHW ASHP network

The sitewide network was phased over 5 phases. Phase 1 includes most of the network spine and needs to be futureproofed to serve the fully developed site

The optimised technology sizing scenario solutions are summarised below.

Technology sizing summary (cumulative)					
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
ASHP capacity	2.3 MW	3.4 MW	4.3 MW	6.8 MW	7.9 MW
Peak boiler capacity	1.0 MW	4.0 MW	8.0 MW	10.0 MW	10.0 MW
Thermal store capacity	200,000 l	200,000 l	200,000 l	200,000 l	200,000 l
Energy centre footprint	1,271 m^2	1,271 m^2	1,271 m^2	1,271 m^2	1,271 m^2

To help minimise the CO_2e emissions for the development, electric peak and reserve boilers have been selected. Therefore, it is recommended that the installed heat pumps are modular so that maintenance activities on one heat pump will not affect the required supply capacity.

A TEM was constructed to assess the economics of the thermal network and allow key variables to be revised and the associated impact assessed. The 40 year economics and carbon savings cumulative values are shown below:

Economic and CO_2e saving summary of thermal network (cumulative)					
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs (incl. contingency)	£11,209,960	£24,106,033	£40,864,822	£53,940,964	£60,651,605
40 year IRR	1.8%	7.1%	7.5%	8.2%	8.8%
40 year social IRR	6.3%	11.9%	12.4%	13.8%	14.2%
40 year Carbon savings (vs individual ASHP), tCO_2e	-363	-2,198	-3,986	-3,930	-3,775

While the thermal network option is potentially economic, the heat has a higher CO_2e intensity than the counterfactual (ASHPs in each building/dwelling).

Ambient Cluster network

The cluster based ambient network options were assessed to find the optimum cluster size based on a combination of peak diversity and pipe sizes. The optimum cluster size was found to be between 100-300 dwellings per cluster which matches well with the proposed build-out rate of the development.

The boreholes will serve as the heat source to the ambient loop and a heat pump located in each connection will connect to the loop. The required boreholes have been minimised based on diversity of load.

The heat pump will be installed by the network developer, but ownership will revert to the dwelling owner on completion of the housing sale. It will then be the responsibility of the homeowner for operation and maintenance costs for the heat pump.

A TEM was constructed to assess the economics of the ambient network and allows key variables to be revised and the associated impact assessed. The presented economics cover the ambient network only without the cost of heat pumps. This assumes that the heat pump can be bought and installed for the connection fee of £5000 and the network operator will receive a £1000 towards cost of the network. The 40 year economics and carbon savings cumulative values are shown below:

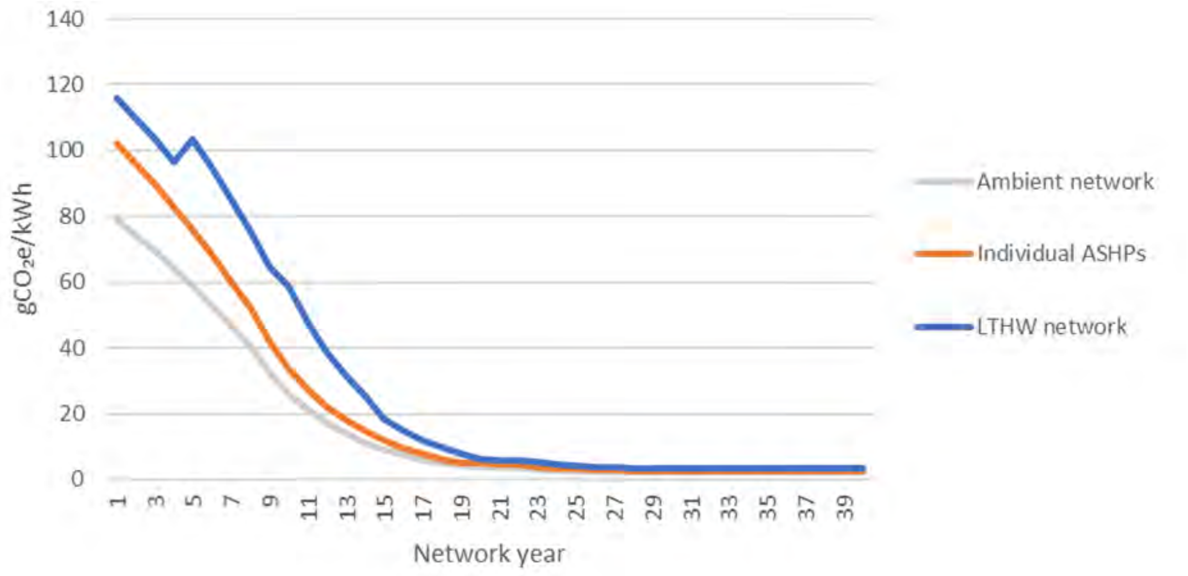
Economic and CO_2e saving summary of ambient cluster network (cumulative)					
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs (incl. contingency)	£2,530,308	£7,996,534	£14,754,301	£18,619,090	£20,864,263
40 year IRR	6.6%	6.1%	4.9%	5.6%	5.6%
40 year social IRR	19.3%	17.1%	17.0%	17.5%	17.6%
40 year Carbon savings (vs ASHP), tCO_2e	874	2,045	2,726	2,910	2,971

Network Comparison

The two proposed networks have been compared to ASHPs as the counterfactual. The 40 year costs, CO_2e emissions and CO_2e intensity are shown below:

40 year costs and CO_2e intensity of DHN option, ambient option and ASHPs in each building			
	ASHP thermal network	Ambient cluster network	Individual ASHPs
40-year net present cost	£97,642,404	£119,902,811	£123,614,880
CO_2e emissions (40 years), tCO_2e	18,255	10,199	13,170
CO_2e intensity of heat delivered (40 year average), gCO_2e/kWh	30	17	22

The ambient network has the lowest CO_2e intensity of the three options due to no network losses but with an improved SPF over ASHPs. The 40 year CO_2e intensity for each option is shown below:



A high level estimate of the electrical capacity requirement for each option has been assessed and is summarised below:

Electricity capacity requirements for DHN and ASHPs in each building			
Summary	ASHP thermal network	Ambient cluster network	Individual ASHPs
Installed heat pump capacity, MW	7.9	42.8	42.8
Installed electric boilers, MW	10	-	-
Assumed “Cold Load” COP	1.5	2.0	1.5
Overall connection capacity, MVA	15.2	21.4	28.5

For ASHPs and the ambient network, the electrical connection to the site needs to be designed for the realistic worst case after diversity maximum demand (ADMD). The “cold load” worst case is the peak that occurs during a 1/20 winter in the UK coupled with a significant power cut at this time. When the fault is remedied, and the heat pump systems come back online there is consequently no diversity as everyone on the feeder is attempting to warm their houses at an increased rate at the same time. For an ASHP, the heat pumps will be operating at a much lower COP as this load is assumed to be during winter. For the ambient network, the COP will be much higher as the ambient network is not affected by outside air temperature.

The acoustic impact of the centralised ASHPs will be deemed significant and attenuation will be required to reduce this to an acceptable level. If ASHPs are installed in each property, there will be a cumulative acoustic impact that has been deemed unacceptable by the master developer.

The district heating option has the lowest overall capacity requirements and will allow additional capacity to be utilised in the Garden Village.

Key Risks

The key risks for the thermal network have been identified and summarised below.

- Heat demand significantly impacts on network viability. If part of the development does not come forward then the energy centre and network will be oversized and will take longer to pay back the initial CAPEX. If heat demand is significantly greater then more heat will be required from the peak electric boilers costing more than the heat sales tariff unless the heat pumps out pump can be increased.
- The network is reliant on a suitable energy centre location being secured. The proposed energy centre location is currently outside of the development boundary. However, the proposed location for the energy centre is under the same ownership as the development. The main concern would be obtaining planning permission for a large industrial application in the rural location. To ensure the energy centre location is secured, continued engagement with FBC planners is required.
- Unless the feed pipes are installed in coordination with other utilities and that house layouts allow pipe length to be minimised, the project is unlikely to be economic.
- The scheme will require grant funding. It has been assumed that network start year for phase 1 is 2023, which is after the closure of the HNIP scheme (2022). Phase 1 options are marginally economic as they include futureproofing measures for later network phases. These projects are likely to be eligible for The Green Heat Network fund. This fund requires networks to generate heat with low CO_2e intensity, which this scheme should achieve.

The key risks for the ambient network have been identified and summarised below.

- The cluster ambient option will be most affected by the ability to source and install ground source heat pumps within each dwelling. If the cost of the heat pump and installation is greater than the connection fee received then the scheme will be marginally economic.
- The ambient network's heat sources are closed loop boreholes. The scheme will be significantly affected if the thermal response of the local area is poor. This will require extra boreholes at a greater cost.
- The ambient loop scheme will not have the same problems with planning as there will be minimal extra building works required and these will all be within the development boundary.

Commercial and delivery strategy

This requires further discussion with the Buckland Development team. Buckland Development would need decide on the contractual roles and ensure that project maximises social and environmental benefits. For Ambient Cluster network there is a risk if separate contractors are employed to deliver and operate different network clusters, even if the commercial conditions are the same then this may lead to differences in service levels between neighbouring clusters which may cause controversy and complaint. Economies of scale may not be realised if different contractors are responsible for separate clusters. Full commercial assessment is required to develop a delivery strategy; however, it is likely that there are significant benefits associated with contracting a single contractor to deliver the networks as part of a long term contract with relevant break clauses etc.

Conclusion

The two network options of the sitewide thermal network and a cluster based closed loop ambient network have been compared in detail alongside the counterfactual of individual ASHPs. The sitewide thermal network offers potentially higher returns to an investor. However, this comes with a much larger upfront cost as the energy centre will need to be futureproofed to serve the entire site. There are also higher carbon emissions associated with the thermal network due to the larger heat losses that come from a low density development.

The ambient cluster network does not provide as high returns due to the income only coming from a fixed yearly cost from each connection. The ambient cluster network offers the lowest carbon emissions from the options presented due to the improved SCOP. Another benefit is that the ambient clusters can be built at the same rate as the housing development lowering the risk and does not need to be futureproofed for the whole development.

If a network approach is to be adopted, the ambient cluster network is the preferred solution to provide heating to the Welborne Garden Village.

Next Steps

If the project is to be progressed, then next steps include:

- Continued engagement with FBC planners and to ensure that all necessary planning permission for an energy centre can be obtained if the centralised thermal network is preferred
- Engagement of ambient loop and heat pump suppliers if the ambient loop option is preferred
- Place conditions on house builders to ensure that roles and responsibilities are agreed and understood and that internal heating systems allow maximum efficiency of heat pump operation
- Apply for GHNF
- Work with all parties to assess roles and responsibilities (including ownership) and delivery strategy for the scheme

1 INTRODUCTION

1.1 General

This report presents the findings of the Welborne Garden Village Feasibility Study (2021). The project is supported by Heat Networks Delivery Unit (HNDU) from the Department for Business, Energy, and Industrial Strategy (BEIS) and Fareham Borough Council. The work has been conducted by Sustainable Energy (SEL).

1.2 Project Scope

We were commissioned to undertake a feasibility study for Welborne Garden Village. The scope of the feasibility study, in line with the DEEP tender scope included:

- Identify implications for the outline planning application for site to include highways design
- Update and confirm the heat strategy for the site with the client, clearly documenting and presenting all assumptions for client approval
- Provide an energy demand and supply assessment
- Assess energy centre and central plant options to include heat pumps, biomass, thermal storage etc.
- Consider planning and architectural issues and environmental issues / benefits (CO_2, NO_x, permitting etc.)
- Determine CO_2 emissions and compare these against the existing or counterfactual heat supply technology
- Complete the concept design (stage 2) for the energy centre, energy distribution systems and network connections
- Undertake detailed network hydraulic analysis, optimisation, pipe sizing, insulation standards and route design for the recommended scheme heating/cooling pipe network.
- Conduct techno-economic cash flow modelling and provide client with bespoke techno-economic model (TEM)
- Consider HNIP and/or GHNF requirements
- Assess social value and risk management
- Identify next steps

1.3 Project Background

The Welborne development will be a Garden Village, which has been recognised by the government as providing high quality and sustainable living for new communities. Welborne Garden Village, which will be located just outside Fareham in Hampshire, will include up to 6,000 dwellings, 10 hectares of employment use, healthcare, a primary and secondary school, local retail, and leisure facilities.

The development's vision is to add to Britain's rich legacy of new communities by creating holistically planned, characterful, and self-sustaining additions. The streets will be vibrant, diverse, and pedestrian-friendly. It will have a complete community ecosystem of schools, retail, playgrounds, and public transportation, all surrounded by a generous network of parks and open space. There will be a variety of housing types and tenures, with the goal of making it a place for everyone, regardless of age or income. Homes will be linked to shops, schools, sports, jobs, and other amenities via an interconnected framework of green spaces. Streets will be safe, verdant, and appealing, encouraging people to walk and cycle between these destinations rather than rely on cars. High standards of urban and landscape design and construction will connect the entire area together. Developments of this scale can be invasive, but Welborne Garden Village project has committed to minimising the impact on the environment and is investing in measures that will enhance biodiversity of flora and fauna.

1.4 Project Drivers

The main driver for this project is to help ensure Welborne Garden Village becomes a sustainable community development, delivering low / zero carbon energy to the village.

Priorities include:

- Energy security
- Provision of affordable warmth (and potentially cooling)
- Provision of low CO_2e intensity heat
- Deliver an exemplar new garden village

2 DATA COLLECTION

This section describes the potential customer and stakeholder engagement that has taken place. Stakeholder engagement is critical to developing successful energy networks and the engagement work carried out to date will need to continue if the project progresses through to subsequent stages of development.

A data collection exercise was undertaken to enable the mapping of future energy demands as well as potential energy sources, barriers and constraints. As part of this process, the energy demand assessment area was reviewed but has not changed from that initially set.

Key stakeholders were consulted to inform the data collection exercise including representatives from the Buckland Development, HDNU and Fareham Borough Council, as discussed in section 2.2.1.

2.1 Network Assessment Area

The Welborne network area was reviewed to identify areas where it could be extended. However, no significant additional heat loads were identified, and the assessment area was not changed, as shown in Figure 1.

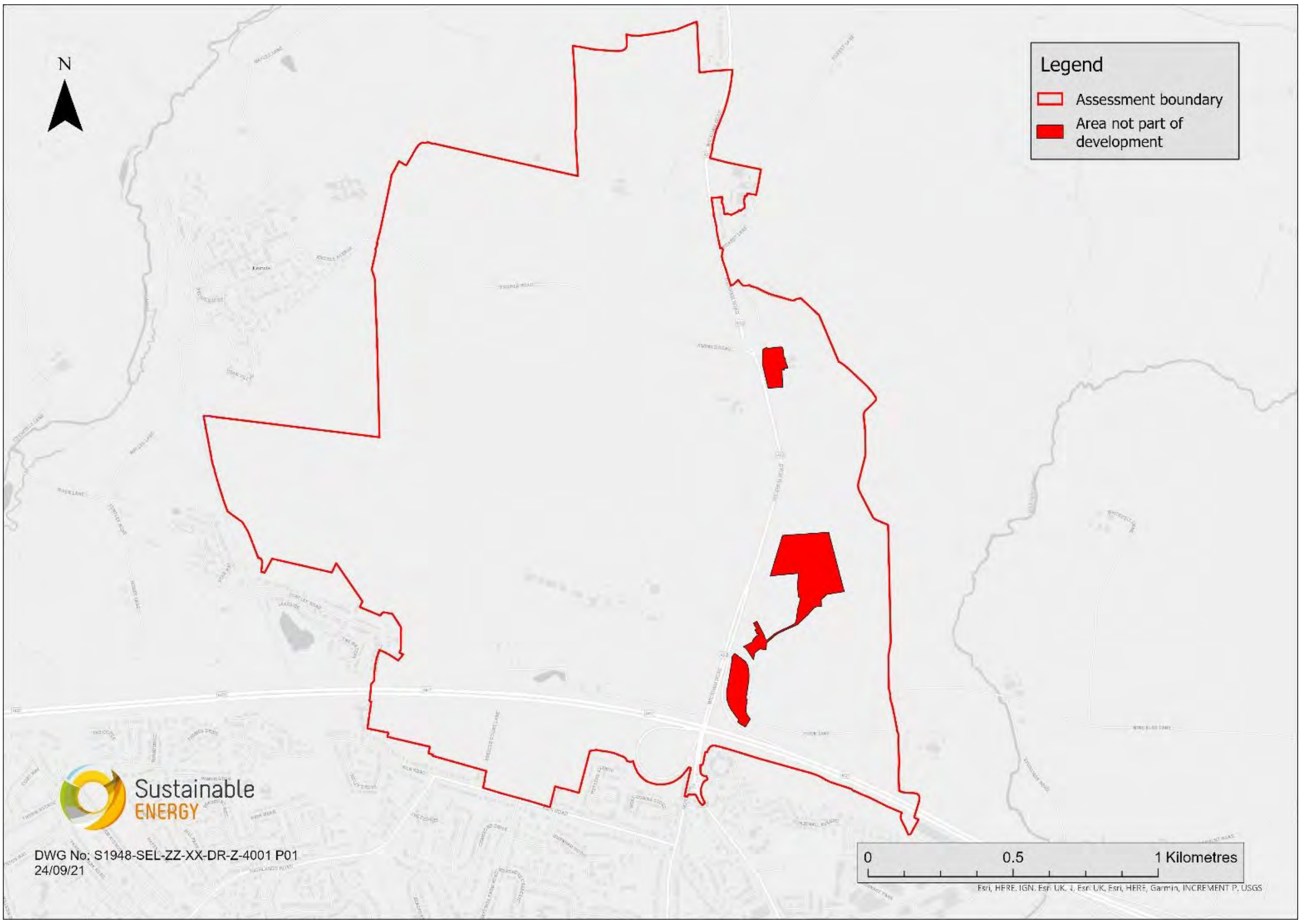


Figure 1: Network assessment area boundary

2.2 Identification of Potential Customers

There are risks associated with energy mapping and basing network assumptions around planned developments such as changes to the density, scale and timing of planned developments. Buckland Development is the master developer for Welborne Garden Village, and it plans to use several local housing developers to construct the various sections of the village. As a result, there is a greater risk associated with the timing of the developments than if they were all built by the same developer.

Figure 2 shows the planned developments (further details are shown in Table 1).

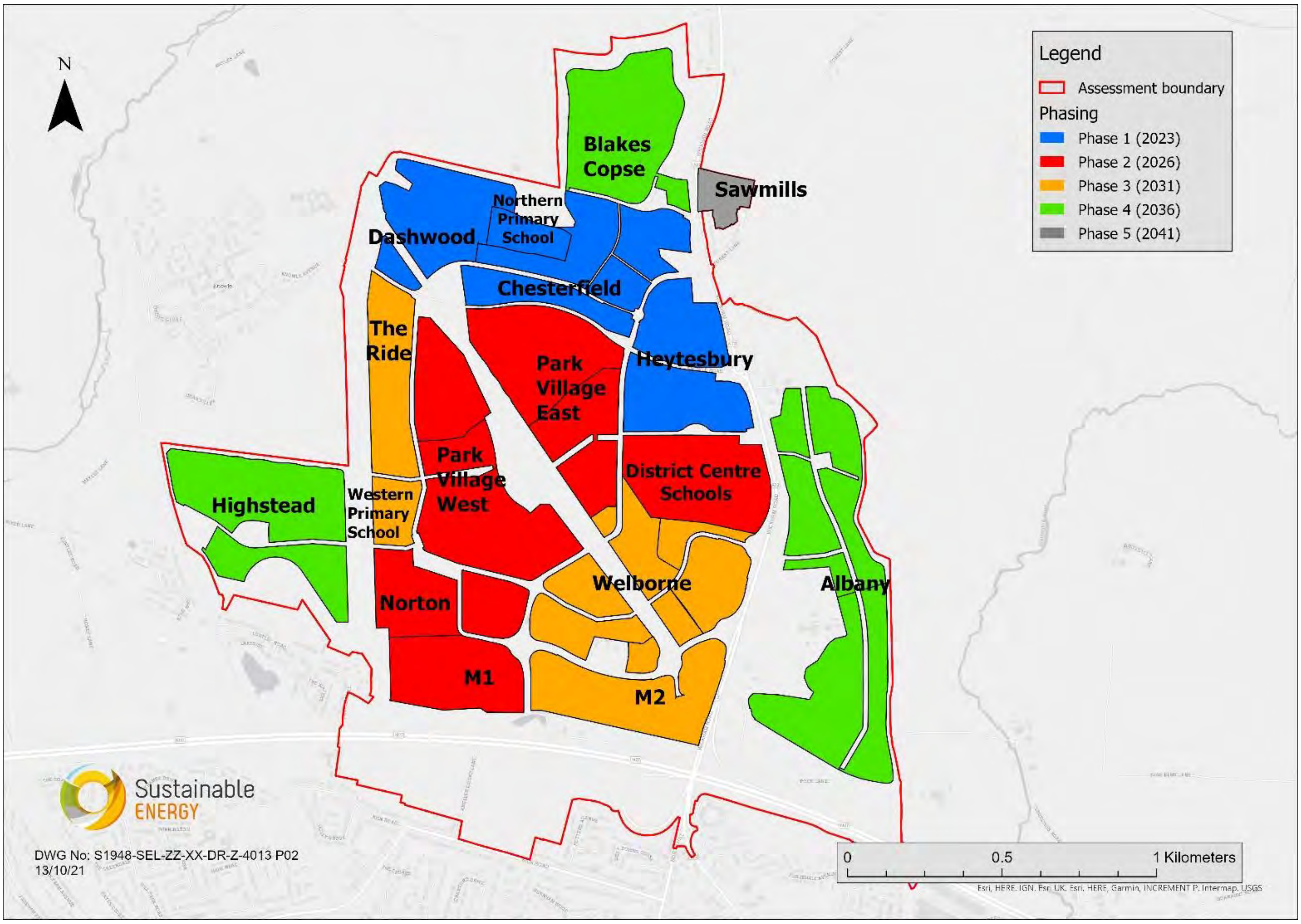


Figure 2: Welborne Garden Village development parcels

Table 1: Current information for planned developments

Parcel Name	Residential	Commercial	Timing
Heytesbury	• 548 residential units	-	2023
Dashwood	• 406 residential units	-	2023
Chesterfield	• 384 residential units	• 4,124 m^2 of shops, offices, hairdressers, GP, cafes, hotel	2023
Northern Primary School	-	• 3, 570 m^2	2023
Park Village East	• 699 residential units	-	2026

Parcel Name	Residential	Commercial	Timing
Park Village West	• 761 residential units	• 281 m^2 office space • 1,352 m^2 shops • 368 m^2 restaurants • 150 m^2 fast food • 550 m^2 nursery	2026
Norton	• 322 residential units	• 263 m^2 shops • 72 m^2 restaurants • 550 m^2 nursery	2026
District Centre Primary School	-	• 3,570 m^2	2026
District Centre Secondary School	-	• 13,191 m^2	2026
M1	-	• 12,455 m^2 office space • 14,986 m^2 industrial space • 17,127 m^2 warehouses	2026
Welborne	• 846 residential units	• 758 m^2 of office space • 4,352 m^2 shops • 1,185 m^2 restaurants • 1,877 m^2 healthcare • 1,100 m^2 nursery	2031
The Ride	• 245 residential units	-	2031
Western Primary School	-	• 3,770 m^2	2031
M2	-	• 16,632 m^2 office space • 20,014 m^2 industrial space • 22,873 m^2 warehouses	2031
Highstead	• 520 residential units	-	2036
Blakes Copse	• 418 residential units	-	2036
Albany	• 794 residential units	-	2036
Sawmills	• 57 residential units	-	2041

2.2.1 Engagement with Potential Key Stakeholders

We contacted stakeholders to obtain information such as development plans, energy data and tariffs, building use and occupancy levels and patterns. Information requests were presented to stakeholders by email and followed up with meetings and calls.

A summary of information received from the data collection exercise for potential key network customers can be seen in Table 2.

Table 2: Summary of engagement with key stakeholders

Contact	Site/Organisation	Notes
Paul Stewart	Buckland Development	• Technical Director
Warren Cann	Buckland Development	• Investment Director
Sarah Ward	Fareham Borough Council	• Welborne Strategic Lead
John Pickford	Portsmouth Water	• Commercial Director
Tharina Conradie	BEIS	• Heat Network Specialist

3 ENERGY DEMAND ASSESMENT

3.1 Energy Demand Profiles

Energy demands and profiles for the development cells were modelled to consider Objective 2.1 of the CIBSE / ADE Heat Networks Code of Practice (to achieve sufficient accuracy of peak heat demands and annual heat consumptions) and comply with Part L of the relevant Building Regulations and the Future Homes Standard (FHS). Hourly annual energy demand profiles were generated using in-house modelling software which apportions demands to hourly loads over the year and considers degree day data[1], building use and occupancy. Peak, base load, seasonal and annual heat demands were then identified, categorised, and mapped.

For domestic properties the overall site buildout plan has not yet been set. However, there are building layouts available for the first phase of the project. A heat demand model was created for each type of property within phase one and the weighted average calculate. It was assumed that the rest of the site would have a similar layout and therefore this weighted average has been used for the future phases of the development.

Hourly cooling profiles for planned developments were also modelled. It was assumed that buildings are cooled for comfort condition to a temperature of 20 °C. To normalise cooling demands, degree day data from the nearest monitoring station (Thorney Island) was used. Peak, base load, seasonal, and annual cooling demands were then identified.

Data derived from hundreds of in-house data collection exercises for similar buildings was utilised and a demand profile for the building was constructed using in-house software or selected from our profile database as appropriate.

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

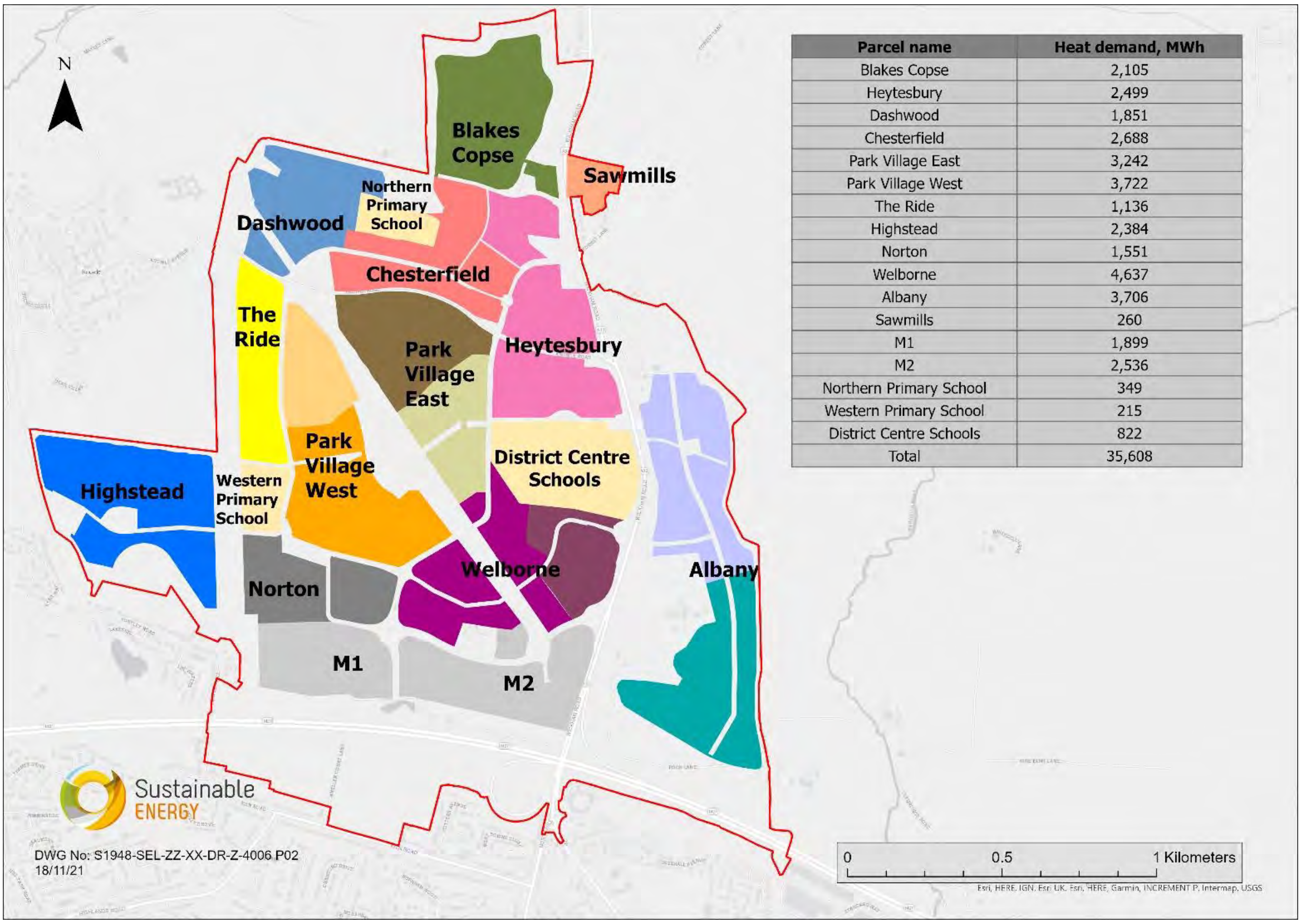
3.2 Energy Demand Assessment Results

Geographic Information System (GIS) software was used to map the key heat, electricity and cooling demands for the Welborne area. The assessment area has been split according to parcel arrangement and legend shows individual demands per parcel. Individual heat, electricity and cooling demands can be found in Appendix 1: Energy Demand Assessment.

[1] Degree days are a type of weather data calculated from outside air temperature readings. Heating degree days and cooling degree days are used extensively in calculations relating to building energy consumption. They are used to determine the heating requirements of buildings, representing a fall of one degree below a specified average outdoor temperature (15.5 °C) for one day.

3.2.1 Heat Demand

Heat demands are shown in Figure 3. The total demand is estimated to be 35,608 MWh. The largest heat demand arises from Welborne parcel (4,637 MWh) which includes residential and commercial buildings.



Parcel name	Heat demand, MWh
Blakes Copse	2,105
Heytesbury	2,499
Dashwood	1,851
Chesterfield	2,688
Park Village East	3,242
Park Village West	3,722
The Ride	1,136
Highstead	2,384
Norton	1,551
Welborne	4,637
Albany	3,706
Sawmills	260
M1	1,899
M2	2,536
Northern Primary School	349
Western Primary School	215
District Centre Schools	822
Total	35,608

Figure 3: Parcel heat demand map

Figure 4 shows the heat demand of each parcel and the distribution across the phases of development.

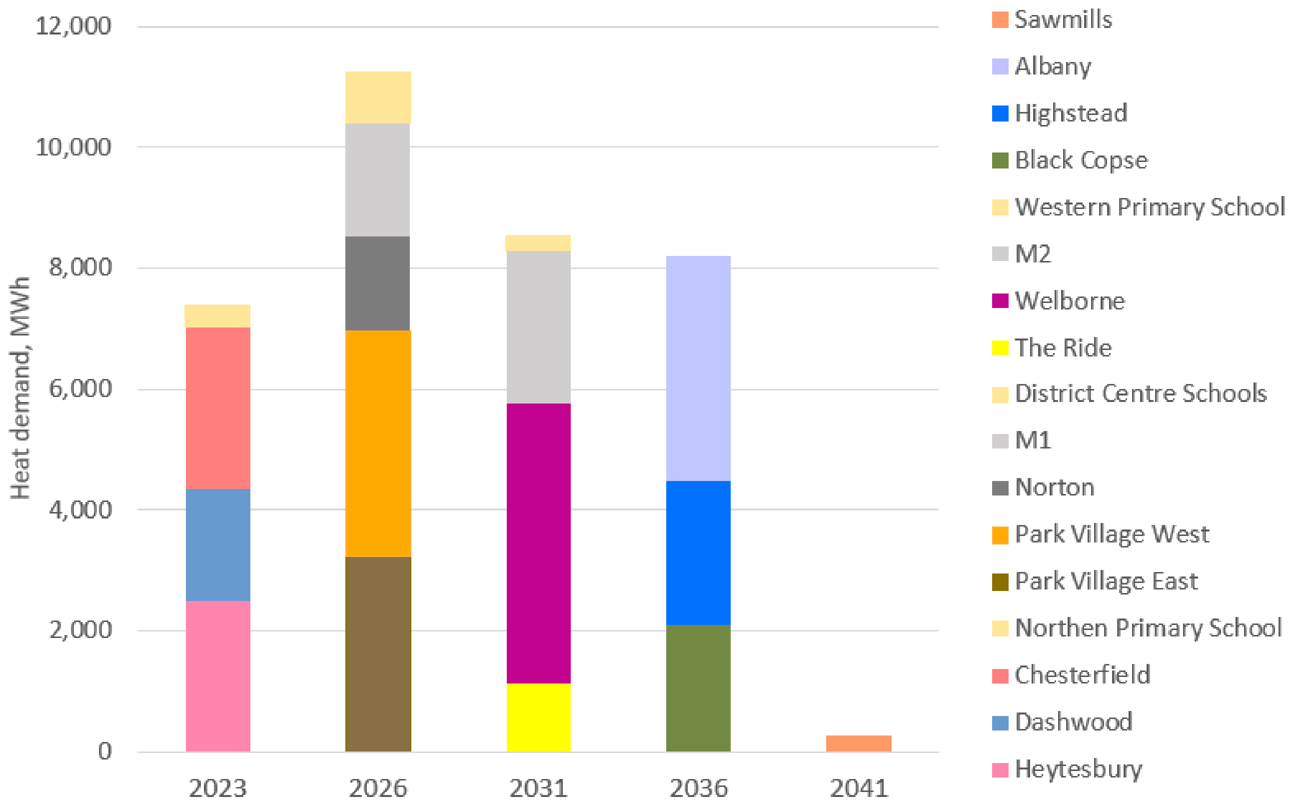


Figure 4: Parcel heat demands per development phase

Figure 5 shows the cumulative peak heat demand for the development.

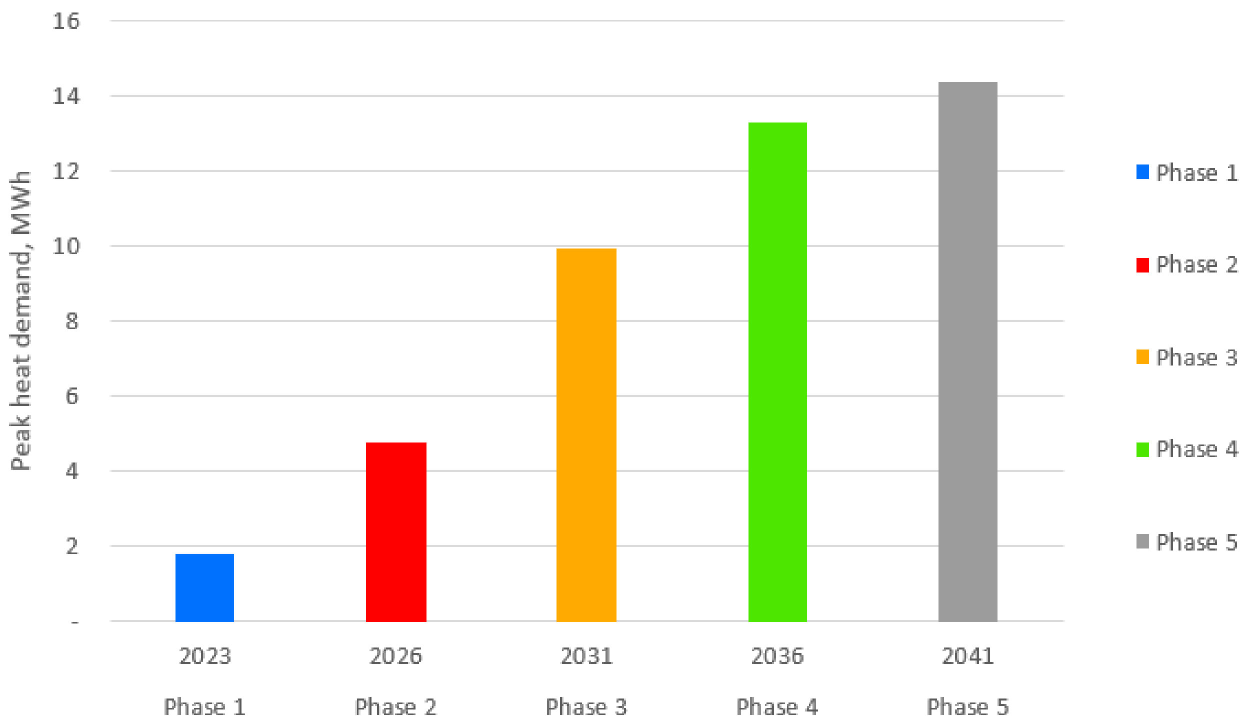
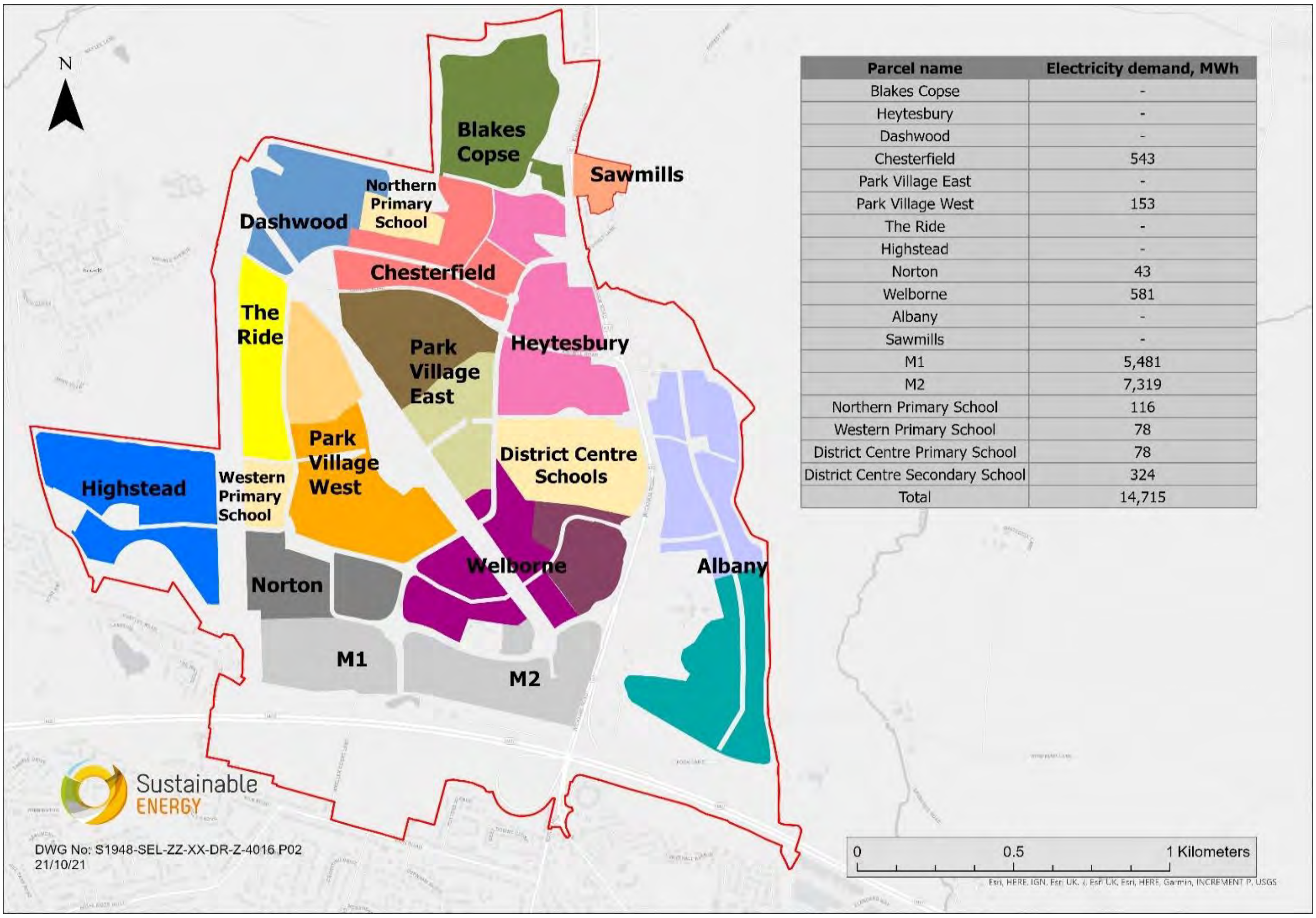


Figure 5: Cumulative peak heat demand

3.2.2 Commercial Electricity Demands

Commercial electricity demands (not including decentralised heat pumps) are shown in Figure 6. The largest electricity demands arise from parcel M2 and M1 which have large area of warehouses and industrial use.

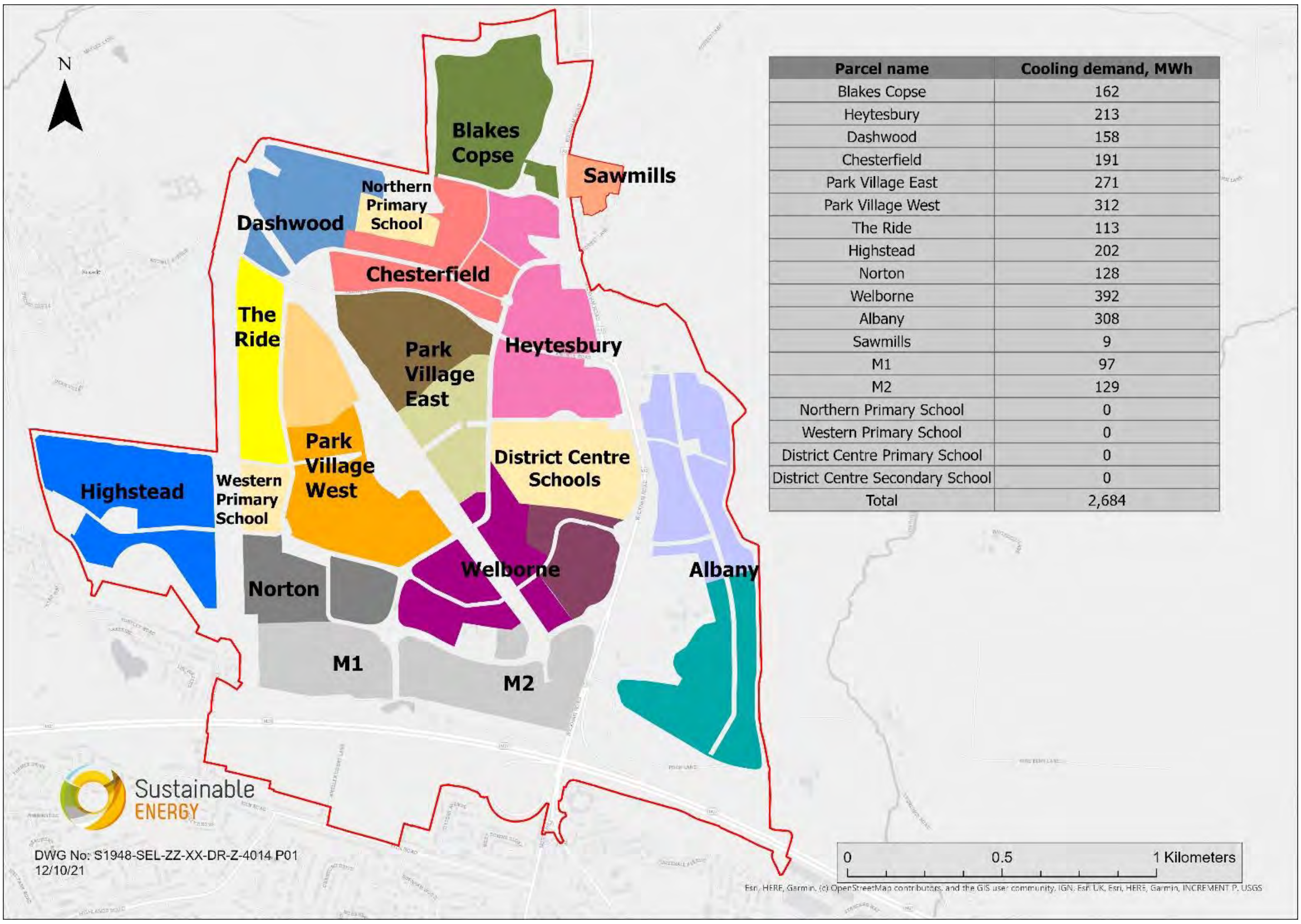


Parcel name	Electricity demand, MWh
Blakes Copse	-
Heytesbury	-
Dashwood	-
Chesterfield	543
Park Village East	-
Park Village West	153
The Ride	-
Highstead	-
Norton	43
Welborne	581
Albany	-
Sawmills	-
M1	5,481
M2	7,319
Northern Primary School	116
Western Primary School	78
District Centre Primary School	78
District Centre Secondary School	324
Total	14,715

Figure 6: Commercial electricity demand map by parcel

3.2.3 Cooling Demands

The total cooling demand is approximately 2,684 MWh. The cooling demands for all sites are shown in Figure 7. The largest cooling demand is attributed to the Welborne parcel (392 MWh).



Parcel name	Cooling demand, MWh
Blakes Copse	162
Heytesbury	213
Dashwood	158
Chesterfield	191
Park Village East	271
Park Village West	312
The Ride	113
Highstead	202
Norton	128
Welborne	392
Albany	308
Sawmills	9
M1	97
M2	129
Northern Primary School	0
Western Primary School	0
District Centre Primary School	0
District Centre Secondary School	0
Total	2,684

Figure 7: Parcel cooling demand map

Figure 8 shows the cooling demand of each parcel and the distribution across the phases of the development.

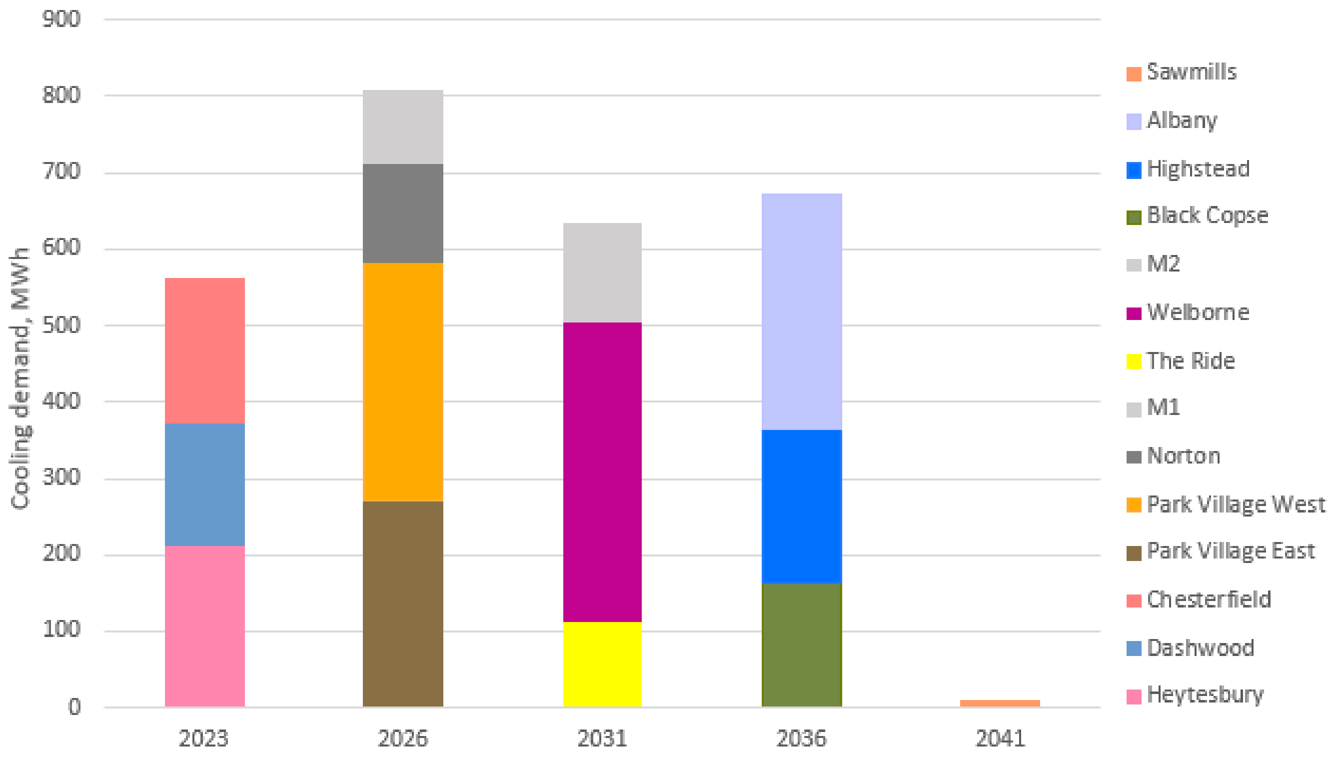


Figure 8: Parcel cooling demands per development phase

Figure 9 shows the cumulative peak cooling demand for the development.

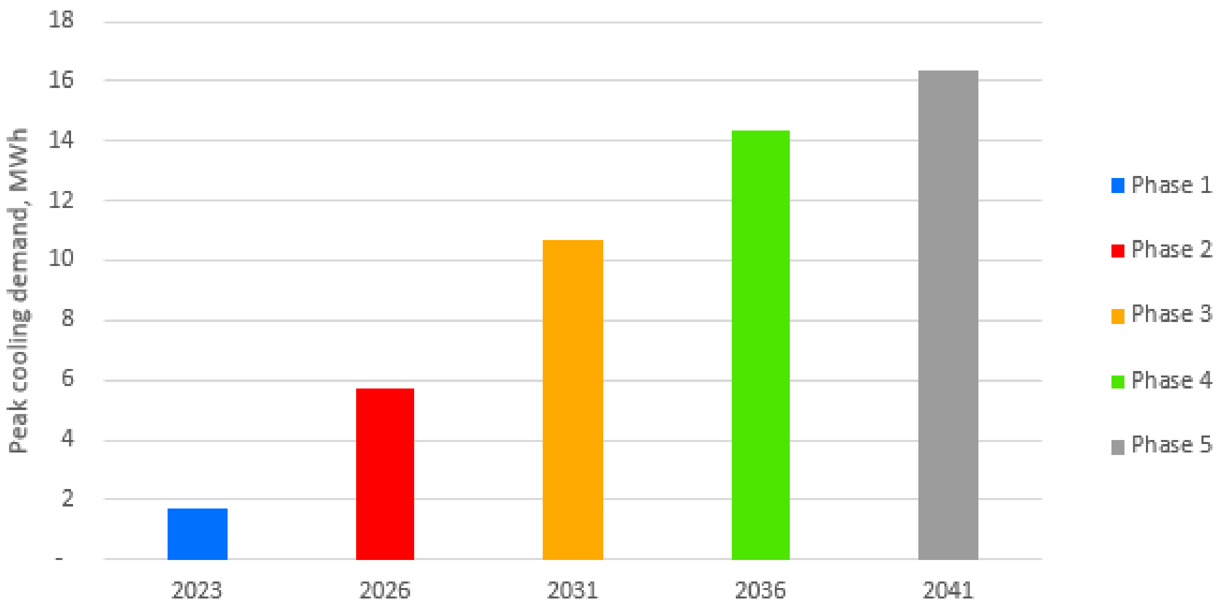


Figure 9: Cumulative peak cooling demand

3.3 Summary

For the domestic properties, the average annual heating demand per dwelling was estimated to be 4543 kWh and average annual cooling demand per dwelling was estimated to be 386 kWh. Figure 10 shows total demand categorisation for the development.

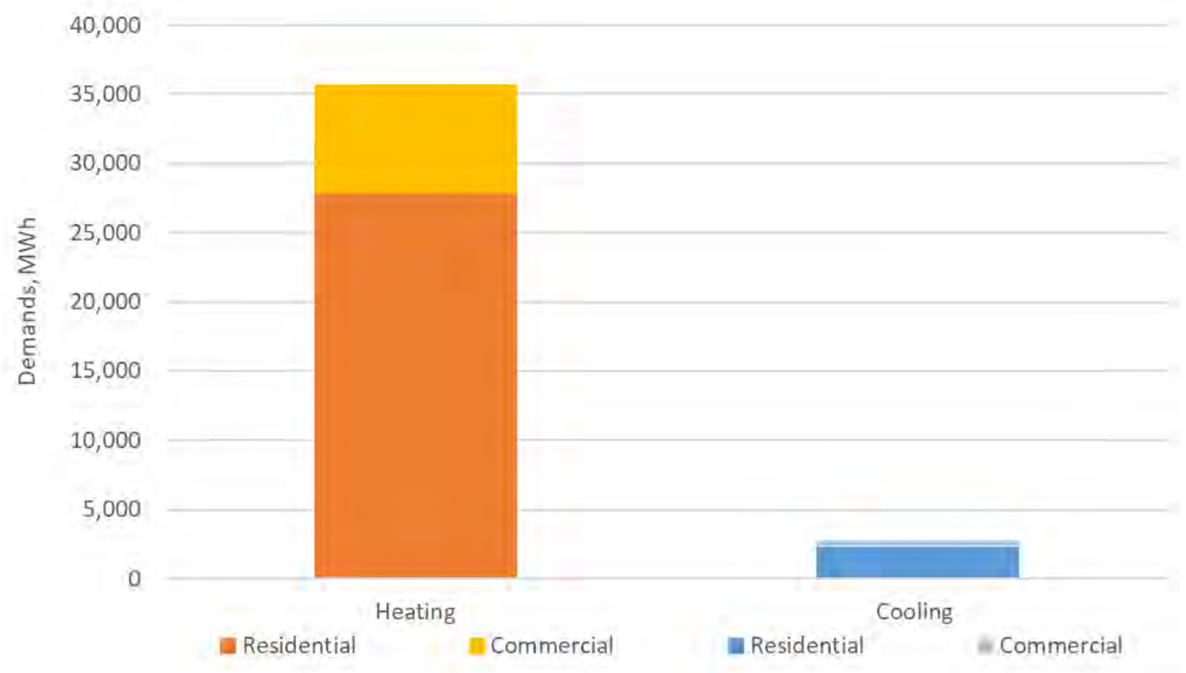


Figure 10: Energy demand categorisation

Most of the heat demand is attributed to residential use and heat demand is far greater than cooling demand. The heating and cooling demand profiles for the development are shown in Figure 11.

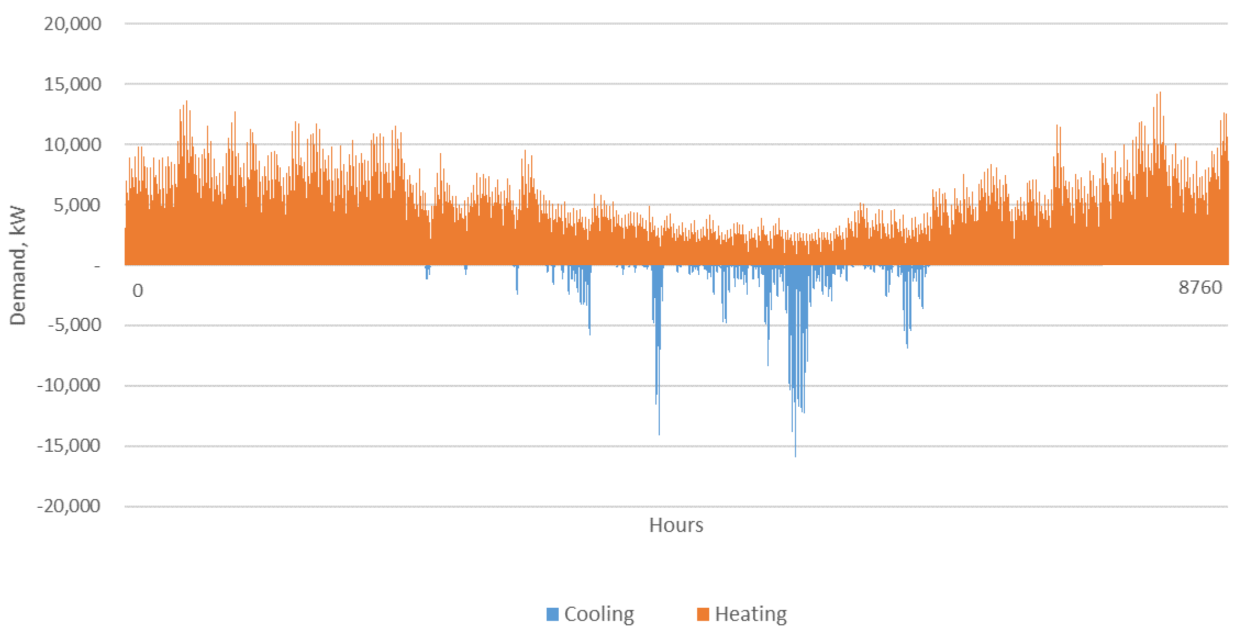


Figure 11: Heating and cooling demand of the development

The profiles were developed based on the assumption that people will heat their houses to 21 °C and cool to 20 °C.

Figure 12 shows net demands, note that there is very little opportunity for load sharing. Cooling to 18 °C instead of 20 °C in residential units would increase current cooling peaks because consumers tend to turn cooling on at the same time - when it is hot outside - and therefore the load sharing opportunity would still remain low.

The possibility of load sharing would increase if commercial demand which requires significant cooling, during winter months (when residential units require the most heating) was connected to the network. However, this will also increase cooling peak demand during the summer months, therefore if more information on the commercial cooling demands is available the heat demand assessment should be revisited.

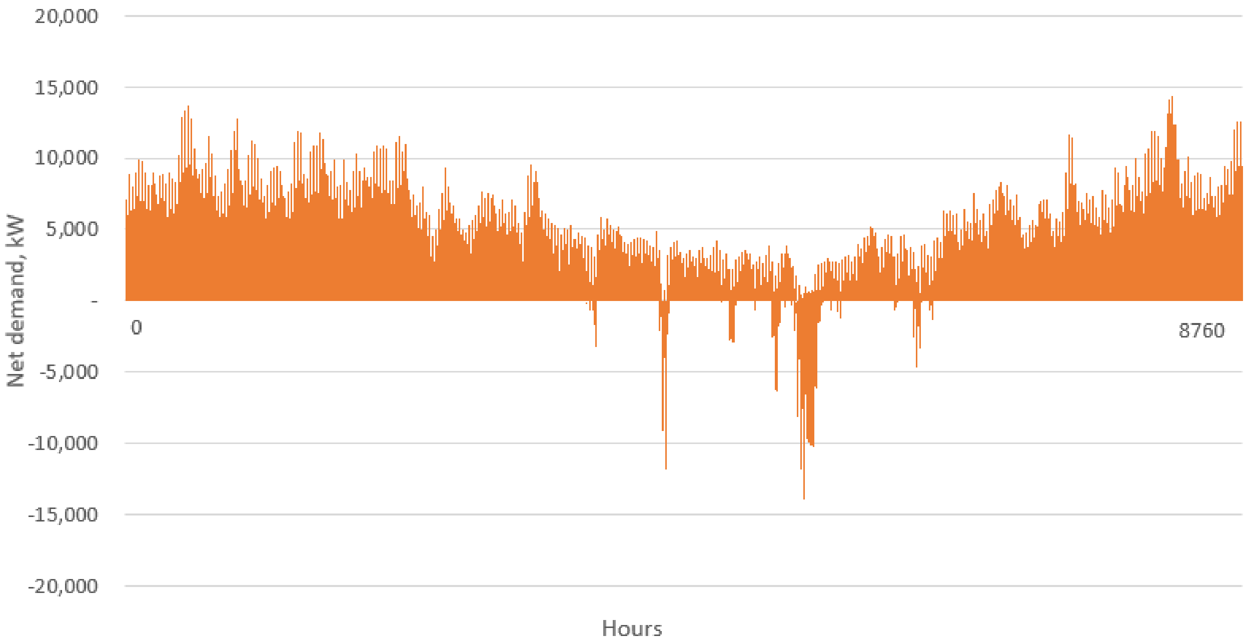


Figure 12: Net demand

4 ENERGY SOURCE ASSESSMENT

Potential renewable energy sources within or near the network assessment area were assessed to identify those with potential to supply an energy network.

4.1 Existing and Planned Energy Sources

The identified existing and potential energy sources are shown in Figure 13 and Table 3. Detailed borehole assessment can be found in Appendix 2: Technology Options Assessment.

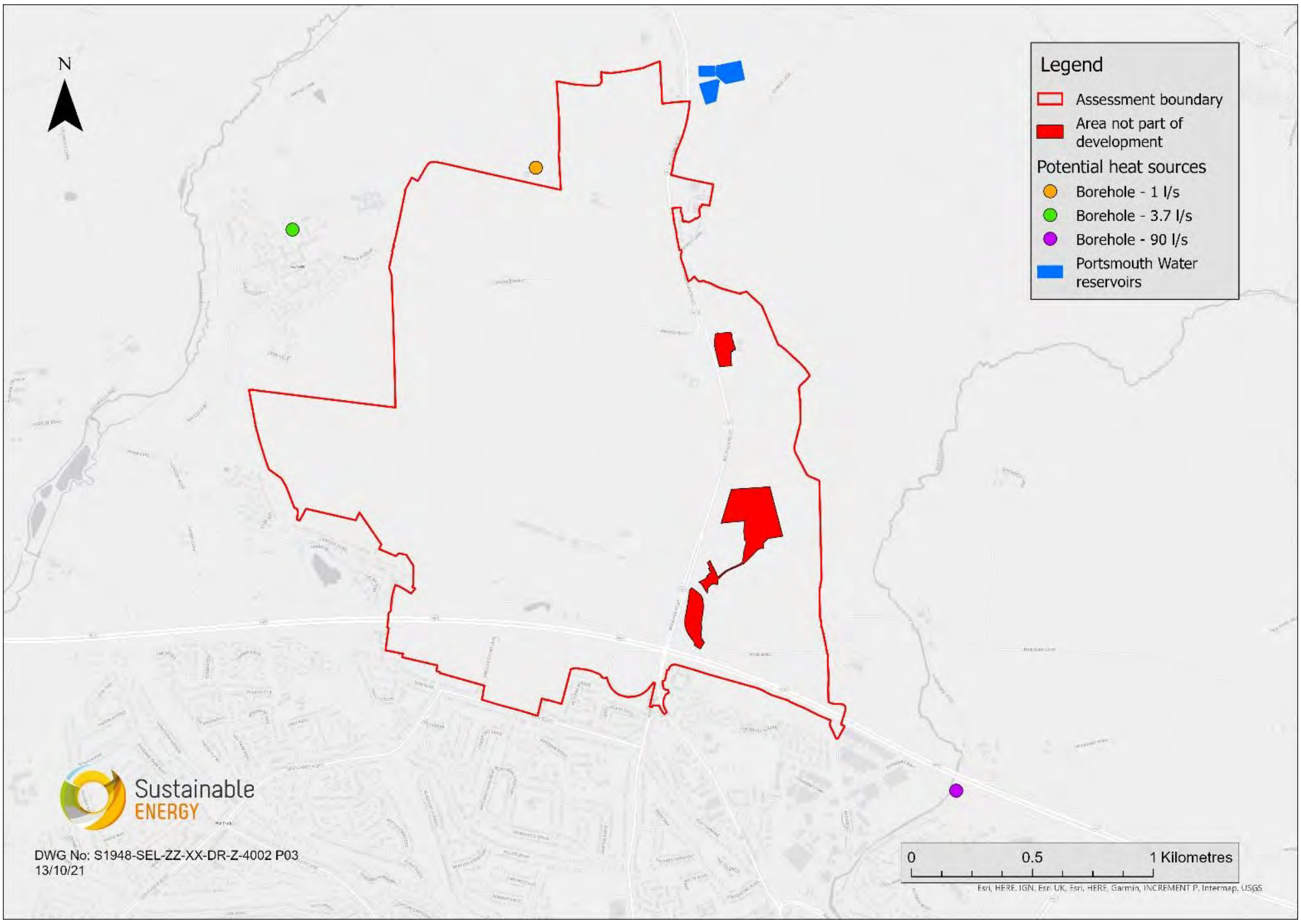


Figure 13: Potential heat source locations

Table 3: Potential water sources

Potential water source	Flowrate	dT	Potential capacity kW	Status	Details
Portsmouth Water reservoir	400 l/s	4	6,815	Existing	• Max. temp at ~16°C above which there will be an issue with dissolved chlorine and the quality of available drinking water • Return temperatures to Hoads Hill reservoirs to be agreed with Portsmouth Water as decreasing temperature increases likelihood of burst water pipes
Heytesbury Farm borehole	1 l/s	4	17	Existing	• Very low flowrate

Potential water source	Flowrate	dT	Potential capacity kW	Status	Details
					• Water depth, 33.45m • Depth 120.6 m
Knowle Hospital borehole	3.7 l/s	4	63	Existing	• Very low flowrate • Water depth, 34.74 m • Depth 30.48 m
Maindell borehole	90 l/s	4	1,533	Existing	• There is currently a pipework running from this borehole to Portsmouth Water reservoir • Water depth, 8.1 m • Depth 30.3 m

4.2 Potential Energy Centre Locations

Potential energy centre locations are shown in Figure 14 and summarised in Table 4. These are located to the north south of the Welborne Garden Village demand assessment boundary, and near the Portsmouth Water reservoirs.

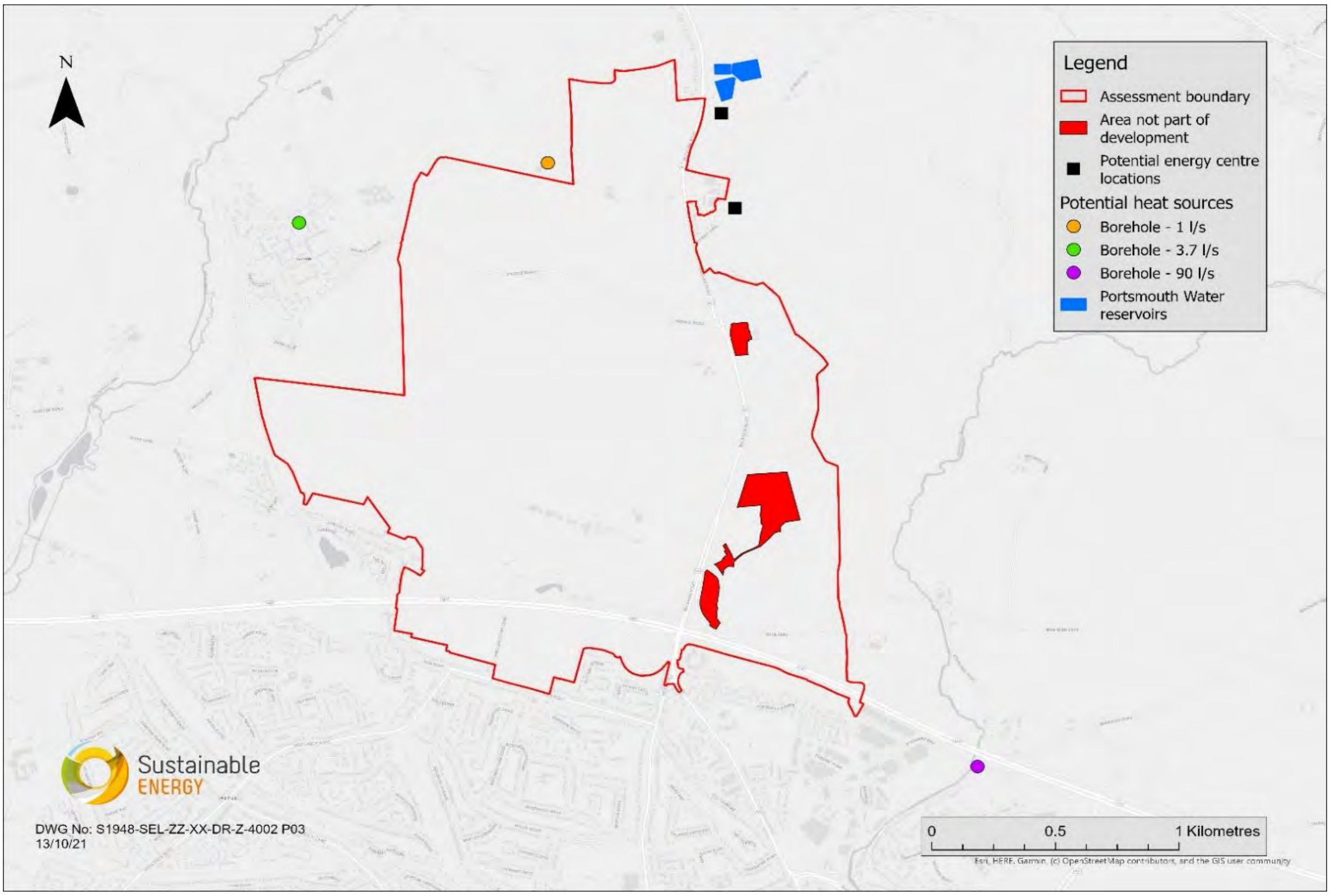


Figure 14: Potential energy centre locations

Table 4: Potential energy centre locations

Location	Land ownership	Comments	Prioritised site
Land by Hoads Hill reservoirs	Southwick Estate	• Greenfield	Yes
Land by Crockerhill		• Greenfield	No

4.3 Renewable/ Low Carbon Heat Source

Table 5 shows the long list of options for potential heat sources as well as different network options.

Table 5: Long list options for potential heat sources

	Technology	High level technical viability considerations	Considered further?
Sitewide LTHW	WSHP using reservoir	• Portsmouth Water Reservoir is potential water source • Return temperatures to Hoads Hill reservoirs to be agreed with Portsmouth Water as decreasing temperature increases likelihood of burst water pipes • Approximately 400 l/s of water available from Hoads Hill Reservoirs	Yes
	GSHP utilising chalk aquifer	• Site may lay within a favourable area for open loop[2] GSHP • Yields uncertain therefore high risk – boreholes in immediate area ~3.7 l/s. • Maindell borehole previous extraction capacity was 90 l/s but is located 2.5km from phase 1 heat demands • Additional CAPEX associated with abstraction infrastructure • Test well required to establish viability	No
	Deep geothermal	• Welborne has a relatively low geothermal[3] potential of rock (approximately 40-60 mW/m²) • Welborne is located within Hampshire basin that has 37°C/km • Significant space requirements • Borehole CAPEX will have significant impact on economics • Significant risk posed by very hot fluids at high pressure, which are difficult to control while drilling geothermal wells	No
	Mine WSHP	• No previous mine workings in the assessment area	No
	ASHP	• Lower initial CAPEX than GSHP or WSHP, however higher operating costs due to lower seasonal CoP • Potential noise restrictions close to residential developments • ASHP at large scale may have cooling effect on local environment	Yes
	Space heating only LTHW network with DHW heat pumps	• Heat source same as sitewide LTHW networks • LTHW option providing space heating only • Lower demand will significantly decrease the capacity of HPs required in the EC • Reduced heat sales income as demand has lowered • Space required within each dwelling for DHW heat pump • Higher CAPEX for building DHW systems • Cooling can be provided via hot water production during summer	No
Sitewide ambient	Open loop network using reservoir	• Ambient loop requires larger pipe in comparison to LTHW • Portsmouth Water Reservoir is a potential water source • Return temperatures to Hoads Hill reservoirs to be agreed with Portsmouth Water as decreasing temperature increases likelihood of burst water pipes but on ambient loop is unlikely to drop the temperature significantly • Average throughput through the reservoir is 400 l/s	Yes

[2] Open loop GSHP refers to systems that exchange heat with subsurface water, and therefore require the existence of aquifers, rivers, docks or gravel water

[3] http://www.bgs.ac.uk/research/energy/geothermal/

	Technology	High level technical viability considerations	Considered further?
		• HP and DHW storage tank need to be situated in each building	
	Open loop network using boreholes	• Ambient loop requires larger pipe in comparison to LTHW • Borehole yields uncertain therefore high risk – boreholes in immediate area ~3.7 l/s. • Maindell borehole previous extraction capacity was 90 l/s but is located 2.5km from phase 1 heat demands • Test well required to establish viability • Smaller energy centre with pumps and heat exchangers will be required • Low onsite cooling requirement • HP and DHW storage tank need to be situated in each building	No
	Closed loop using boreholes	• Significant land requirement for borefield • 45km of boreholes required • Borefield CAPEX will have significant impact on economics • Ambient loop requires larger pipe in comparison to LTHW • Low onsite cooling requirement • HP and DHW storage tank need to be situated in each building	No
Cluster ambient	Closed loop using boreholes	• Economics unaffected by development phasing • Series of boreholes would be developed near the heat demands • HP and DHW storage tank need to be situated in each building • Ambient loop requires larger pipe in comparison to LTHW • Low onsite cooling requirement • Could be adapted to a sitewide ambient network in the future	Yes
Individual ASHPs		• Counterfactual scenario • ASHPs s efficiency will vary with air temperature • ASHP will be less efficient and have lower output in winter • Potentially higher heat cost to customers • Space required at each building • Heat demand is not diversified, and significantly greater heat pump capacity required • Potential opposition to ASHP near Village Centre (perceived visual and noise impact) • HP and DHW storage tank need to be situated in each building • External space required for outdoor unit	Yes
Gas CHP		• Higher carbon emissions compared to other technologies • Unlikely to be medium and long-term low carbon option	No
Electric boilers		• Expensive if used during peak electricity usage times • Possible price reduction per kWh in future	Yes, only as peak and reserve
Gas boilers		• High CO_2e • Potentially lower OPEX than electrode boilers	Yes, only peak and reserve

Technology	High level technical viability considerations	Considered further?
Biomass heating/CHP	• Air quality considerations for biomass • High cost of fuel compared to natural gas, however reduced carbon emissions • Unlikely to be sufficient space due to larger space requirements compared to other heat sources because of solid fuel delivery and storage • May cause congestion / environmental impact due to frequency of fuel deliveries • Sustainability of biomass dependent on availability of a local, reliable source of fuel • Not economic	No, due to limited space available, air quality and economic viability
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 d to be transported by road • Economic and regulatory issues relating to private wire • Fuel cell market not developed	No
EfW	• At the time of this study there are no planned energy from waste sites planned within a feasible distance	No
Industrial waste heat	• No industrial waste heat sources identified near or within the assessment area	No
Solar thermal	• Significant initial capital costs • Significant land required for collector arrays • Solar thermal in each household would only cover 40-60% of the demands of each individual and would require further heating systems alongside extra capital cost	No

4.3.1 Short list assessment

The short-listed options are:

LTHW Network Options

- Sitewide LTWH – WSHP using reservoir
- Sitewide LTHW – ASHP

Ambient Network Options

- Sitewide ambient – open loop network using reservoir
- Cluster ambient – closed loop using boreholes

Counterfactual

- Individual ASHPs

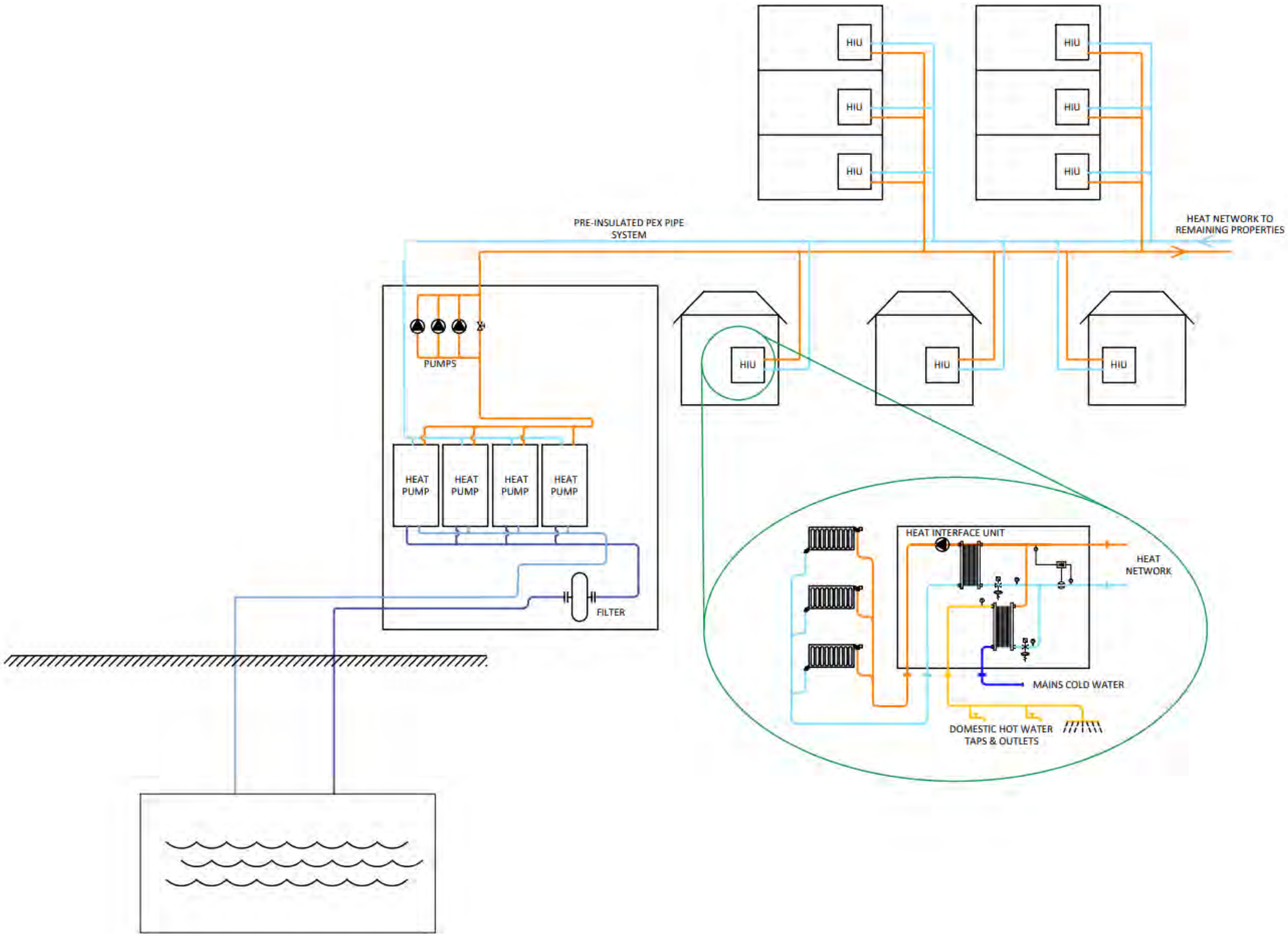


Figure 15: Schematic of LTHW WSHP network using reservoir as source

Table 6: Specific issues, risks, benefits and disbenefits for sitewide LTHW network with WSHP using reservoir

Short list option	Viability consideration		Risks	Benefits	Disbenefits
Sitewide LTWH – WSHP using reservoir	Technology selection	• Open loop • Water company engaged	Winter water temperatures, will decrease the COP of the HP and they will increase the chance of dropping water temperature below the permitted return temperature to the water company		
	Heat resource	• Hoads Hill Reservoirs • Temperature drop of the biggest reservoir of volume 33ML, at steady state is predicted to be 5.37 degrees		If correctly designed and modelled, temperature of heat resource likely to be stable and sustainable	
	Plant operation	• Heat generated from the WSHP will be prioritised with electric / gas boilers only supplying peak demands and in times of GSHP maintenance / failure		>90% of network heat demand can be delivered by WSHP	
	Energy Centre design	• Energy Centre would need to be build as close as possible to the Hoads Hill reservoir			
	Commercial	• Third party negotiations that may impact the cost of heat	Relying on Portsmouth Water assets Regulatory risk related to the EA permitting		Future certainty is not guaranteed
	Impact on the development	• A large building would be developed near the Village Centre		No disruption caused by drilling borefield	EC will have visual impact
	Noise	• Energy centre would be designed to ensure acceptable levels			

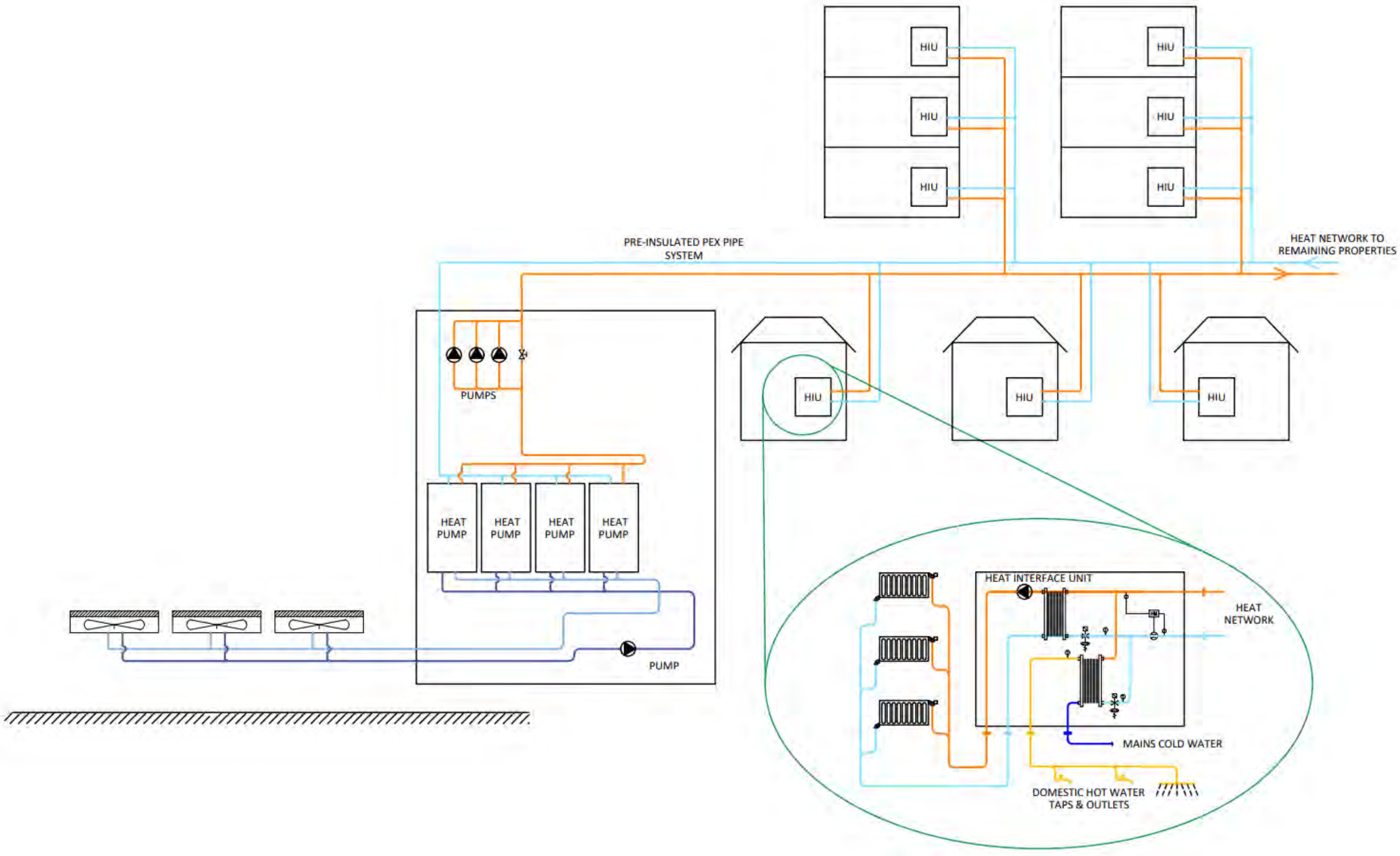


Figure 16: Schematic of sitewide LTHW ASHP network

Table 7: Specific issues, risks, benefits and disbenefits for sitewide LTHW ASHP network

Short list option	Viability consideration		Risks	Benefits	Disbenefits
Sitewide LTHW – ASHP	Technology selection	• Potentially low CAPEX option • ASHPs will be less efficient than the GSHPs; operating temperatures will be important and, as efficiency will vary with external air temperature, an ASHP will be less efficient in winter and have a lower output	Lower CoP will impact project economics, CO_2e savings and renewable heat availability during cold periods		
	Heat resource	• Heat output and project economics will be negatively impacted by external air temperature in cold winter periods • Potential opposition to ASHP near Village Centre (perceived visual and noise impact)		Not dependant on accessing ground water and so reduced project CAPEX and disruption	
	Plant operation	• Heat generated from the ASHP will be prioritised with gas boilers only supplying peak demands and in times of ASHP maintenance / failure		~90% of network heat demand will be from renewable technology	
	Energy centre design	• Additional space required for air heat exchangers • Acoustic attenuation will impact cost and efficiency			Will require larger EC
	Impact on the development	• A large building would be developed near the Village Centre		No disruption caused by drilling borefield	EC could have significant visual impact
	Noise	• Acoustic assessment and attenuation required	Acoustic attenuation will negatively impact CAPEX		

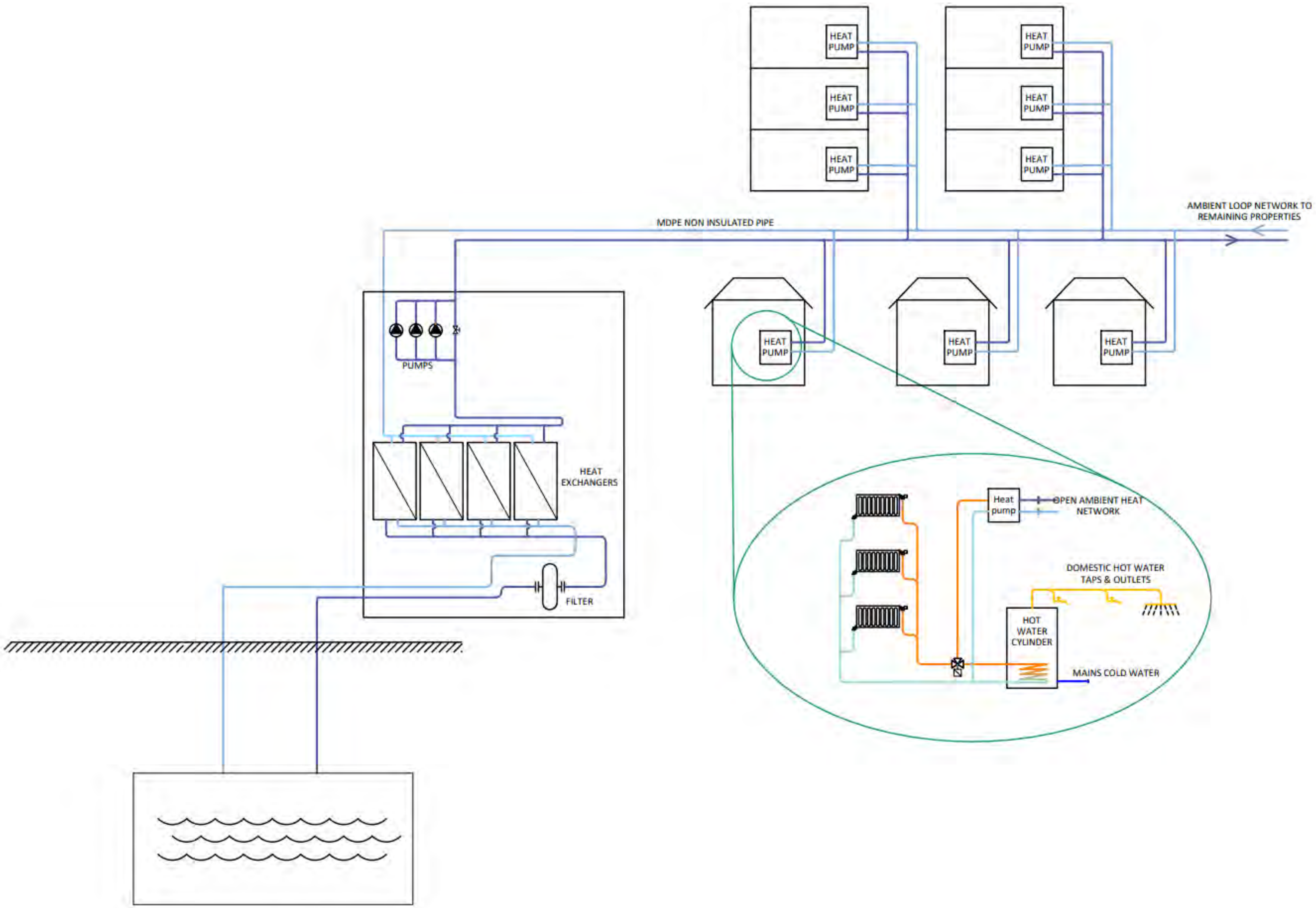
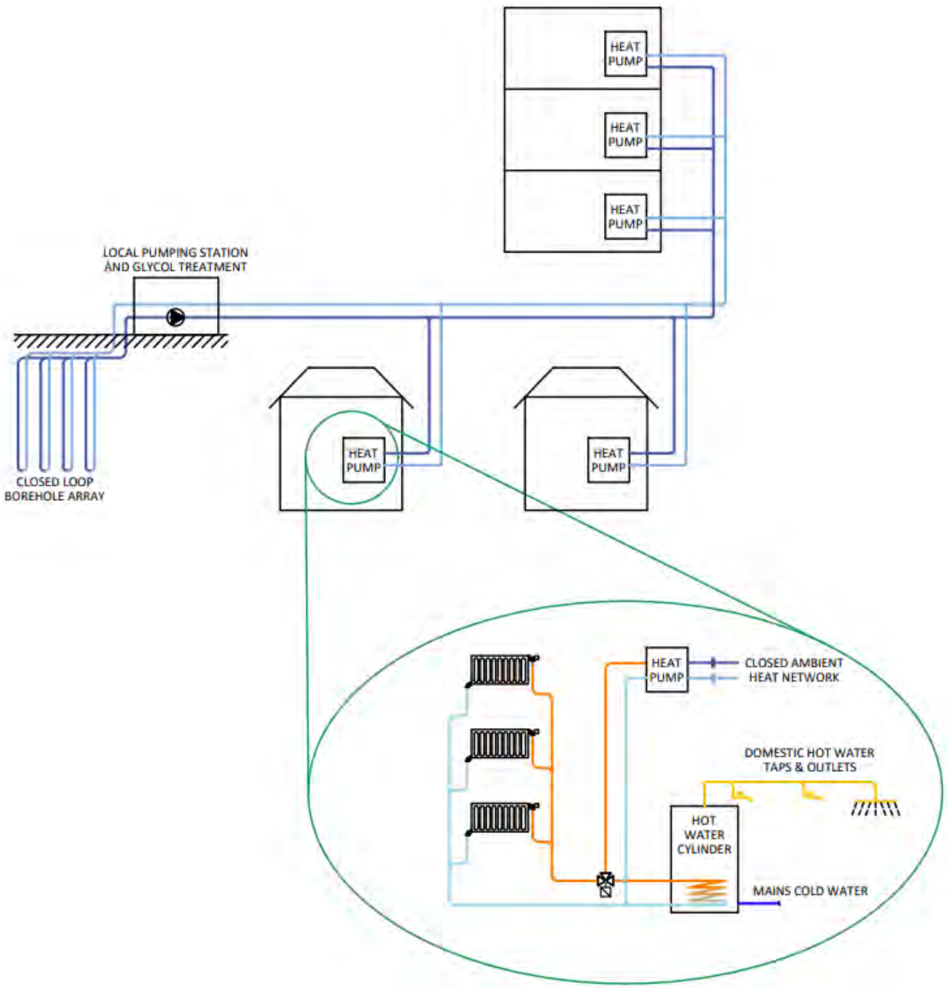


Figure 17: Schematic of sitewide ambient open loop network using reservoir

Table 8: Specific issues, risks, benefits and disbenefits for sitewide ambient open loop network using reservoir

Short list option	Viability consideration		Risks	Benefits	Disbenefits
Sitewide ambient – open loop network using reservoir	Technology selection	• Open loop • Water company engaged	Wi Winter water temperatures, will decrease the COP of the HP and they will increase the chance of dropping water temperature below the permitted return temperature to the water company		
	Heat resource	• Hoads Hill Reservoirs • Lower temperature drop of the reservoir is expected in comparison to LTHW		If correctly designed and modelled, temperature of heat resource likely to be stable and sustainable	
	Plant operation	• Ambient heat recovered from reservoir, only pumping cost and CAPEX to be considered • Higher GWP refrigerants may be used in smaller heat pumps		Higher COP for individual heat pumps, Lower energy centre CAPEX and OPEX	
	Commercial	• Third party negotiations that may impact the cost of heat	Relying on Portsmouth Water assets		Future certainty is not guaranteed
	Impact on the development	• GSHP in each building • Small pumping station and heat exchanger energy centre required near reservoir		Little visual and noise impact	Additional space required at each dwelling (internal for heat pump and hot water cylinder)



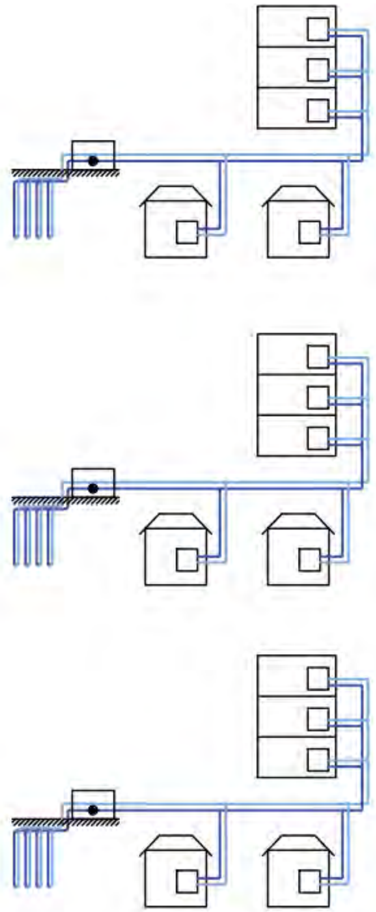


Figure 18: Schematic of cluster ambient closed loop using boreholes

Table 9: Specific issues, risks, benefits and disbenefits for cluster ambient closed loop using boreholes

Short list option	Viability consideration		Risks	Benefits	Disbenefits
Cluster ambient – closed loop using boreholes	Technology selection	• Potentially high CAPEX • The phasing of the development	Long term performance of boreholes	Economics unaffected by the development phasing	
	Heat resource	• Borefield • Borehole yields uncertain – test well required to confirm		If correctly designed and modelled, temperature of heat resource likely to be stable and sustainable	
	Plant operation	• Small network shared between multiple households • Small pumping station would be required for each cluster • Higher GWP refrigerants may be used in smaller heat pumps	Uncertainty around maintenance responsibility	100% of network heat demand can be delivered by GSHP	
	Impact on the development	• Series of wells would be developed near the Village Centre • GSHP needs to be placed in each house		No visual impact	Additional space required at each dwelling (internal for heat pump and hot water cylinder))

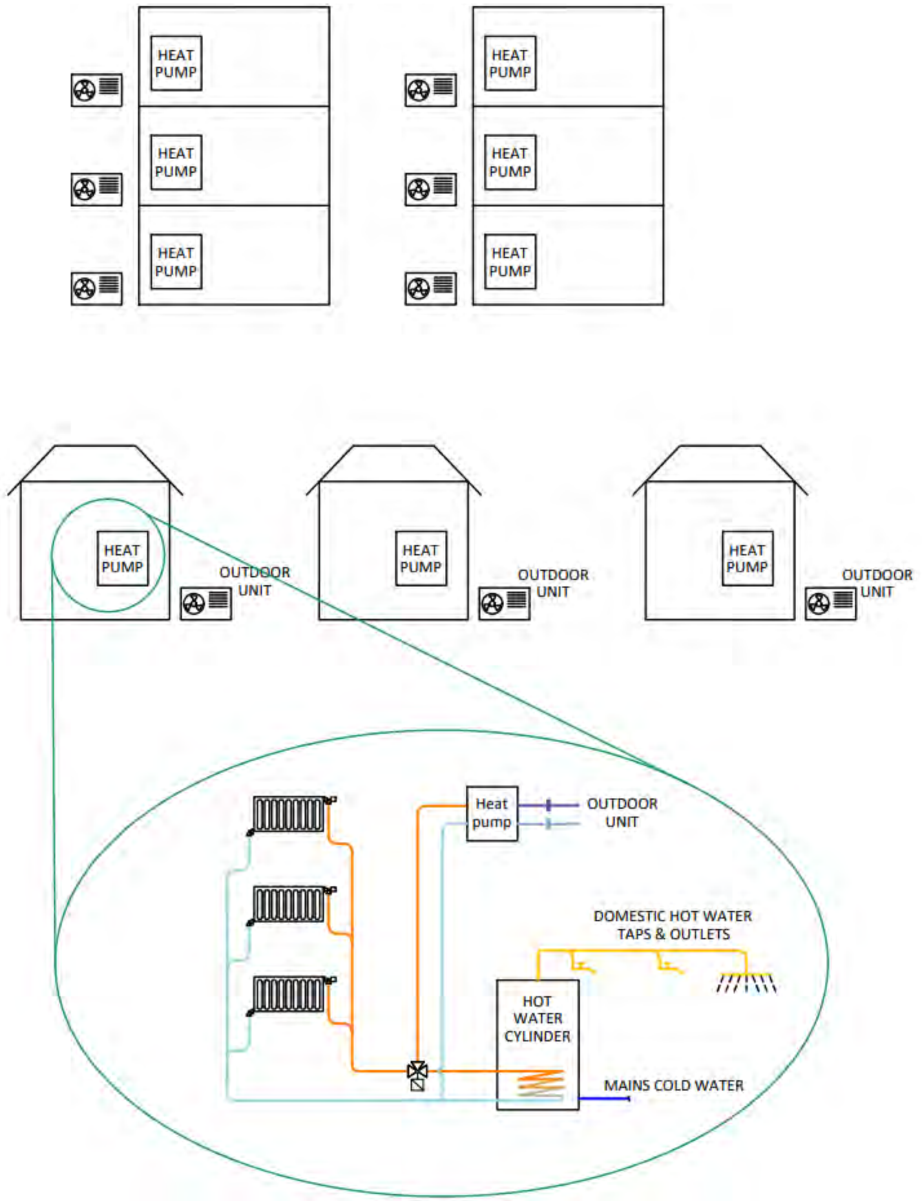


Figure 19: Individual ASHPs

Table 10: Specific issues, risks, benefits and disbenefits for individual ASHPs

Short list option	Viability consideration		Risks	Benefits	Disbenefits
Individual ASHPs	Technology selection	• Counterfactual • Potentially low risk option • ASHPs will be less efficient than the GSHPs; operating temperatures will be important and, as efficiency will vary with external air temperature, an ASHP will be less efficient in winter and have a lower output	Lower CoP will impact project economics, CO_2e savings and renewable heat availability during cold periods	Lower CAPEX	
	Heat Source	• Heat output and project economics will be negatively impacted by external air temperature in cold winter periods • Potential opposition to ASHP near Village Centre (perceived visual and noise impact)		Not dependant on accessing ground water and so reduced project CAPEX and disruption	
	Plant Operation	• Higher GWP refrigerants may be used in smaller heat pumps	May not be operated and maintained in most efficient manner	Potentially higher CO_2e savings if operated and maintained efficiently	
	Impact on the development	• Higher heat cost to customers • Space required at each building • Heat demand is not diversified, and significantly greater heat pump capacity required • Higher capacity electricity connections required for each dwelling		Not impacted by development build out rate or changes to development plans	Additional space required at each dwelling (external and internal for heat pump, DHW cylinder, buffer vessel and controls), significant grid reinforcement and distribution costs may be required
	Noise	• Acoustic assessment and attenuation required	Acoustic attenuation will negatively impact CAPEX		

4.4 Summary

A range of low carbon and renewable technologies have been assessed and the following options have been identified as potentially viable and will be assessed further:

- Sitewide LTHW network using Hoads Hill Reservoir and WSHPs
- Sitewide LTHW network using ASHPs
- Sitewide ambient network using Hoads Hill reservoir
- Cluster based ambient network using closed loop boreholes
- ASHPs in each dwelling

The sitewide LTHW networks will be able to provide all heating and hot water for the site from a single energy centre. The CoP associated with the ASHP option varies significantly throughout the year as the air temperature fluctuates. The ASHP CoP will be at its lowest during winter months, when the air temperature is at its lowest, which is also when network heat demands will be at their highest.

The temperature of Hoads Hill reservoir varies significantly less throughout the year, compared to air temperature, and WSHPs will therefore have a higher seasonal CoP. However, there is a temperature variation with the lowest temperature and therefore CoP again coinciding with the highest heat demands. Temperature data for the last 5 years has been received for the reservoir and is shown in Figure 20. Return temperatures to Hoads Hill reservoirs need to be agreed with Portsmouth Water as decreasing temperature increases likelihood of burst water pipes.

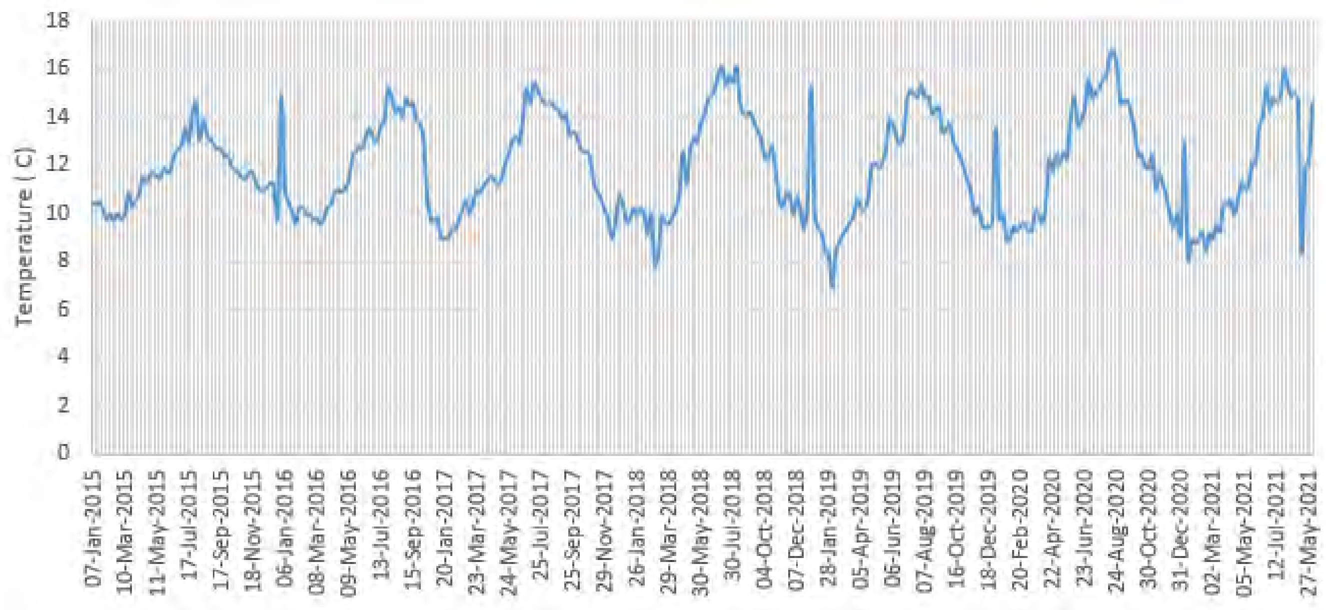


Figure 20: Hoads Hill Reservoir Temperatures 2015 – 2021

The scheme will also require peak and reserve gas-fired or electric boilers in LTHW network schemes for times of peak demand or when the renewable heating plant is not operational. The peak and reserve boilers could be located within an energy centre.

The option of extracting ground water was investigated. However, there is very little information on current extraction rates from boreholes in the area. The risk and CAPEX associated with drilling a test well, along with the additional CAPEX required for drilling the additional wells required by the scheme was deemed to be significant compared to other potential options, and so this has not been investigated further.

Ambient loops have been considered in both a sitewide and smaller cluster layouts and will be assessed further. The sitewide ambient network could potentially use the reservoir as a heat source and provides a greater opportunity for load sharing cooling and heating demand. However, due to the large heat demand and low temperature differences the ambient sitewide network will be significantly more expensive than an equivalent LTHW network.

Another option for further consideration is constructing separate ambient loops with closed loop boreholes within the different development clusters. Above ~300 homes, the diversity for space heating and hot water does not increase and therefore the demand on the ambient loop will rise proportionally after this limit and the number of boreholes per property does not increase. One of the major benefits of this solution is that the viability is less dependent on the overall build-out rate and can be deployed as and when properties are constructed.

5 NETWORK ROUTE ASSESSMENT

A potential network route has been identified based on the parcel schematics provided by Buckland Development. The key assumptions used for network route assessment can be found in Appendix 3: Network Assessment. The results of the economic assessment for thermal network and ambient cluster network is shown in section 6.2.5 and 6.3.3 respectively.

5.1 Sitewide Energy Network Route Identification

Site terrain and land ownership, as well as any potential natural and infrastructure constraints have been assessed. The proposed network spine route is shown in Figure 21. This is the route of the sitewide LTWH options as well as a sitewide ambient options.

The network spine route follows the indicative primary street network. This would allow installation of the main spine during initial construction work and will minimise disruption to existing infrastructure.

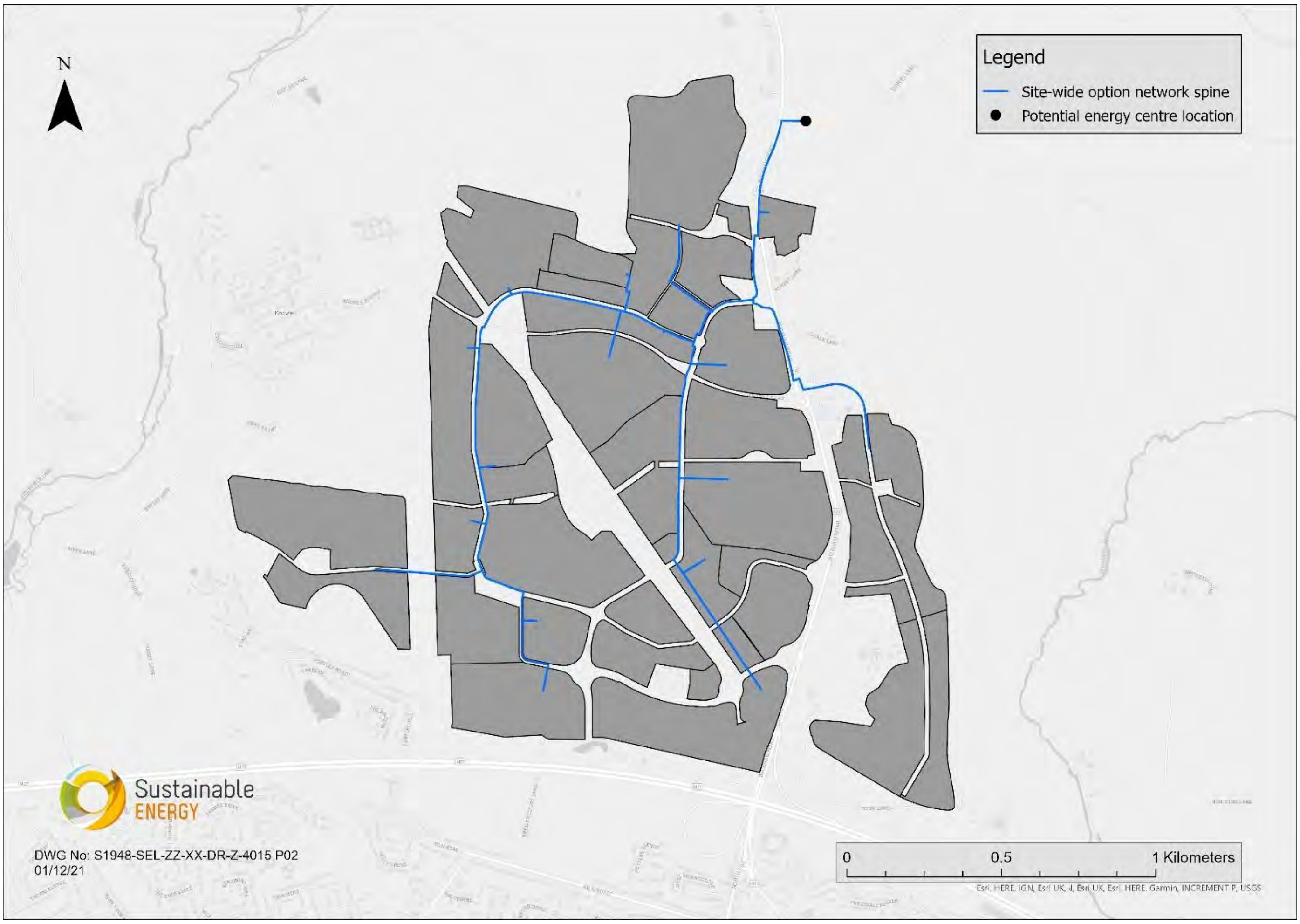


Figure 21: Proposed network spine

Figure 22 shows the proposed phase 1 network. Shared feed pipes connecting terraced and semi-detached dwellings have been used in modelling economic viability of all options to minimise network length, cost and heat losses.

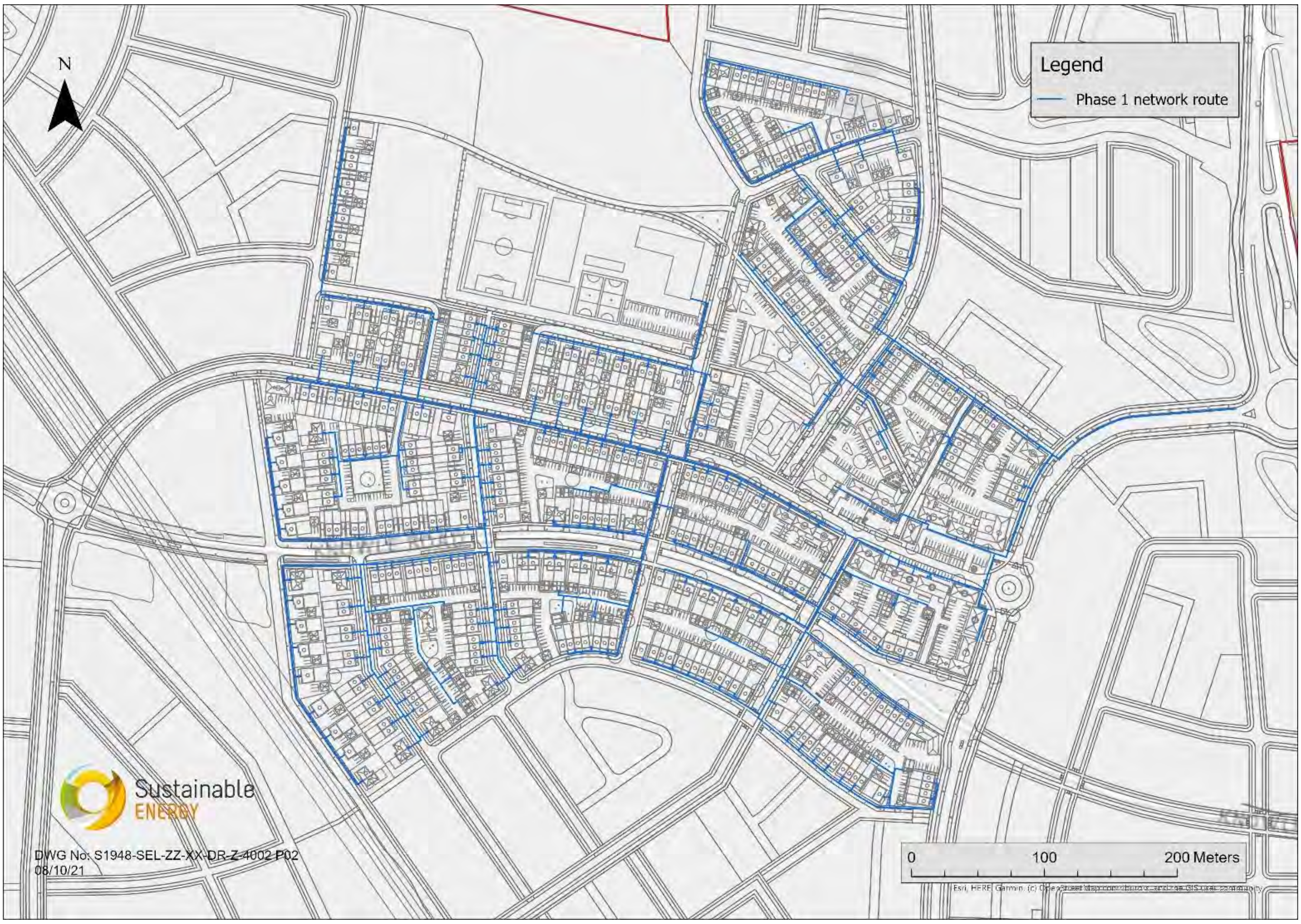


Figure 22: Proposed network for phase 1

5.1.1 Key Potential Constraints

A desktop study was undertaken to assess CAPEX and identify key potential network constraints. are no historical or natural constraints within the assessment area boundary. Wickham Road passes through the assessment area and will need to be crossed when installing the first network phase.

5.1.2 Terrain

Figure 23 shows the variation in elevation across the assessment area. Changes in elevation are unlikely to pose a risk to the development of a heat network or the location of the energy centre and present no restrictive pumping requirements.

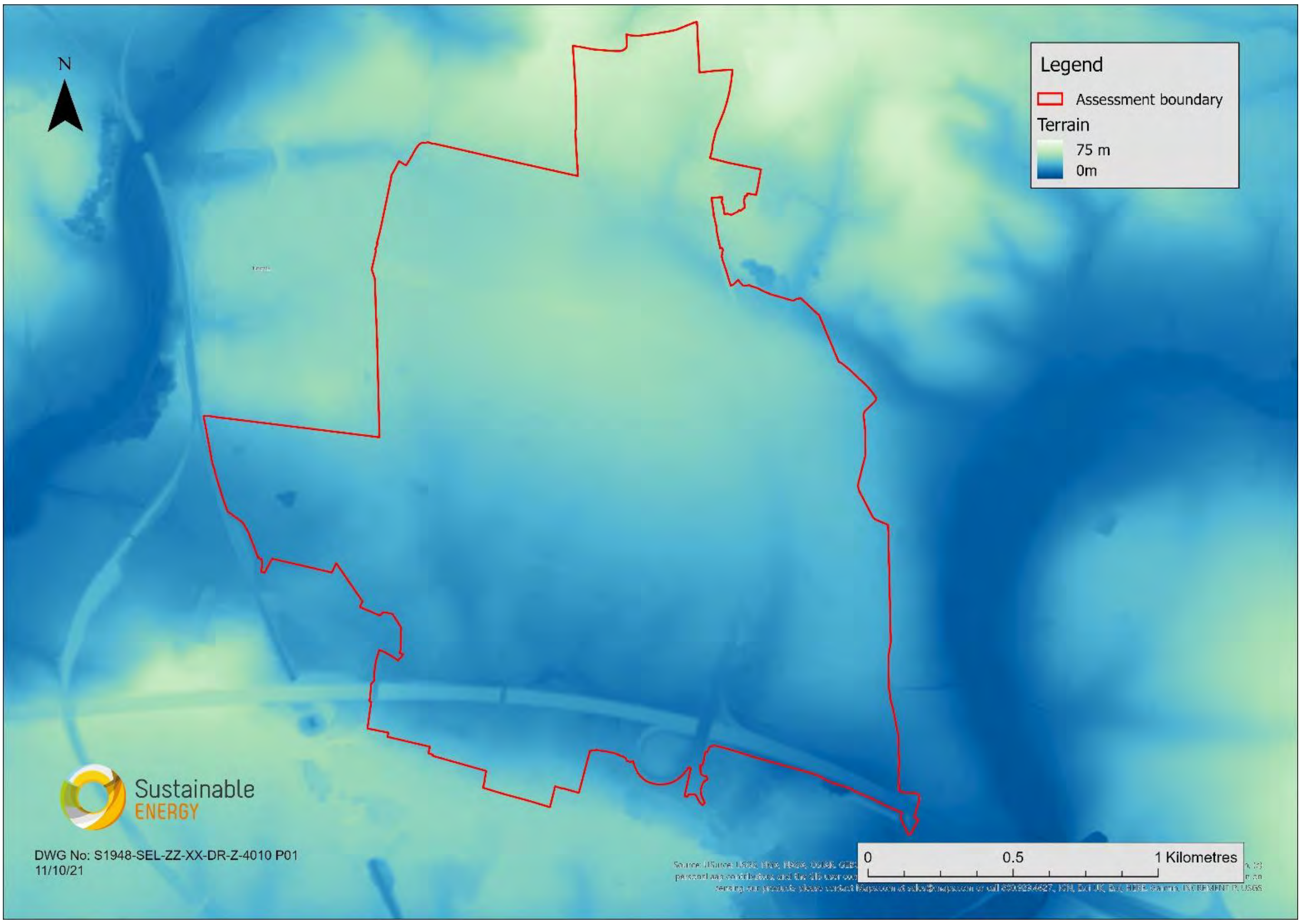


Figure 23: Terrain constrains

5.2 Linear Heat Density for Network Spine

The linear heat density of the network has been assessed to identify sections with a low linear heat density that are likely to significantly reduce the economics of the scheme. Route sections with a linear heat density below 3 MWh/m have been classed as low. The results of the linear heat density assessment are shown in Figure 24. Only one section has been identified with linear heat density of <3 MWh/m; a connection leading to Northern Primary School.

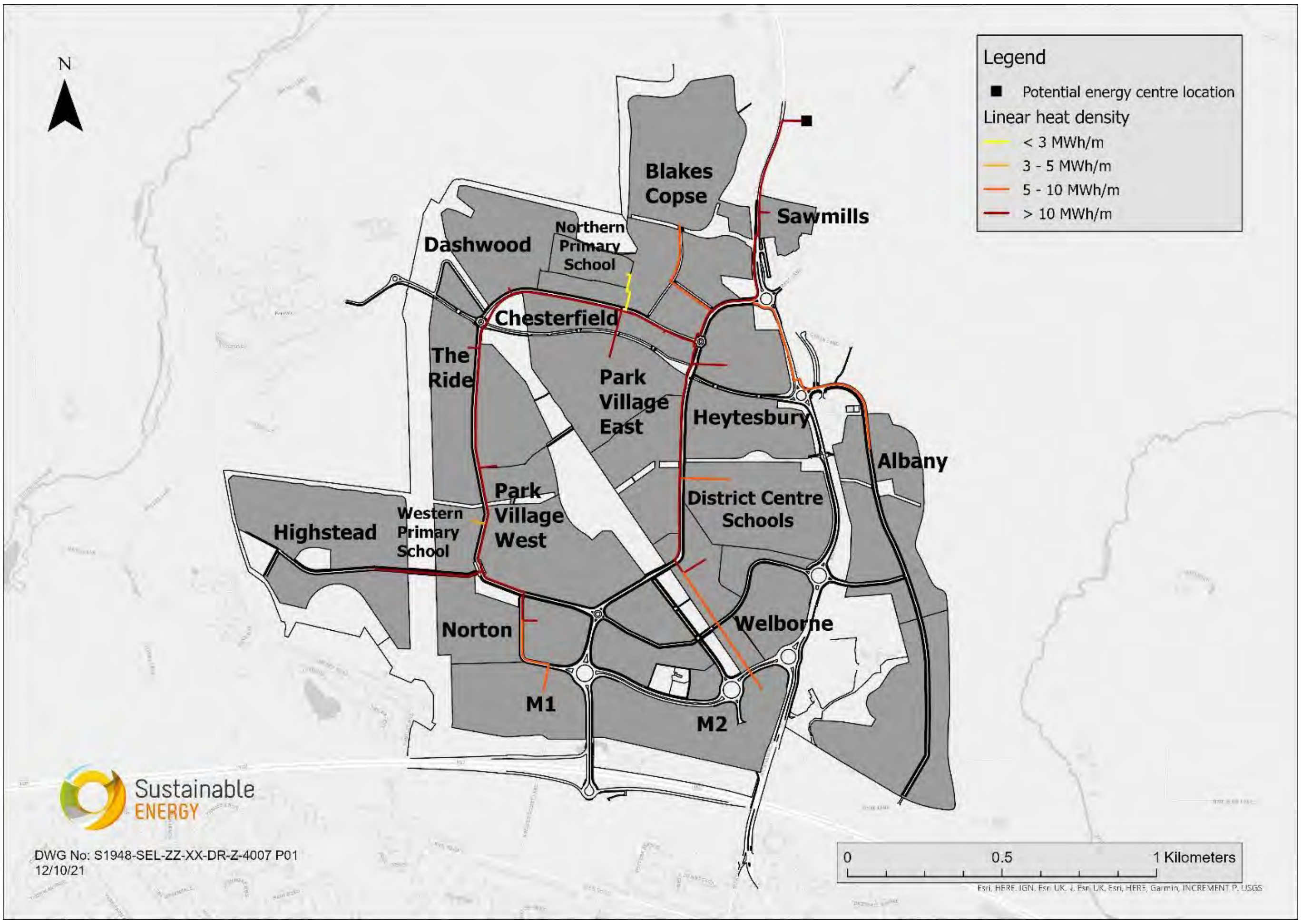


Figure 24: Linear Heat Density assessment

Average linear heat density of network spine for individual phases is shown in Table 11.

Table 11: Linear Heat Density for spine network

Phase	Network spine trench length (including previous phases), m	Average linear heat density, MWh/m
Phase 1	1,951	3.8
Phase 2	4,233	4.4
Phase 3	5,176	5.2
Phase 4	6,627	5.3
Phase 5	6,660	5.3

As linear heat density was assessed for the network spine, it does not consider the additional lengths of pipe required within each development parcel.

5.3 Ambient Cluster Networks

Smaller ambient networks serving the parcels that do not connect to a wider network have also been assessed. This option will have the significant advantage of being phased to correspond with the development build-out. The option includes a series of closed-loop boreholes connecting to a network within the parcel, and houses will connect individually to this network.

An example of the potential cluster network for the first development phase is shown in Figure 25.

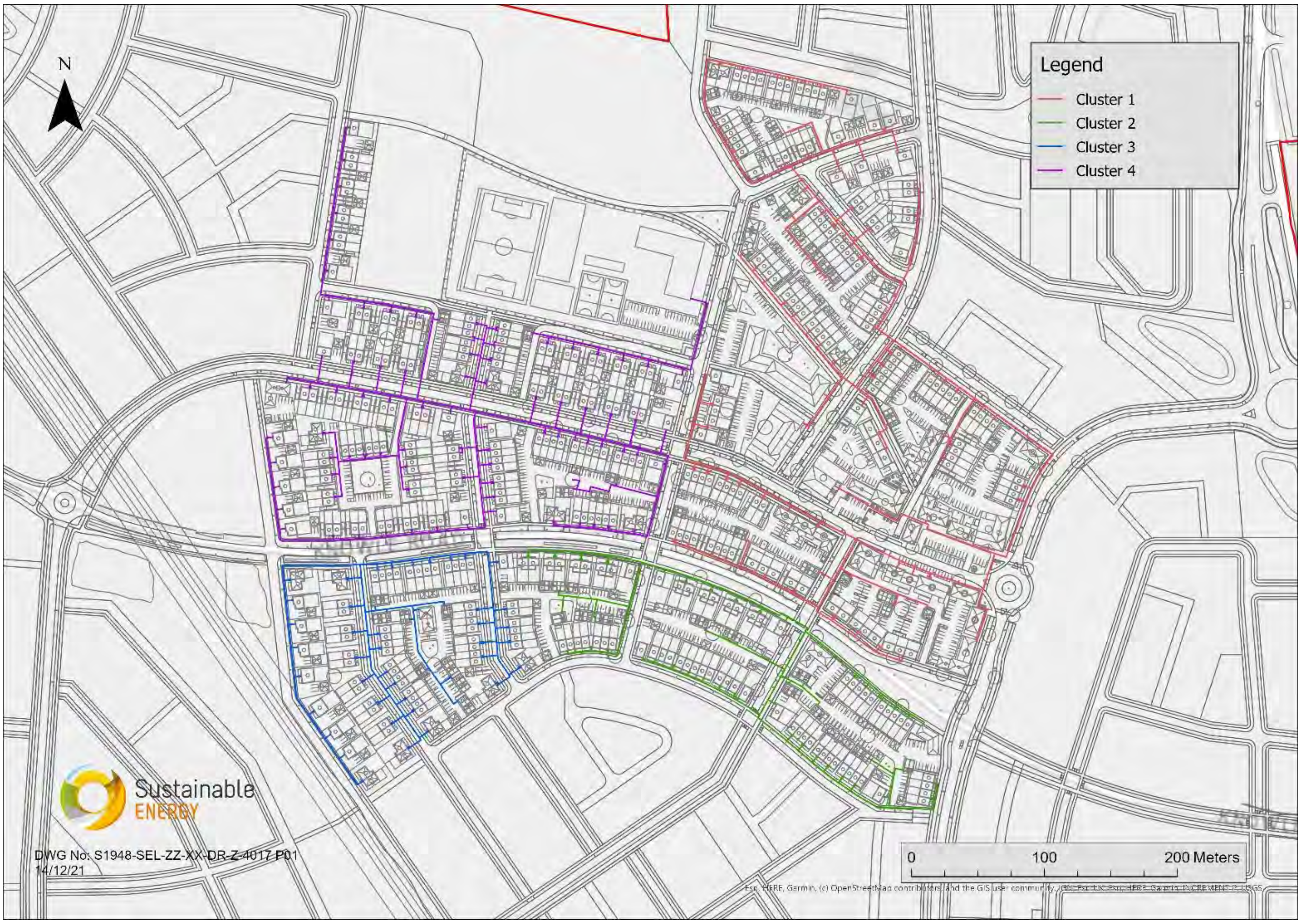


Figure 25: Development phase 1 cluster layout

5.4 Summary

The selected network route considers:

- Minimising pipe length
- Trench excavation, backfilling and reinstatement costs for green field conditions
- Physical constraints and site barriers
- The outputs of hydraulic modelling exercises (including pipe lengths, diameter, insulation and materials)
- Calculated heat distribution losses throughout the network
- CIBSE / ADE Heat Networks Code of Practice (specifically Objective 2.5)
- Linear heat density
- Potential for co-location / multi-utilities approach

6 SCHEME OPTIONS ASSESMENT

Initial scheme assessments were undertaken for shortlisted options as discussed in section 4.3.1.

6.1 Initial Network Assessments

Initial assessments have been completed to identify the heat source technology, technology sizing and heat network options i.e., following options have been identified as potentially viable and are assessed further:

- Sitewide LTHW network using Hoads Hill Reservoir and WSHPs
- Sitewide LTHW network using ASHP
- Sitewide ambient network using Hoads Hill reservoir
- Cluster based ambient network using closed loop boreholes
- ASHPs in each dwelling

6.1.1 LTHW Network Assessment

A sitewide network using WSHP (with connection to Portsmouth Water Reservoirs) and ASHP were assessed to identify the preferred technology option for the scheme as shown in Table 12.

Table 12: LTHW options risks, benefits and disbenefits

	Sitewide LTHW network using Hoads Hill Reservoir and WSHPs	Sitewide LTHW network using ASHP
Risks	• Planned developments might not come forward • Return flow temperatures may decrease reservoir temperatures, resulting in increase in burst pipes owned by the water company (this could make this option unviable) • Possible issues with planning permission for EC outside the assessment boundary	• Planned developments might not come forward • Possible issues with planning permission for EC outside the assessment boundary (particularly in relation to acoustic impact and cold air 'pluming')
Benefits	• Potentially lower cost of heat to customers • Higher SPF_{H2} due to more consistent source temperature, and therefore higher CO_2e savings	• Potentially shorter network route • EC location is not dependant on the heat source • Lower CAPEX • Not dependent on third party heat source
Disbenefits	• Commercial contract with water company required • High CAPEX to connect to reservoirs • EC is required to be located close to reservoirs	• Lower SPF will increase costs to customers and decrease CO_2e savings • Increased space for evaporators at energy centre would be required • Acoustic attenuation may be required

Each option has been assessed for the full phase 5 network (as if built as a single phase) and has been initially sized to provide the highest economic returns. The heat sources have been compared based on the high level 40 year IRR along with the energy centre CAPEX. The initial technology assessment has been completed for individual ASHPs as the counterfactual, CO_2e savings have also been estimated and are shown in Table 13.

Table 13: Summary of techno-economic modelling of DHN options

Short listed option	High level 40 year assessment				Total carbon emissions
	CAPEX	IRR	NPV (3.5% discount rate)	Average $CO_{2}e$ intensity	
WSHP only DHN	£61,739,125	8.4%	£21,226,617	26.8 g/kWh	15,792 t
ASHP only DHN	£60,651,605	8.8%	£20,971,236	29.9 g/kWh	18,225 t

As shown in the table above the difference in the economics of using the reservoir as a heat source versus ambient air are marginal. The initial CAPEX for the WSHP is greater due to the energy centre needing to be located next to the reservoir and the connection to the reservoir. In the long term, the improved performance of the water source heat pump means this option has lower operating costs and lower carbon emissions.

Due to the marginal difference in high level economics and the increased risks associated with connecting to the reservoir, the preferred option for the thermal network is an ASHP.

6.1.2 Ambient Loop Network Assessment

A sitewide ambient network using Hoads Hill reservoir and a cluster based ambient network using closed loop boreholes were assessed and a summary is shown in Table 14.

Table 14: Ambient loop options risks, benefits and disbenefits

	Sitewide ambient network using Hoads Hill reservoir	Cluster based ambient network using closed loop boreholes
Risks	• Planned developments might not come forward or be built out • Impacted by development build out rate or changes to development plans • Reliant on co-operation of water company	• Very small clusters may not be eligible for GHNF funding (see 6.3.3) • Potential issues with commercial structure and operation and maintenance arrangements
Benefits	• Potential for grant funding through the GHNF	• Can be built to correspond with build out rate • Phase economics will not be impacted by changes to the development plan • CAPEX spread over the site build out duration
Disbenefits	• ~630 OD pipe required from the energy centre • High initial CAPEX • Space requirements for energy centre with heat exchangers and pumps • Connecting building require own heat pump and DHW cylinder	• Only phase 1 eligible for funding from the GHNF due to build out timing • Space requirements for pumping station for each cluster • Connecting building require own heat pump and DHW cylinder

To compare the ambient network options an initial CAPEX assessment was conducted. The majority of CAPEX for the sitewide option is attributed to the network spine and reservoir pipework. Most of the CAPEX for the cluster options is attributed to the closed loop boreholes. All other costs, such as heat pumps within the dwellings and network cost with the parcels are both required and are not included in this initial high-level assessment.

Table 15: Summary of heat source CAPEX for ambient options

CAPEX Item	Sitewide network	Cluster network
Network Spine	£8,878,083	-
Connection to reservoir	£1,408,606	-

CAPEX Item	Sitewide network	Cluster network
Reservoir heat exchanger	£854,923	-
Cluster Boreholes	-	£9,127,068
Total	**£11,141,612**	**£9,127,068**

Due to the higher CAPEX costs for the sitewide ambient network (and that most of this spend is required for phase 1) and the high technical and commercial risks associated with accessing local water sources, the cluster network approach is selected as the preferred ambient solution. As discussed in chapter 3, there is not a large overall cooling demand that could potentially improve the efficiency and economics of a sitewide network.

6.1.3 Summary

A sitewide thermal network served by ASHPs and cluster ambient network have been selected for further techno-economic assessment and to be compared to the counterfactual option (ASHPs in each dwelling). Each option has been assessed for the full development.

Table 16 summarises the risks, benefits and disbenefits associated with each of the selected options.

Table 16: Prioritised option and ASHPs in each building risks, benefits and disbenefits

	ASHP thermal district heat network	Cluster based ambient network using closed loop boreholes	ASHPs in each dwelling
Risks	• Upfront CAPEX associated with network future proofing may cause commercial complications and planned developments might not come forward or be built out • Heat network feeds need to be installed in coordinated manner in line with best practice to minimise length, costs and heat losses or scheme will be unviable	• Ambient network feeds need to be installed in coordinated manner in line with best practice to minimise length and cost • Thermal response from boreholes may be lower than expected and more boreholes may be required • Higher capacity of heat pumps required and increase to the electricity grid connection and distribution capacity which may result in significant additional CAPEX • May not be operated and maintained in most efficient manner • Higher GWP refrigerants such as R32 often used in domestic heat pumps	• Lower CoP will increase costs to customers and decrease CO_2e savings • Higher GWP refrigerants such as R32 often used in domestic heat pumps • Higher capacity of heat pumps required and increase to the electricity grid connection and distribution capacity which may result in significant additional CAPEX • May not be operated and maintained in most efficient manner
Benefits	• Network operator able to maximise CO_2e and cost savings through utilising thermal stores and operating technologies at times of lowest electricity price and CO_2e emissions • Potential for grant funding through GHNF	• Potentially greatest CO_2e savings if operated and maintained efficiently • Not impacted by development build out rate or changes to development plans • Potential for grant funding through GHNF	• Potentially high CO_2e savings (if good quality heat pump operated and maintained efficiently) • Not impacted by development build out rate or changes to development plans

	ASHP thermal district heat network	Cluster based ambient network using closed loop boreholes	ASHPs in each dwelling
	• Potentially lower cost of heat to customers • Access to more competitive non-domestic energy tariffs that can be exploited through smart operation	• Low acoustic and visual impact	
Disbenefits	• Space requirements for energy centre • Low linear heat density resulting in high network heat losses and lower CO_2e savings than high density network • Acoustic and visual impact of energy centre • May require peak and reserve (back up) gas boilers resulting in higher CO_2e intensity and local air quality impacts	• Additional space required at each dwelling (internal unit, DHW cylinder, buffer vessel and controls) • May not be operated and maintained in most efficient manner	• Additional space required at each dwelling (external and internal unit for heat pump, DHW cylinder, buffer vessel and controls) • May not be operated and maintained in most efficient manner • Higher cost of heat to customers (under modelled assumptions) • Higher cost to developers (under modelled assumptions) • Acoustic and visual impact resulting from numerous outdoor units

6.1.4 Environmental benefits and impacts

The following section describes the benefits and impacts associated with the recommended network options. The CO_2e emissions have been assessed annually for each network option for 25 years. This has been compared to the business as usual (BAU) emissions and overall CO_2e savings calculated.

CO_2e Assessment

CO_2e intensity projections for grid electricity and natural gas are shown in Figure 26. The CO_2e emissions for the electricity grid are expected to reduce overtime 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 considered:

- BEIS long run marginal figure (commercial)
- BEIS long run marginal figures (residential)

The BEIS 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 other key variables 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 and energy centre electricity demand).

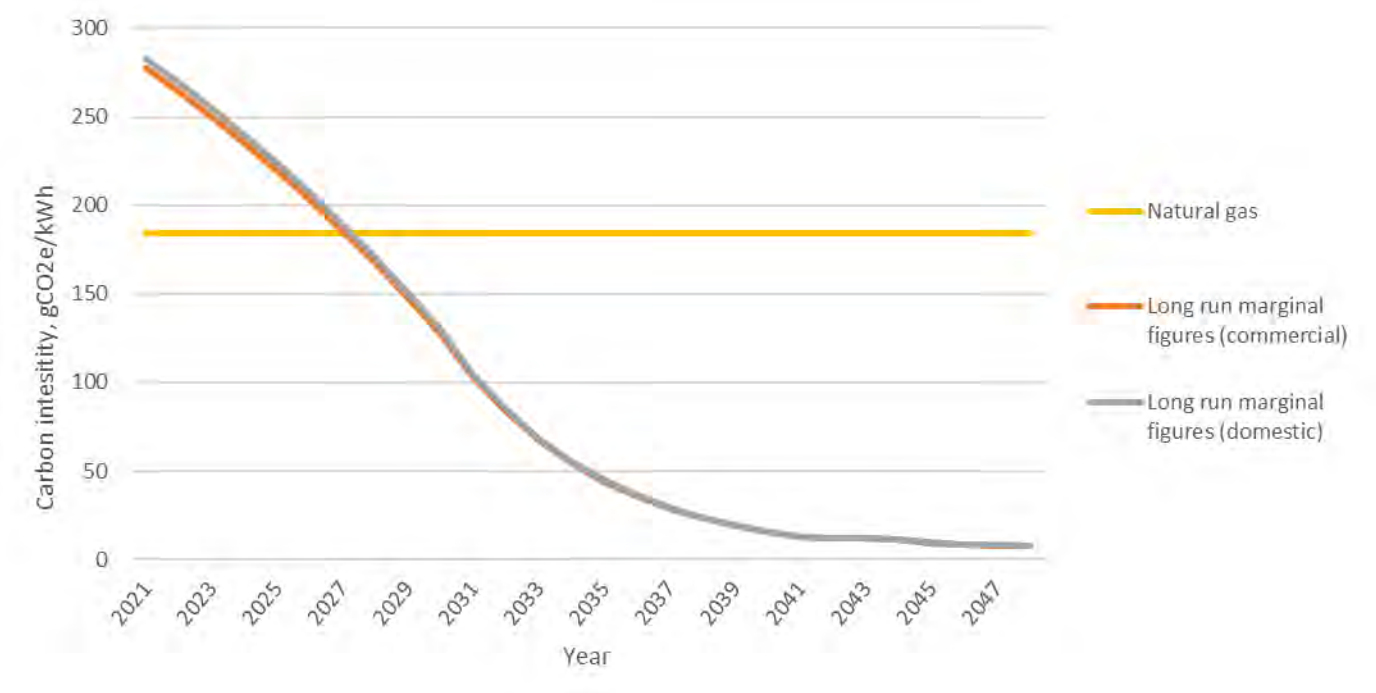


Figure 26: CO_2e emissions projections

Air Quality (Centralised Generation Options Only)

Electric peak and reserve boilers have been included in the base case, however they will decrease the economic viability of the network (particularly in the short term) and significantly increase risk associated with the resilience and reliability of the centralised heat pumps (if the heat pumps are unavailable for significant periods, the operation electric peak and reserve boilers may be an unacceptable risk for O&M contractors obligated to deliver heat at a specific price).

If gas boilers are installed, they should be compliant with the Medium Combustion Plant Directive. Gas boilers will be low NOx versions and will run only at peak heat demands and when the heat pumps are not operating. The low carbon technology has been sized to meet >90 % of the network heat demand in wherever possible.

Dispersion modelling should be conducted, if a district heating project is progressed with gas boilers, to ensure that any impact is within regulatory limits and meets local air quality objectives (and this information will be fed back into the flue design process). Air dispersion analysis simulates the exhaust gases for each hour and models the dispersion of gases and, where appropriate, particulate emissions (although these are considered negligible for natural gas fuelled plant) over a wide geographical area. The output of the analysis provides concentrations levels of particulates and NOx at specified locations.

Cold Air

The fully built-out ASHP option would be one of the largest in the UK (as of 2021). The impact of cold air would be significant, and a detailed modelling exercise will be required to assess the impact on the local environment. While, due to the location, nuisance impact is potentially low, there is a high risk of the scheme impacting the local flora and fauna.

Acoustic Impact (ASHP options)

The acoustic impact of the centralised ASHPs will be deemed significant and attenuation will be required to reduce this to an acceptable level. If ASHPs are installed in each property, there will be a cumulative acoustic impact that has been deemed unacceptable by the master developer.

Visual Impact

The energy centre will have significant visual impact in the case of the ASHP option, the evaporators may need to be screened. In Ambient cluster option local pumping stations will have visual impact, however smaller than energy centre in thermal network option. If ASHPs are installed in each property, there will be a significant cumulative visual impact that has been deemed unacceptable by the master developer.

6.2 ASHP Thermal Network

The thermal network would be supplied by ASHPs and associated energy centre equipment (such as peak and reserve boilers) located at the identified site to the north east of the development. Table 17 shows a summary of the scheme generation and supply.

Table 17: Network summary

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Total heat demand (not including losses)	6,116 MWh	18,165 MWh	32,728 MWh	46,553 MWh	51,579 MWh
Peak heat demand	1.9 MW	5.6 MW	10.6 MW	14.8 MW	16.2 MW
ASHP capacity	1.1 MW	2.3 MW	3.4 MW	5.7 MW	6.8 MW
Peak and reserve boiler capacity	1.0 MW	4.0 MW	8.0 MW	10.0 MW	10.0 MW
Heat demand met by heat pumps	5,945 MWh	16,164 MWh	26,469 MWh	40,318 MWh	46,684 MWh
Heat demand met by peak and reserve boilers	171 MWh	2,001 MWh	6,259 MWh	6,235 MWh	4,895 MWh
% heat demand met by low carbon / renewable technology	97%	89%	81%	87%	91%

Figure 27 shows the hourly network heat demand ordered from highest to lowest. Heat demand below the capacity thresholds shown in the duration curves can be met by the heat pump. The heat demand above these lines is met by the thermal stores and peak and reserve boilers.

The heat from the heat pumps will meet 91% of the full network heat demand, including heat losses in the network. The 9% of the heat demand which is not met by renewable and low carbon technologies will be met by the peak and reserve plant (assumed to be electric boilers in the base case).

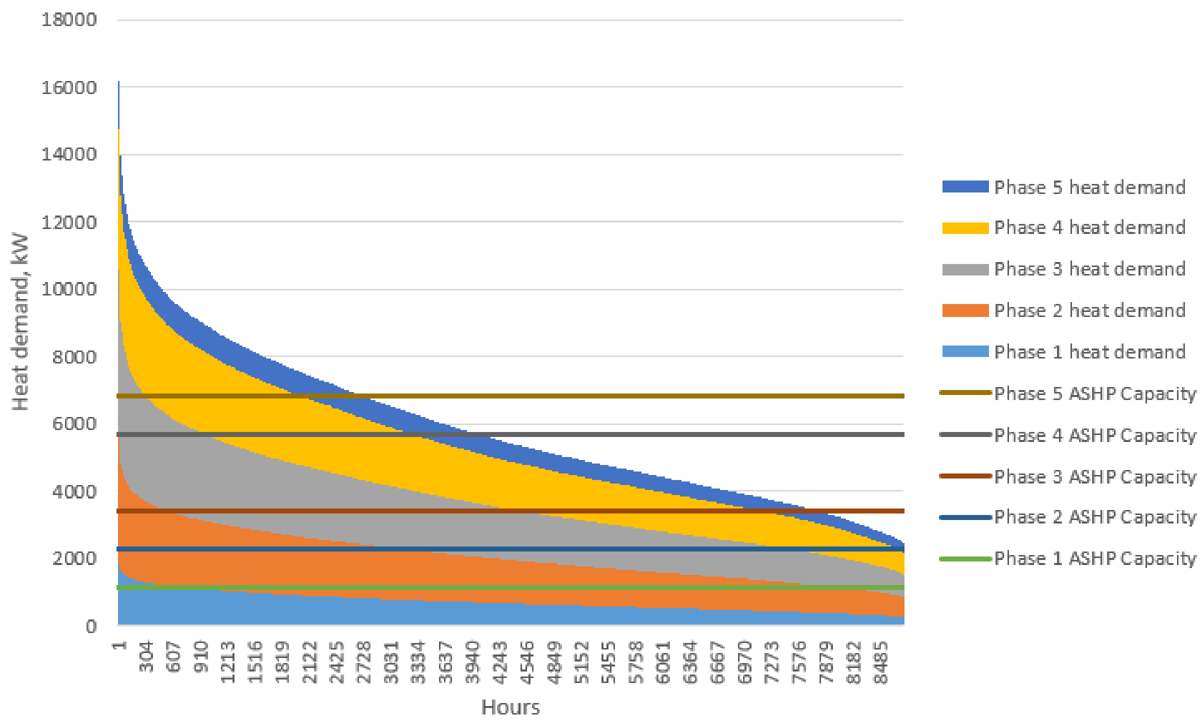


Figure 27: Load duration curve (including losses)

6.2.1 Concept design

This section summarises the scheme concept design and includes details of the primary heat sources, peak and reserve boilers, other energy centre equipment, utilities connection requirements and metering for the proposed thermal ASHP network.

Energy Centre

The proposed energy centre includes modular ASHPs as the main heat generator. The backup boilers will be located within the energy centre building and will be used to provide heat at times of peak demand (if this exceeds the capacity of the heat pump and thermal stores). The heat pumps have been designed to be modular to ensure that maintenance can be performed on a heat pump at any time without significantly reducing the capacity of low carbon heat sources. Controls will prioritise heat from the heat pump using thermal stores over the peak and reserve boilers to maximise the use of renewable technologies. A summary of the technology capacities at the proposed energy centres are shown in Table 18. Figure 28 shows a Process flow diagrams (PFDs) for the proposed energy centre. Figure 29 and Figure 30 show 3D model of EC and GA drawing respectively.

Table 18: Welborne energy centre summary

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Heat pump capacity	2.3 MW	3.4 MW	4.3 MW	6.8 MW	7.9 MW
Peak boiler capacity	1.0 MW	4.0 MW	8.0 MW	10.0 MW	10.0 MW
Thermal store capacity	200,000 l	200,000 l	200,000 l	200,000 l	200,000 l
Energy centre footprint	1,271 m^2	1,271 m^2	1,271 m^2	1,271 m^2	1,271 m^2

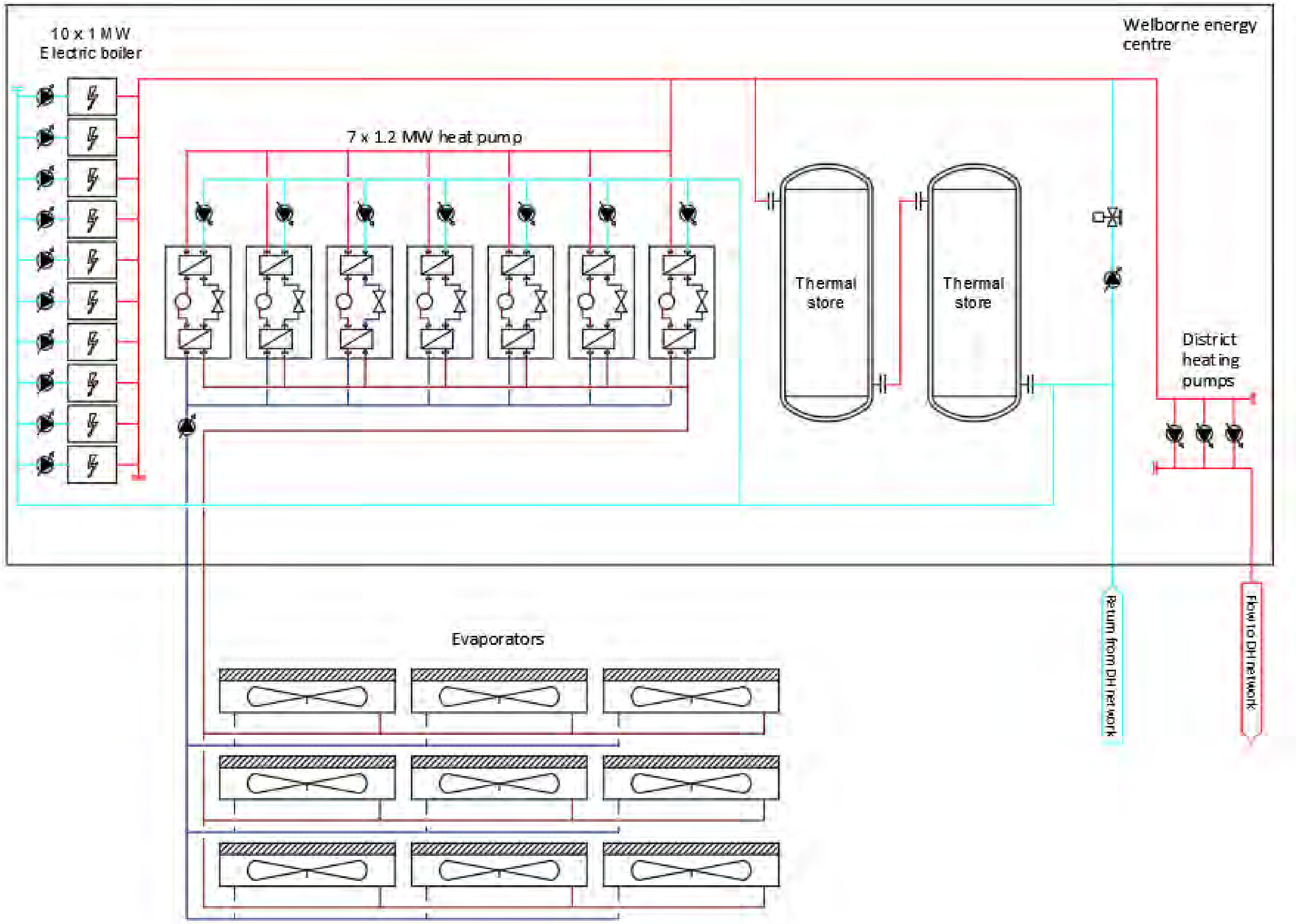


Figure 28: Energy centre PFD

Figure 29: Energy centre 3D model

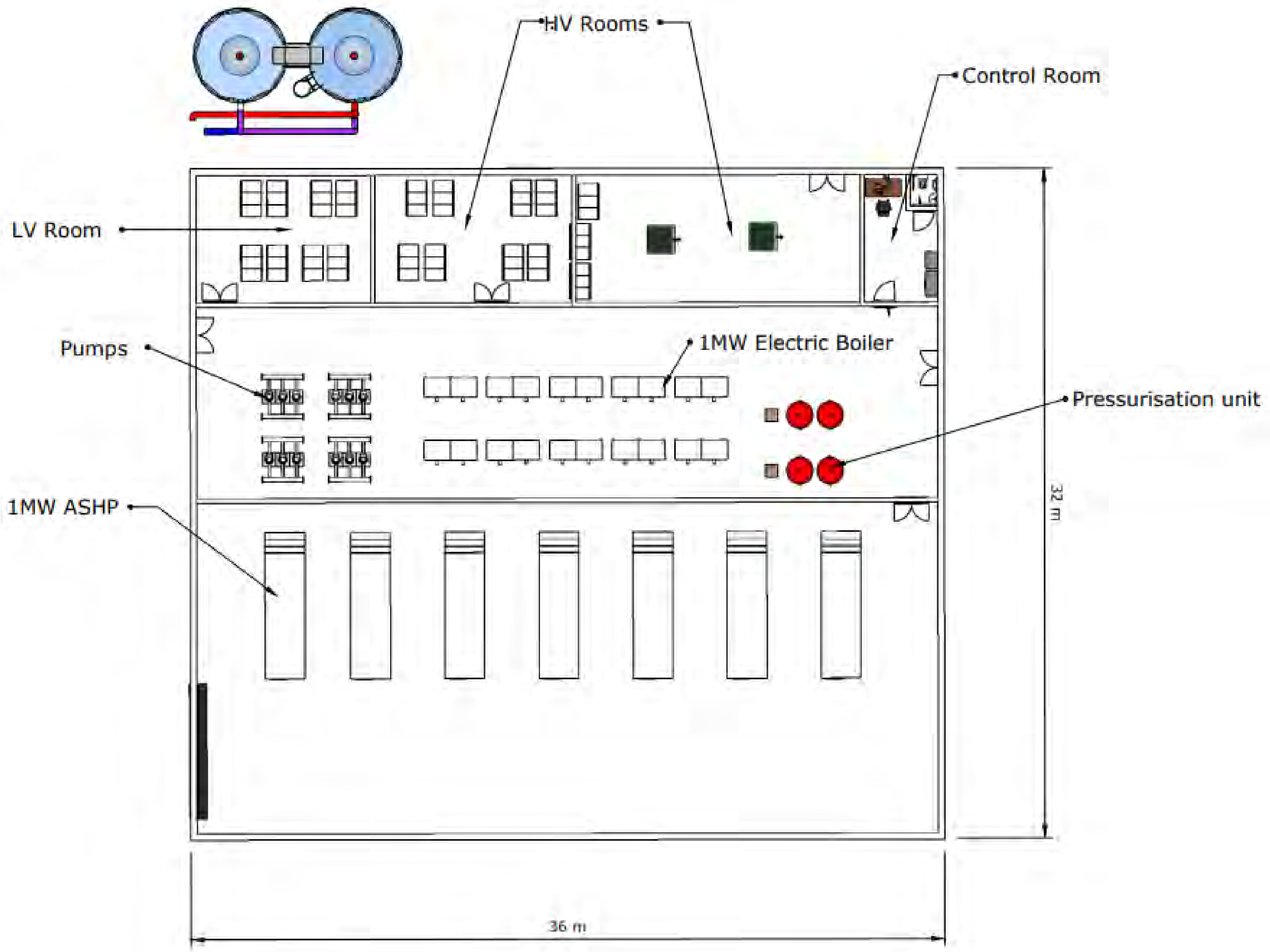


Figure 30: Energy centre GA

Futureproofing

Futureproofing measures have been considered throughout the concept design process for the network options. For planned developments, the most recent development plans have been used when estimating energy demands.

Heat Pump

Where heat pumps are included in the scheme, these should be packaged units connected within the energy centre to two main circuits; the dry air cooler circuit and the primary heating circuit. The dry air cooler circuit operates by running a low-temperature, low pressure refrigerant fluid through a heat exchanger and fan to extract the heat from the air.

The refrigerant fluid 'absorbs' the heat and boils at low temperature with the resulting gas being compressed to increase the temperature, the gas is then passed through another heat exchanger, where it condenses, releasing its latent heat to the primary heating circuit.

The heat pump refrigerant circuit should be hermetically sealed and subject to the F-gas directive and the working fluid should be a Low Global Warming Potential refrigerant.

The heat pump capacity will be limited based on the phased network demand. Consideration has also been given to the optimum balance between heat generation capacity, capital cost, maintenance costs and physical size.

A detailed sizing exercise has been undertaken using SEL's heat pump and thermal store sizing tool. The tool analyses the hourly network heat demand, network losses, water source temperature, heat pump capacity and modulation and thermal store size on an hourly basis for a full year taking into account hourly, daily and seasonal variation as well as peak and off peak electricity tariffs. Further details of SEL's heat pump and thermal sizing tool are included in Appendix 4: Thermal Network Technology Sizing.

Following this exercise a total of six 1,138 kW ASHPs would be required to make this scheme economic. As the energy centre will only have electric peak boilers it is recommended that the heat pumps are installed on an n+1 basis. This is to ensure that low carbon and low cost heating is available at all times following an unforeseen failure of any of the heat pumps. Therefore 7 ASHPs will be installed at the energy centre as shown in Table 18.

Utilities Connections

An electricity connection able to supply the heat pumps and the energy centre will be required at the energy centre with a ~13 MVA peak capacity required if electric peak and reserve boilers are included. The cost an electrical connection has been estimated at £1,500,000.

If gas boilers are used for peak and reserve, then the electrical capacity required would be ~6 MVA and medium pressure gas connection would be required.

A mains water supply and drainage will be required for the energy centre.

Peak and Reserve Boilers

Any heat demand not met by the heat pump and thermal store will need to be met by peak and reserve boilers which will either be electric or gas boilers.

Heat generated from electric boilers is considerably more expensive than the heat generated from the heat pumps as more electricity is required to generate the same amount of heat (boilers efficiency of 0.99, heat pump efficiency of >3).

Heat generated from gas boilers is cheaper than electric boilers and comparable to heat pumps, however these will generate significant additional carbon emissions compared to electric boilers as the grid decarbonises.

The base case assumes that electric boilers are included in the energy centre to ensure that the scheme has the lowest possible CO_2e emissions.

The energy centre design could include both electric and gas boilers if required by O&M contractors during commercialisation. The electric boilers would generate heat at peak times and during scheduled maintenance of the GSHPs. The gas boilers will only supply heat in the event of a failure of all heat pump equipment (where repairs cannot be made in the short term). This option should be explored further as the project progresses.

Thermal Storage and Control

Thermal storage has been included at the energy centres to maximise the proportion of heat that can be provided from the heat pump and reduce the use of the peak and reserve boilers. The thermal storage comprises large cylindrical, insulated water tanks which will be connected in series with each other to maximise the stratification of the stored volume. The thermal storage should be connected in parallel with the heat pump so that a proportion of low carbon heat is always used to charge the thermal stores when they are below full capacity.

The energy centre will utilise 2 x ~100 m^3 thermal stores of circa 4 m diameter and 11 m height to be built in phase 1.

Metering

All metering should be specified with suitable accuracy class in accordance with the Measurement Instrumentation Directive to satisfy the utility requirements for the purchase and sale of heat, water, and electricity for the energy centre.

- ***Heat***

The energy centres should have heat meters installed for the following: one combined heat pump heat meter, a combined electric boiler heat meter, a combined gas boiler heat meter (if gas boilers are included), and a combined export heat meter. The ultrasonic flow sensors measure flow and return temperatures and flow rates and the multi-function meters should calculate the heat energy exported. The heat meters will provide output signals (via mbus) for instantaneous measurements and cumulative measure of flow and energy. Data from all meters should be imported into the control system and used for control and monitoring of system performance.

- ***Water***

There should be water meters to determine the cumulative use by each of the system pressurisation units, water treatment plant and the overall incoming mains water to each of the energy centres. All data should be collected by the control system.

- ***Electricity***

Electricity meters should be fitted to measure the supply to the heat pumps (where appropriate) and the import electricity from the grid.

Variable Speed Pumps

The designs utilise variable speed pumps in a multi-pump arrangement (3 pumps – 1no. duty, 1no. assist and 1no. standby). They should be controlled to maintain a minimum pressure difference at specific locations using index differential pressure sensors within the network. The pump set will be speed controlled to maintain a set point differential pressure at the systems pressure index. The pumps should be sized to operate as duty/assist/standby - allowing for modulation in the full range of required supply.

The benefits of the variable speed function will be realised as peak flow rate conditions will typically only occur for brief periods during a heating season, with average demands being much lower.

Flues

Depending on the requirements from O&M contractors around peak and reserve boilers, a flue may be required. This have been shown in the General Arrangements should gas boilers be deemed necessary. The flues shown are based on the information in this section.

The design of the flues needs to achieve sufficient velocity of exhaust gas to achieve adequate dispersion, avoiding concentrations of harmful gasses such as nitrogen oxides (NOx). The effects of wind loading, and structural requirements of the flues must also be assessed and incorporated into the structural design of the energy centre, and any building constructed above the energy centre if this is brought forward.

Gas boilers should be low NOx versions and will run only when the network demand exceeds the capacity of the heat from the heat pump and thermal stores, therefore impact on the air quality of the city centre should be minimal. Dispersion modelling should be conducted, if the project is progressed, to ensure that any impact is within regulatory limits and meets local air quality objectives (and this information should be fed back into the flue design process).

Flue dispersion modelling should be required to assess the impact on surrounding buildings, in particular the adjacent residential developments.

This will require further assessment and discussion with the FBC air quality team if the project is progressed.

6.2.2 Operating Conditions

A detailed assessment of the proposed networks has been undertaken and the proposed operating conditions reflect the optimal network efficiency. To ensure heat network losses are kept below 10%[4], the heat network should operate variable temperature conditions.

Primary Network Temperatures

The primary heat networks should provide heat via plate heat exchangers which means the flow temperature on the primary networks into each building will need to be slightly higher than required on the secondary side. The network temperatures have been modelled at circa 70°C at peak conditions and 60°C flow temperatures for summer conditions. These conditions are deemed adequate due to the entire site being a planned development that will require low temperature heating options. The network must still be able to provide DHW at 55°C at the end user due to legionella.

The energy generating plant in the energy centres will be made up of various technologies that have different temperature conditions that affect the efficiency of each technology (i.e. electric boilers and heat pump). Electric boilers can operate at higher temperatures of 90°C without impacting negatively on efficiency. Heat pumps however, have a performance which is significantly impacted by the temperature conditions of the network and, to maintain effective performance, network flow and return temperatures should be as low as possible.

Controlled scheduling of heat pumps and peak and reserve boilers will be required to maintain an overall efficiency of each technology. Heat pumps should not be used to supply higher temperature peak demands, so the higher temperatures required for peak demands should be supplied by peak and reserve boilers. However, when temperatures and loads are lower (e.g. summer conditions), the heat pump should supply higher levels of demand. Detailed modelling and sizing have been carried out to consider varying demand profiles, temperature conditions and carbon impacts.

Planned developments should be designed to reduce secondary side temperatures in accordance with CIBSE / ADE CP1 and so, when connected to heat networks, will result in lower average return temperatures and therefore increase the efficiency of the network and the heat generating technologies.

[4] The CIBSE/ADE HNCoP states that the calculated annual heat loss from the network up to the point of connection to each building when fully built out is typically expected to be less than 10 %

Secondary Systems Temperatures

The proposed networks comprise only planned developments. These should be designed to reduce building heating system temperatures in accordance with CIBSE / ADE CP1 and will result in lower average return temperatures and therefore increase the efficiency of the network and the heat generating technologies. Target secondary side temperatures in future should aim to be 55°C flow and 30°C return.

Operating Pressure

The topography of the assessment area has minimal height variation and no planned high rise buildings. The calculated static pressure required in the network should be circa 1 barG.

The pumping pressure defines the maximum operating pressure to generate enough head to deliver the flow rate to all buildings. Hydraulic modelling was carried out to assess how the pressure in the network will vary throughout the seasons and the concept design considers maintaining maximum pressure in the systems at less than 9 barG.

6.2.3 Building Connections

All network connections are assumed to be indirect (where a heat exchanger separates the heat network hydraulically from the building space heating and hot water systems). The residential building connections will consist of an HIU per dwelling to which the district heat main will connect to supply heat. The commercial connections will consist of a heat substation.

The HIU and substation packages will include:

- Supplier meter to meter all heat usage on the primary side of the connection.
- Two-port differential pressure control to control the supply flowrate and temperatures across the heat exchanger via two-port control methodology. Control valves can either be a single PICV or a DPCV with a separate two-port control valve.
- Plate heat exchanger (PHE) at which the district heat is transferred to the customer secondary side network. PHEs will be specified with a maximum 3°C approach temperature across the return lines and a maximum 80kPa pressure drop on the secondary side of exchanger.
- Means of flow measurement and test points on both sides for commissioning purposes.
- Filtration to protect the plate heat exchangers and valves from fouling.
- Flushing, filling and draining details for chemical flushing of all pipework on the primary and secondary side.
- Pressure relief, control and instrumentation to allow the supplier control and monitor of the supply of heat.

Residential Connection

The HIU includes a plate heat exchanger for the space heating, a plate heat exchanger for instantaneous domestic hot water, pressure independent/differential pressure control valves and a heat meter. The key functional features are shown in the simplified schematic in Figure 31.

HIUs are comparable in size to a domestic combination boiler and are usually wall hung. The hot water is best provided via an instantaneous PHE with a suitable means to ensure the network side of the plate is controlled (to ensure satisfactory hot water supply response to dwelling taps whilst minimising the supply pipework heat losses during standby periods). Space heating supply will be in-direct connection (where a PHE is used to transfer supply heat into the secondary circuit).

The location of the HIU should be as close as possible to the main district heat network to minimise pipe lengths and network losses. Ideally the HIU will be accessed from outside the dwelling to enable access for maintenance.

The utilities required for the HIU are:

- 240 V spur connection
- 15 mm mains cold water service (MCWS) connection

Commercial Connection

The commercial connections will consist of a heat substation. The substation includes heat exchangers, control valves and heat metering and will be maintained by the network operator. The substation can include one or more plate heat exchangers (PHEs) (two shown in the example in Figure 32), depending on the size, turn-down and redundancy required for each building. Typically, two PHEs are installed in parallel, each installed at 60 % of peak load, provide a full thermal range, and some redundancy to permit service and maintenance periods. Larger substations may include more than two PHEs. Only the key functional features are shown in the simplified schematic in Figure 32.

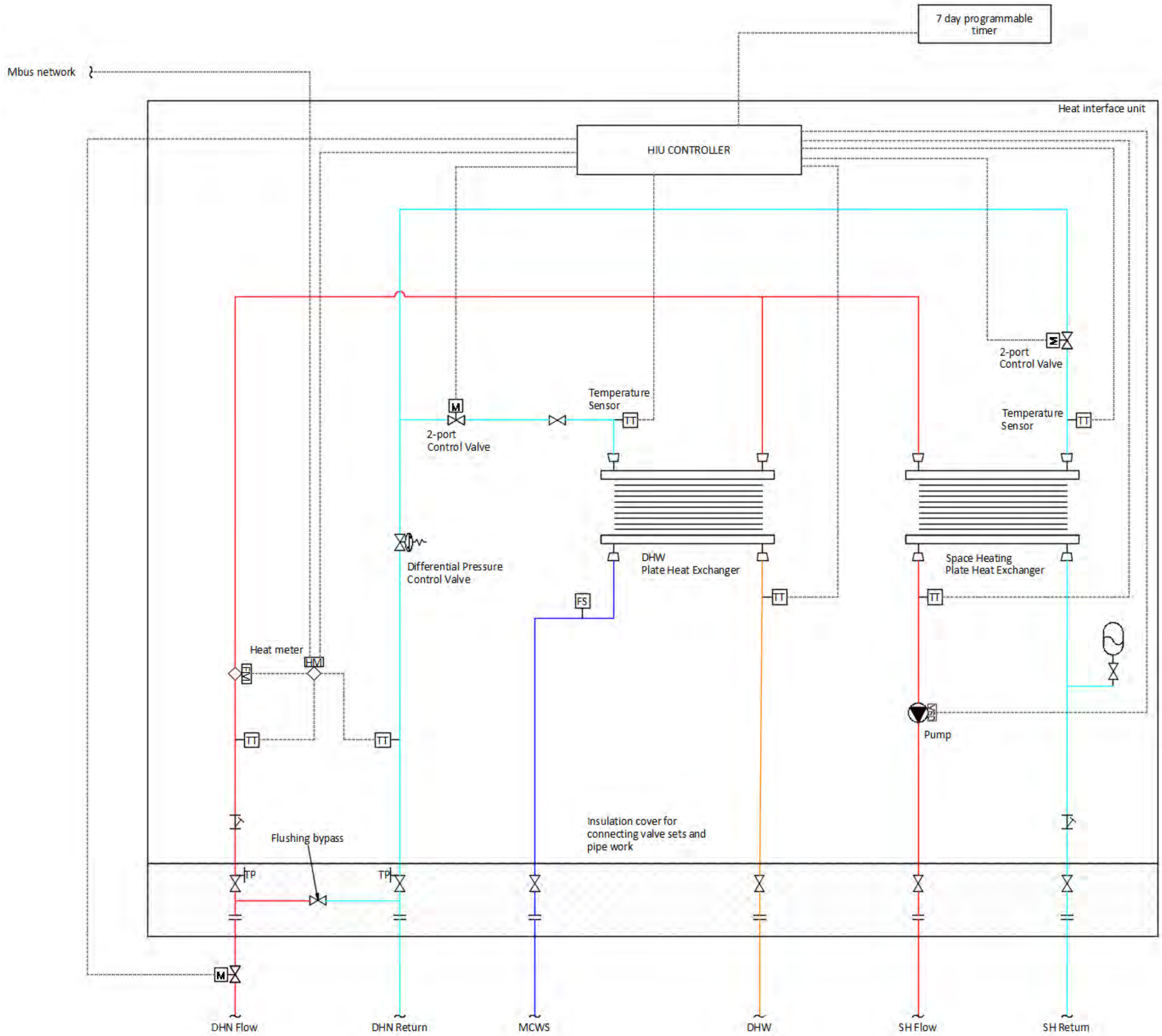


Figure 31: Example of typical domestic HIU connection

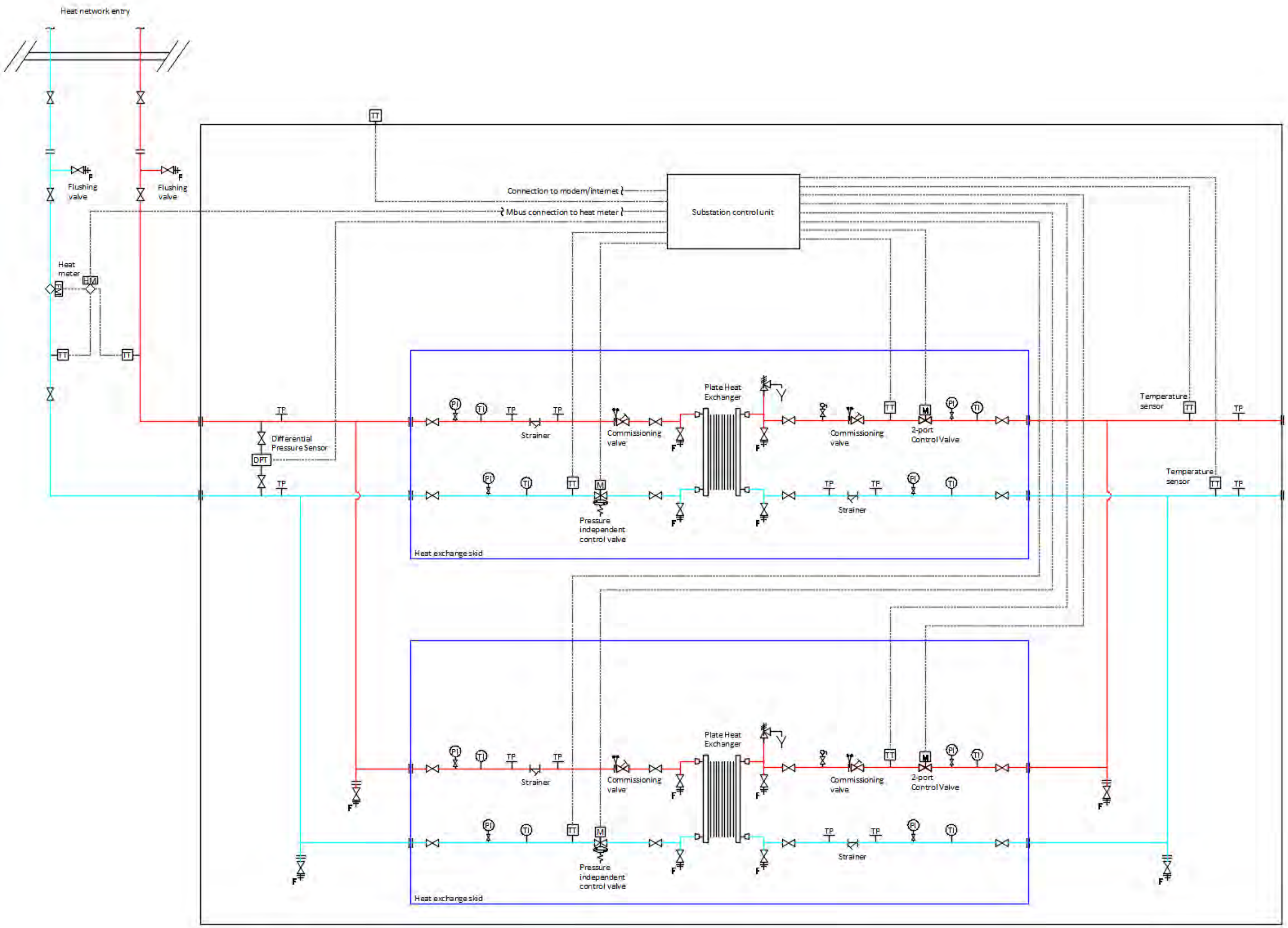


Figure 32: Example of typical substation connection for commercial development

Sustainable ENERGY

6.2.4 Energy Balance

Figure 33, Figure 34, Figure 35, Figure 36 and Figure 37 show the energy balance for all 5 phases.

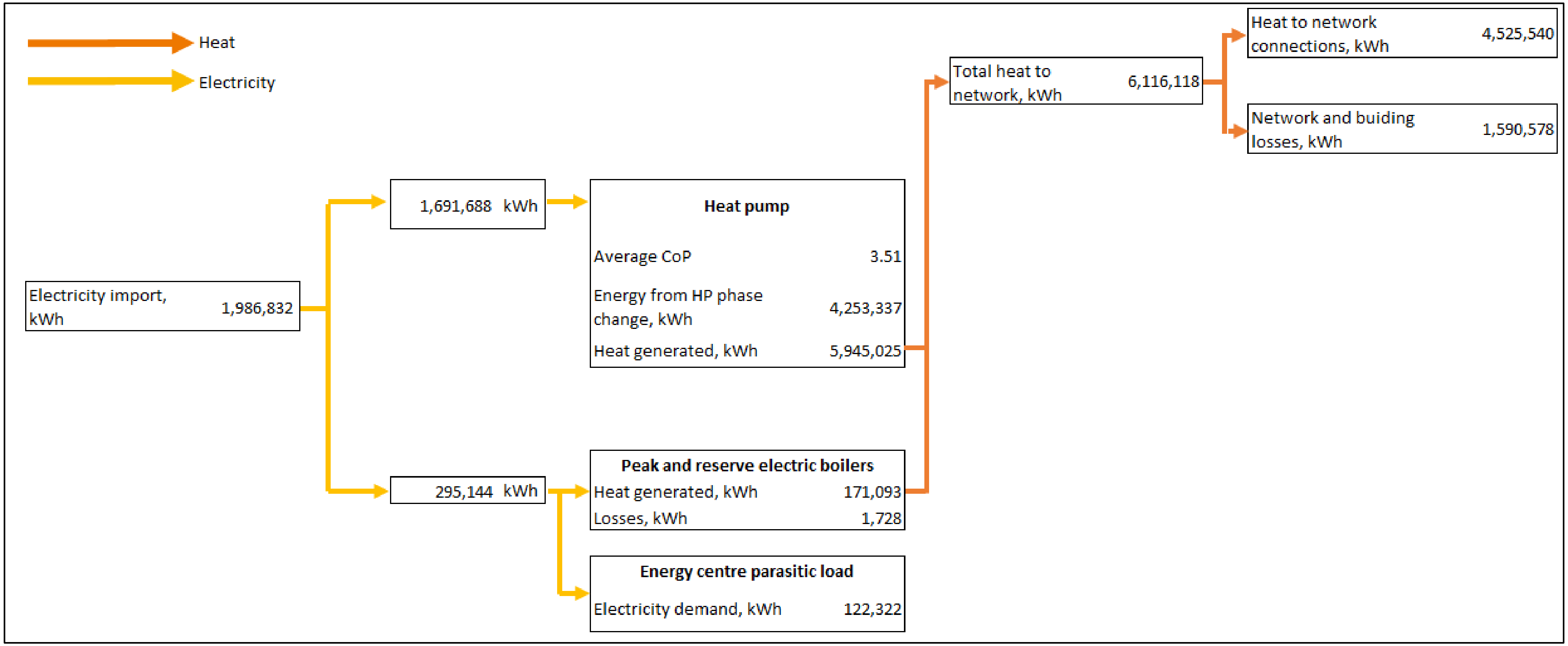


Figure 33: ASHP Phase 1 energy balance

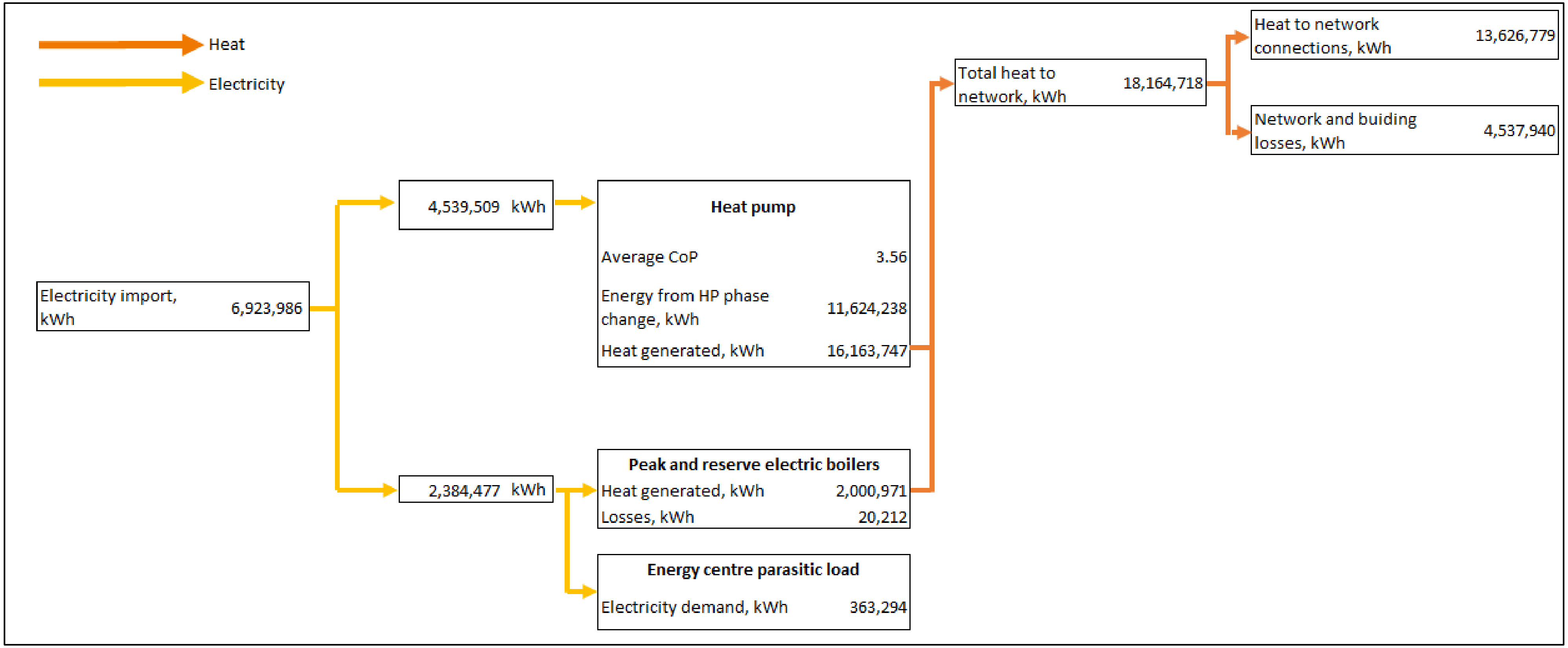


Figure 34: ASHP Phase 2 energy balance

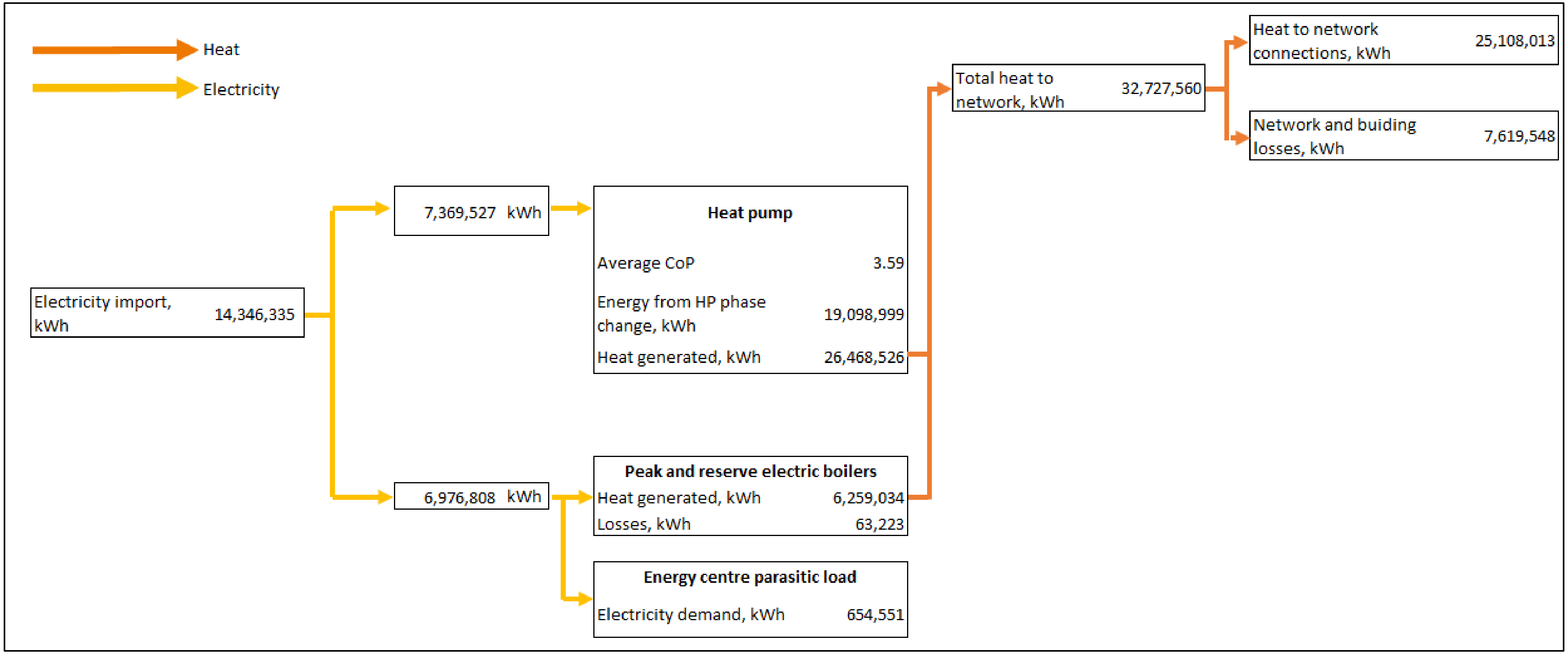


Figure 35: ASHP Phase 3 energy balance

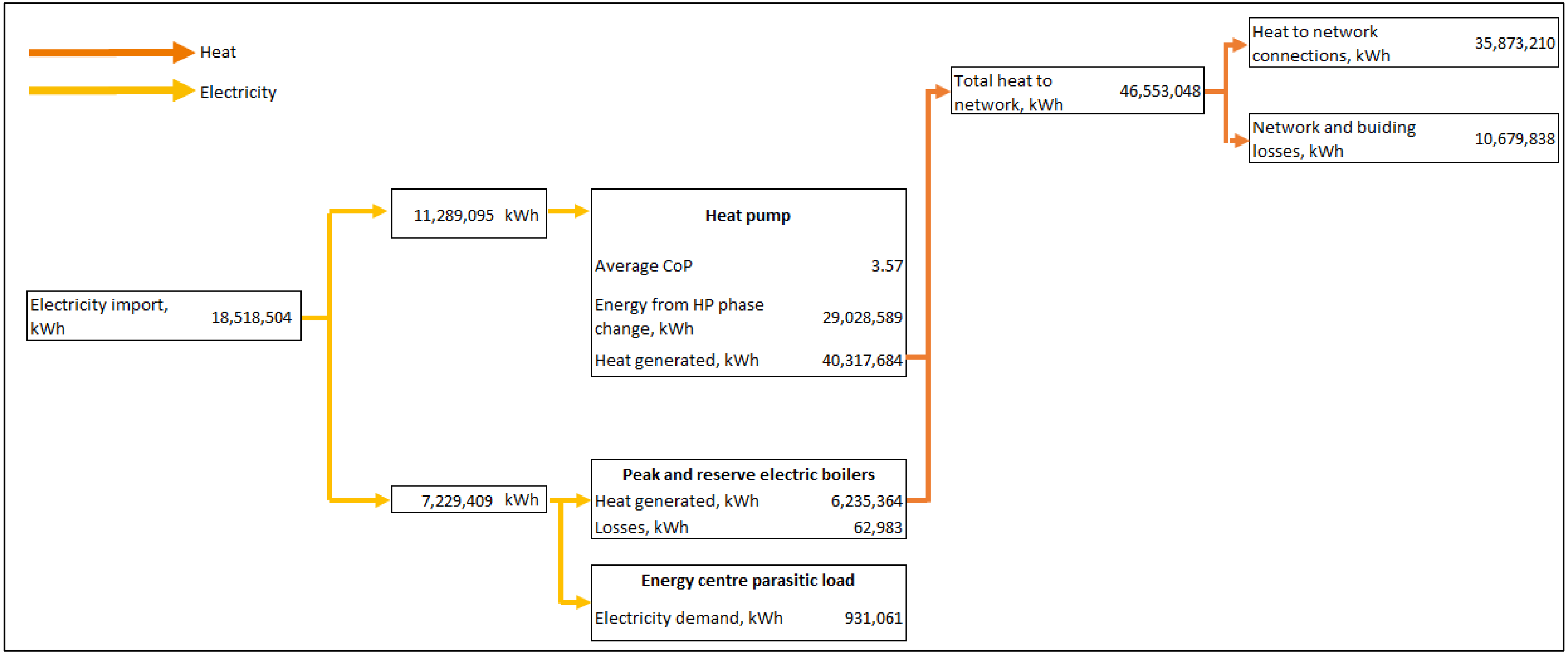


Figure 36: ASHP Phase 4 energy balance

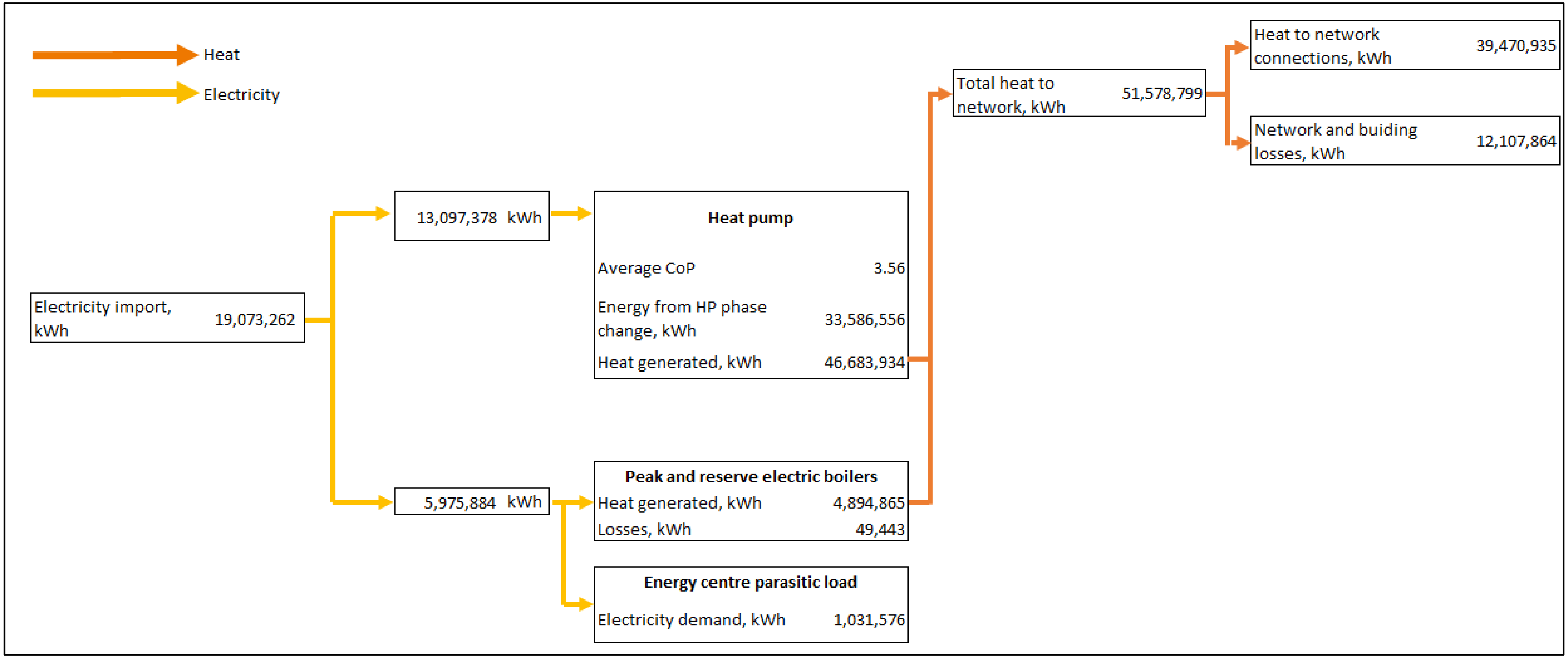


Figure 37: ASHP Phase 5 energy balance

Network losses

A summary of the heat losses for all phases is shown in Table 19.

Table 19: Network heat losses summary

	ASHP				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Annual heat demand, MWh	6,116	18,165	32,728	46,553	51,579
Annual losses from heat network, MWh	1,591	4,538	7,620	10,680	12,108
Annual losses from heat network %	26%	25%	23%	23%	23%

6.2.5 Economic Assessment

Details of the techno-economic modelling are shown in Appendix 6: Techno Economic Modelling - Key Parameters and Assumptions. The 25 year, 30 year and 40 year economic assessments for each phase the network are shown in Table 20.

Table 20: Economic assessment

		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs for each phase (including contingency)		£11,209,960	£12,896,073	£16,758,789	£13,076,141	£6,710,641
Total cumulative capital costs (including contingency)			£24,106,033	£40,864,822	£53,940,964	£60,651,605
25 years	IRR	1.2%	7.2%	7.3%	7.5%	8.0%
	NPV	-£ 1,638,444	£ 5,006,709	£ 6,828,761	£ 8,485,618	£ 10,305,136
	Simple payback	22 years	13 years	15 years	17 years	17 years
	Net income	£ 1,154,129	£ 13,839,652	£ 19,339,939	£ 24,270,350	£ 28,305,937
30 years	IRR	1.5%	7.2%	7.5%	8.0%	8.6%
	NPV	-£1,643,594	£5,959,975	£8,641,174	£ 12,018,077	£ 14,775,876
	Simple payback	24 years	14 years	16 years	18 years	18 years
	Net income	£ 1,742,008	£ 17,382,272	£ 25,485,419	£ 35,046,979	£ 41,569,567
40 years	IRR	1.8%	7.1%	7.5%	8.2%	8.8%
	NPV	-£ 1,722,152	£ 7,238,069	£ 11,031,567	£ 16,889,957	£ 20,971,236
	Simple payback	29 years	15 years	17 years	18 years	18 years
	Net income	£ 2,855,942	£ 24,197,314	£ 37,057,315	£ 55,436,587	£ 66,576,522

The capital costs, operational expenditure, revenue, and cumulative cash flow for the 40 year case for the full network is shown in Figure 38.

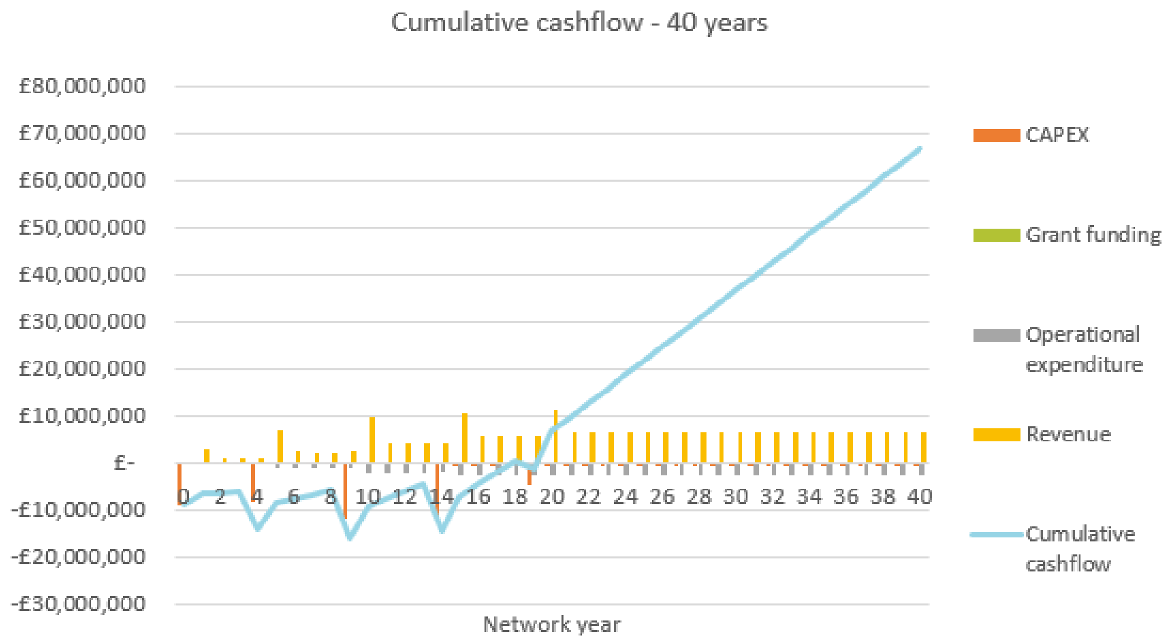


Figure 38: ASHP option - cumulative cash flow - 40 years

Green Heat Network Fund core metrics

Table 21 shows GHNF criteria and thermal network parameters.

Table 21: Green Heat Network Fund core metrics

Metric	Minimum score	Welborne scheme
Carbon gate	100gCO_2e/kWh thermal energy delivered	100gCO_2e/kWh reached in year 4 of operation
Customer detriment	Domestic and micro-businesses must not be offered a price of heat greater than a low carbon counterfactual for new buildings and a gas/oil counterfactual for existing buildings	Customer sale tariffs have been using an ASHP counterfactual
Social IRR	Projects must demonstrate a Social IRR of 3.5% or greater over a 40-year period	The 40 year social IRR is 6.3% for phase 1
Minimum demand	For urban networks, a minimum end customer demand of 2GWh/year. For rural networks, a minimum number of 100 dwellings connected	End customer demand is 4.3 GWh/year for phase 1 and 34 GWh/year for the fully built network
Maximum capex	Grant award requested up to but not including 50% of the combined total capex + commercialisation costs	Grant funding request amount to be determined
Capped award	The total 15-year kWh of heat/cooling forecast to be delivered will not exceed 3.33 pence of grant per kWh delivered (subject to review by GHNF)	The maximum grant funding available according to this metric is £8,686,460 - significantly higher than the 50% maximum in the row above
Non-heat/cooling cost inclusion	For projects including wider energy infrastructure in their application, the value of income generated/costs saved/wider subsidy obtained should be greater than or equal to the costs included.	No non-heat/cooling infrastructure included

6.2.6 Environmental benefits and impacts

Network emissions

Planned developments have been assessed with individual air source heat pumps as the base case counterfactual. Individual ASHPs CO_2e emissions, network CO_2e emissions and CO_2e savings for the network are shown in Figure 39, and Table 22. The yellow line shows the difference between CO_2e emissions in the individual ASHPs emissions and the network emissions. The individual ASHPs emissions decrease due to the reduction in emissions factor for grid electricity used in assessments and increases with the increase in heat demand with each network phase. The network emissions reduce over time as the grid decarbonises. The network emissions are higher than the individual ASHPs in this case due to the heat losses within the network and the peak and reserve demands greater than the installed heat pump capacity are being met with electric boilers.

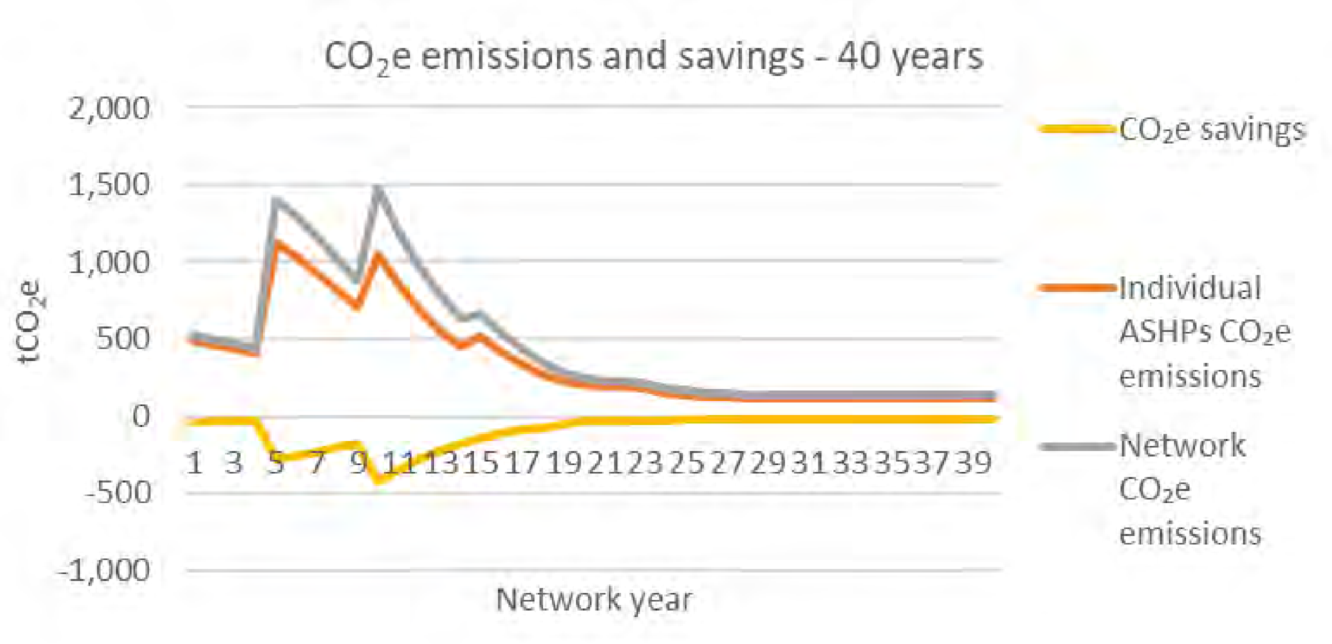


Figure 39: Network CO_2e emissions and savings – ASHP option

Table 22: Network CO_2e emissions and savings

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Network CO_2e emissions (25 years), tCO_2e	4,654	11,429	15,440	16,224	16,260
Total CO_2e savings (25 years), tCO_2e	-347	-2,053	-3,551	-3,514	-3,455
Network CO_2e emissions (30 years), tCO_2e	4,726	11,679	15,957	16,892	16,948
Total CO_2e savings (30 years), tCO_2e	-353	-2,103	-3,701	-3,658	-3,565
Network CO_2e emissions (40 years), tCO_2e	4,862	12,153	16,940	18,160	18,255
Total CO_2e savings (40 years), tCO_2e	-363	-2,198	-3,986	-3,930	-3,775
Annual CO_2e savings (year 1), tCO_2e			-39		
CO_2e intensity of heat delivered (year 1), gCO_2e/kWh			116		
CO_2e intensity of heat delivered (40 year average), gCO_2e/kWh	27	29	30	30	30
CO_2e intensity of heat from individual ASHPs (year 1), gCO_2e/kWh			102		
CO_2e intensity of heat from individual ASHPs (40 year average), gCO_2e/kWh			22		

The CO_2e intensity of heat delivered in the first year of network operation is significantly lower than the current SBEM/SAP (2012) figure for notional building connected to a district heat network of 190 $g/CO_2e/kWh$. And is lower than proposed 350 gCO_2e /kWh threshold for existing network in the Part L 2022 uplift.

Visual impact

The energy centre is proposed to be located within a light industrial development, however, may be in proximity to the proposed RBG residential development to the south. Further discussion is required with Fareham Borough Council regarding the character of the building and visual impact of the thermal stores.

Social IRR and NPV

The environmental benefits to the scheme are determined by monetising the CO_2e savings and the improvements in air quality against the use of individual gas boilers. The economic value of the carbon and air quality improvements are included in the project cashflow to generate a social IRR and NPV, shown in Table 23. The social IRR helps to identify the wider benefits of the scheme for the community and is a vital consideration for local authorities.

Table 23: Social IRR and NPV

		IRR	Social IRR	NPV	Social NPV
Phase 1	25 years	1.21%	5.88%	-£1,638,444	£2,150,714
	30 years	1.50%	6.15%	-£1,643,594	£2,844,206
	40 years	1.80%	6.31%	-£1,722,152	£3,872,517
Phase 2	25 years	7.16%	12.17%	£5,006,709	£15,156,431
	30 years	7.23%	12.17%	£5,959,975	£18,202,433
	40 years	7.12%	11.96%	£7,238,069	£22,795,218
Phase 3	25 years	7.30%	12.28%	£6,828,761	£20,886,346
	30 years	7.50%	12.45%	£8,641,174	£26,563,441
	40 years	7.47%	12.35%	£11,031,567	£35,102,945
Phase 4	25 years	7.52%	13.64%	£8,485,618	£29,153,593
	30 years	8.01%	13.88%	£12,018,077	£38,191,912
	40 years	8.19%	13.80%	£16,889,957	£51,784,277
Phase 5	25 years	8.02%	13.92%	£10,305,136	£31,730,764
	30 years	8.58%	14.20%	£14,775,876	£42,274,676
	40 years	8.78%	14.15%	£20,971,236	£58,090,251

6.2.7 Sensitivity

Sensitivity analysis has been undertaken for the prioritised network based on the key network risks and key parameters and variables for each network. The base case 40 year IRRs are shown in grey cells in tables.

Key risks for the network include:

- Capital costs
- Network feed length
- Network heat demand
- Heat pump SPF_{H2}
- Energy tariffs including heat sales tariffs, energy centre electricity purchase tariffs and indexation of energy tariffs
- Carbon savings of gas or electric peak and reserve boilers

Capital Costs

The effect of a variance in capital costs is shown in Figure 40 for each network phase. A decrease in capital costs of approximately 15% would be required for phase 1 to achieve 40 year IRR of 10%.

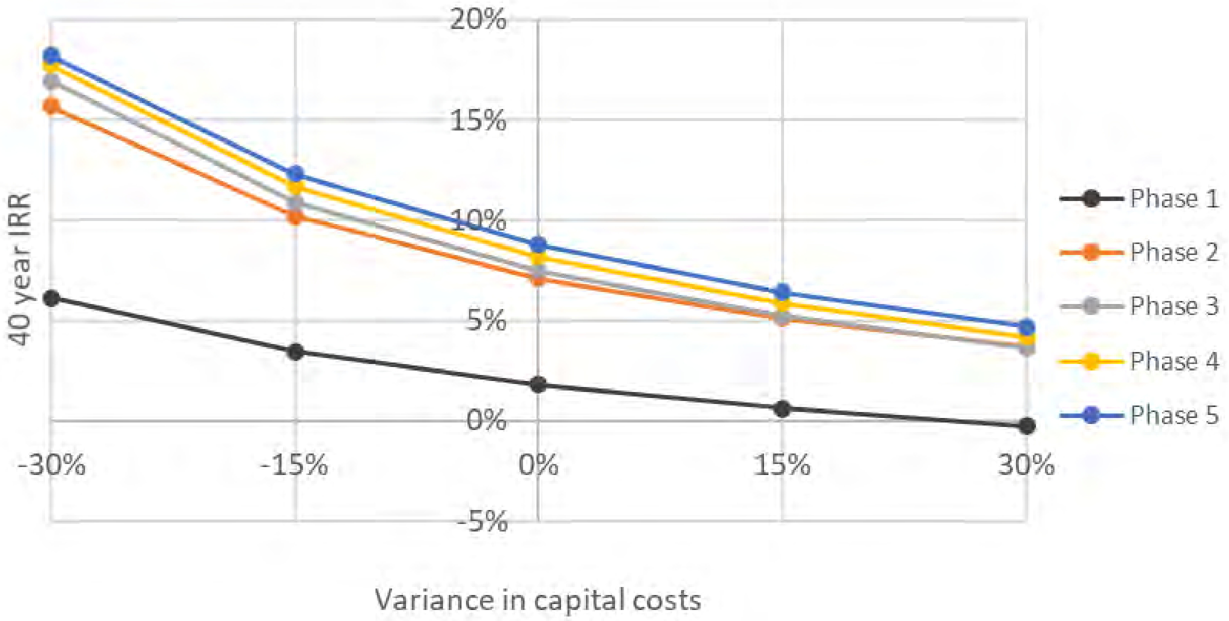


Figure 40: Effect of variance in capital costs

Table 24 shows the 40 year IRR for each network phase if the capital costs did not include contingency.

Table 24: Contingency applied to capital costs

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs including contingency (including previous phases)	£11,209,960	£24,106,033	£40,864,822	£53,940,964	£60,651,605
40 year IRR including contingency	1.8%	7.1%	7.5%	8.2%	8.8%
Capital costs not including contingency (including previous phases)	£9,500,867	£20,166,894	£34,230,337	£45,043,181	£50,618,436
40 year IRR not including contingency	3.9%	10.9%	11.6%	13.0%	13.5%

Network Feed Length

Table 25 shows the effect of an increase in network length if the network does not connect to houses in line with best practice, with each dwelling requiring its own feed pipe from the road to the front of the dwelling and heat interface units (HIUs) are not located at the nearest point to the network (further details are shown in Appendix 3: Network Assessment) This would result in a considerable increase in CAPEX and a significant impact on the 40 year IRR.

Table 25: Effect of increase in network feed length

Feed length, m	Network length, m	CAPEX	Network losses	40 year IRR
Base case (best practice)	91,454 m	£60,651,605	12 GWh (22%)	8.8%
50% increase	107,756 m	£69,719,310	14 GWh (26%)	6.0%
100% increase	124,058 m	£78,787,014	16 MWh (29%)	3.7%

From this we can conclude that unless the feed pipes are installed in coordination with other utilities and that house layouts allow pipe length to be minimised, the project is unlikely to be economic.

Heat Demand

Figure 41 shows the effect of a variance in the total network heat demand for each phase, with all other parameters remaining constant. An increase in heat demand is shown to have a detrimental effect on the IRR for all network phases. This is due to only having electric boilers to cover peak capacity and does not consider the installation of additional or larger capacity heat pumps. If the heat demand was to significantly increase, then a larger or additional heat pump could improve the economic viability. A reduction in heat demand results in a slight reduction in the 40 year IRR.

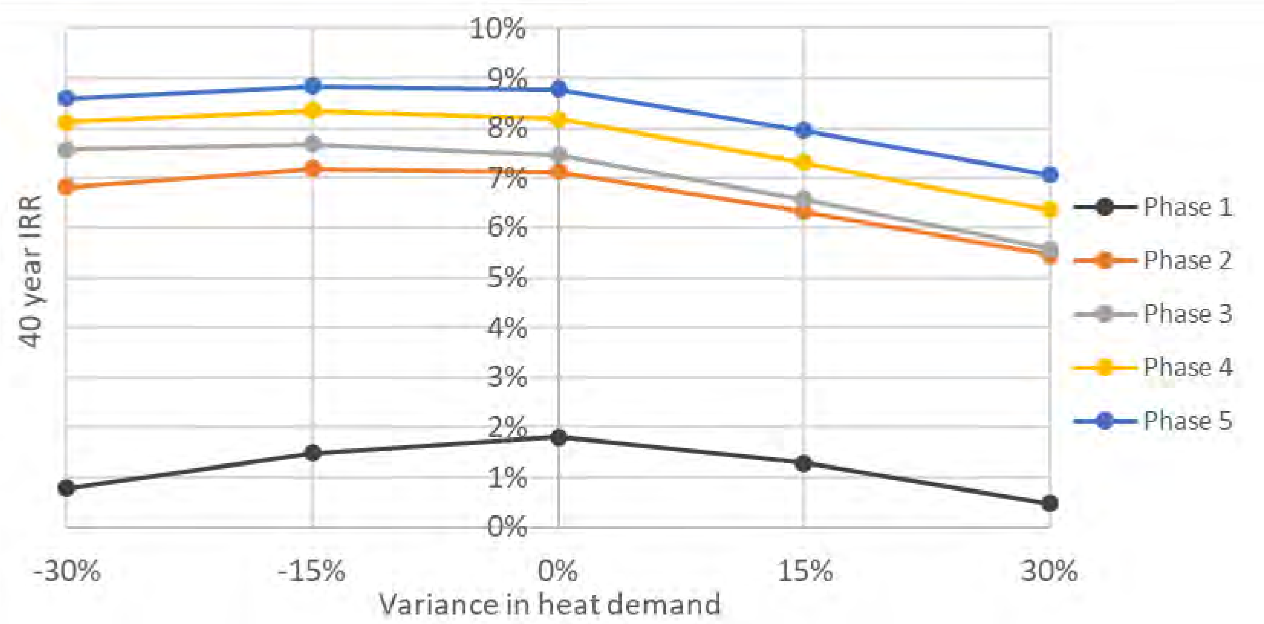


Figure 41: Effect of variance in heat demand

Heat Pump SPF$_{H2}$

Figure 42 shows the effect of variance in the SPF$_{H2}$ of the centralised ASHPs. This will have a significant effect on the scheme as the heat pumps supplier the majority of heat to the network. Base case SPF$_{H2}$ is 3.5.

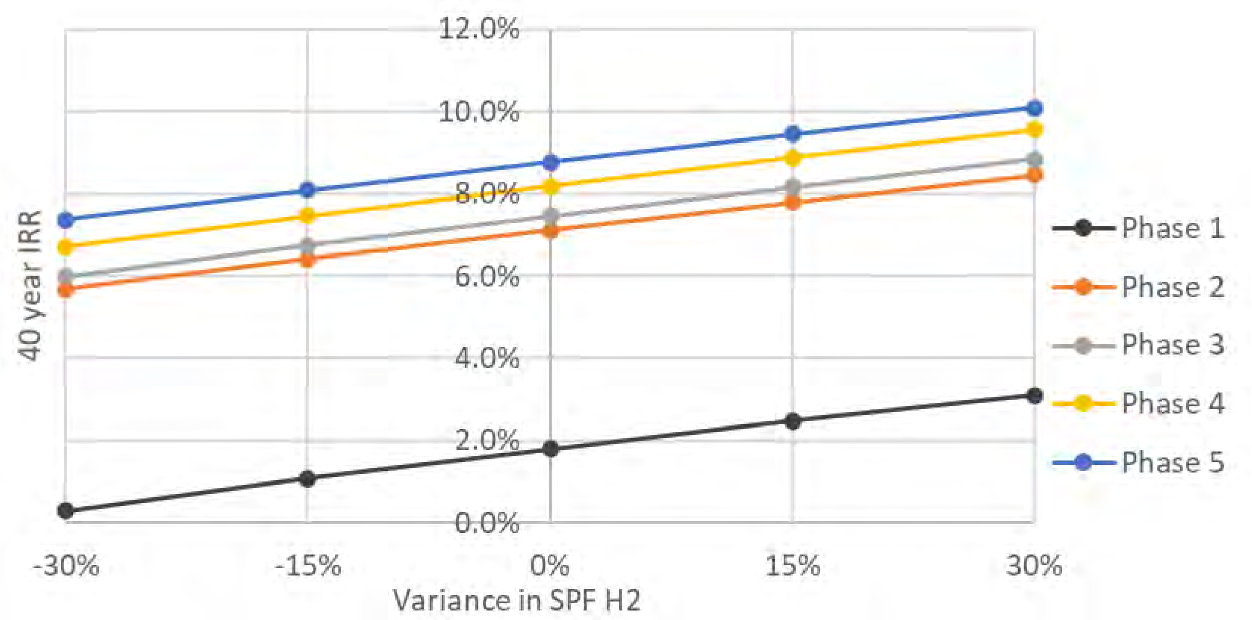


Figure 42: Effect of variance of heat pump SPF$_{H2}$

Heat Sales Tariff

Figure 43 shows the effect of a variance in heat sales tariff. It has been assumed as a base case that the variable element of the heat sales tariff will vary in line with the cost of electricity (based on the BEIS central scenario price projections for electricity). Fixed heat sales tariff has been assumed to be £1.41/day/connection and variable heat sales tariff has been calculated to be 7.97p/kWh for residential connections (see Appendix 6: Techno Economic Modelling - Key Parameters and Assumptions).

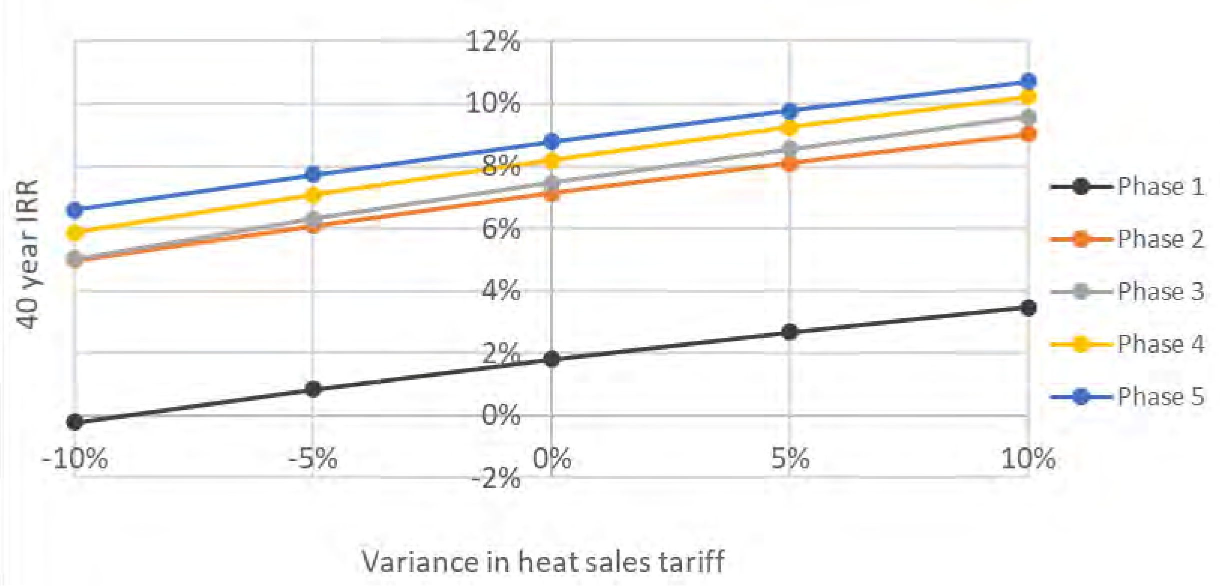


Figure 43: Effect of variance in heat sales tariff

Energy Centre Electricity Tariffs

Figure 44 shows the effect of a variance in electricity purchase tariff for the energy centre. This has a significant effect on the 40 year IRR for all network phases as all the energy centre electricity demand is met by import from the grid and makes up the highest operational expenditure for the network.

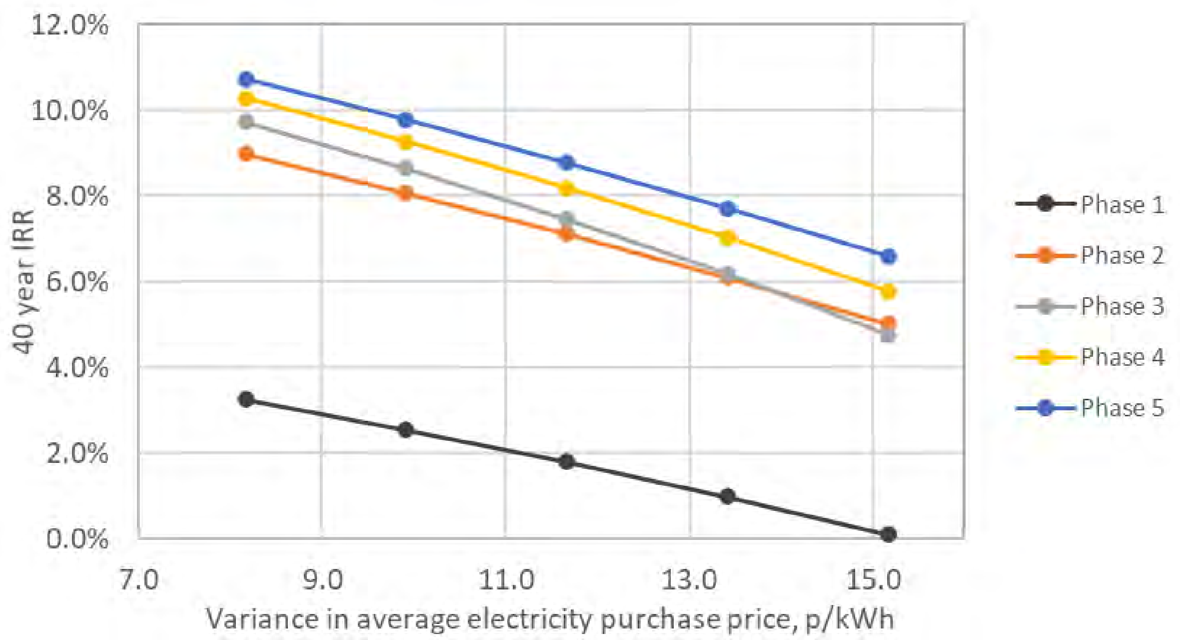


Figure 44: Effect of variance in energy centre electricity purchase tariff

Energy Price Indexing

The effect of price indexing on all energy tariffs is shown in Table 26. As all the energy centre demand is met by imported electricity and the heat sales prices are indexed against grid electricity too, there is very little variation between each of the scenarios.

Table 26: Effect indexing on all energy tariffs

Indexing for energy tariffs	40 year IRR				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
BEIS central scenario	1.80%	7.12%	7.47%	8.19%	8.78%
BEIS low scenario	1.92%	7.36%	7.81%	8.46%	9.02%
BEIS high scenario	1.85%	7.09%	7.38%	8.15%	8.76%
Fixed rate: 0 %	1.86%	7.10%	7.43%	8.20%	8.80%
Fixed rate: 2.5 %	1.94%	7.17%	7.48%	8.26%	8.86%

Table 27 below shows the effect of assuming variable heat sales tariffs only, and fixed and variable tariffs. In the base case, it has been assumed that the heat sales tariff would include a fixed and variable element with the variable tariff fluctuating in line with the BEIS electricity price projections and the fixed tariff remaining constant. It is recommended that there is a fixed and variable element to the heat sales tariff, however Table 27 shows the importance of the split between fixed and variable tariffs under current assumptions.

Table 27: Effect of variable and fixed heat sales tariffs

Heat sales tariffs	40 year IRR				
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Fixed and variable heat sales tariffs	1.80%	7.12%	7.47%	8.19%	8.78%
Variable heat sales tariffs only	-2.35%	2.95%	2.33%	3.47%	4.21%

Peak and reserve boilers

Figure 45 shows the effect on CO_2e emissions if the energy centre was to have peak and reserve gas boilers or electric boilers. As the grid decarbonises the difference between the CO_2e emissions of the network increases.

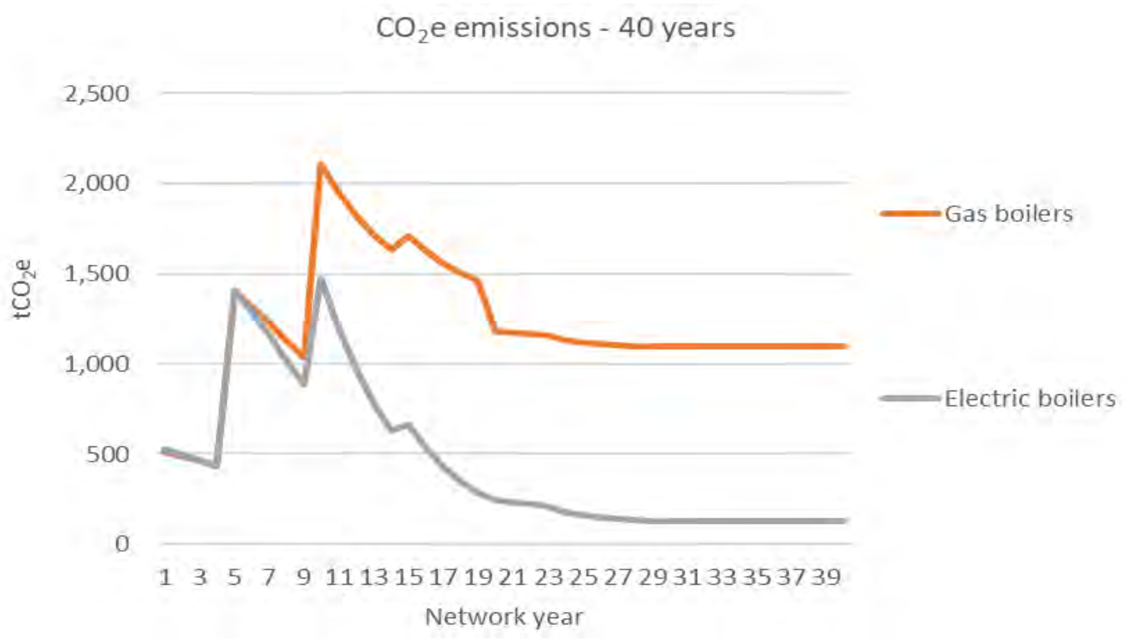


Figure 45: Effect on CO_2e if using gas or electric boilers

6.2.8 Risks

The main risks and constraints for the implementation of the ASHP heat network options have been considered and assessed. Table 29 outlines potential risks and issues that apply to the thermal network including both current risk and re-scored values.

Risk ratings are the product of impact and likelihood. The impact measures how much of an affect the risk being realised would have, and the likelihood is a measure of how probable the risk realisation is. The score associated with current risk is the level of risk present if no further action is taken, and re-scored risk levels are a measure of the risk present once the mitigating measures have been carried out.

A key showing the level of risk is shown in Table 28.

Table 28: 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 29: Summary of risks and issues – ASHP thermal network option

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Energy demand assessment	**ED1** Energy demands for the whole site are planned developments and are based on high level information.	Risk rating: 3	4	12	Energy demands for some planned developments have been based on high level information that is likely to change as development plans are progressed.	Energy demands have been estimated based on the most recent information available. Energy demands should be re-considered as development plans progress and more information becomes available.
		Mitigated risk rating: 3	3	9		
Energy demand assessment	**ED2** Planned developments are not brought forward. This can cause network demands to change.	Risk rating: 4	4	16	Volume risk is likely to sit with the network operator. Heat demand significantly impacts on network viability. If planned developments are either not built out or are built out but do not connect, then this will reduce the viability of network options. A lower heat demand does not have a large effect on the economics.	Master developer is clear that one of the conditions for building on the site will be to connect to a proposed network.
		Mitigated risk rating: 4	2	8		
Energy demand assessment	**ED3** Engagement with developers is not achieved and developments do not connect to network.	Risk rating: 5	3	15	All of the network demand is provided from planned developments.	Master developer is clear that one of the conditions for building on the site will be to connect to the proposed network. Planning policy / developer conditions are sufficiently robust and appropriate developer engagement will be required.
		Mitigated risk rating: 5	1	5		
Energy demand assessment	**ED4** The timing of the planned developments is estimated.	Risk rating: 4	4	16	If planned developments are brought forward sooner than expected, or are delayed, this will impact the network timing, phasing and the network viability. Which means that they might be built before the network is installed and therefore will require extra CAPEX for short term heating solution e.g., gas boilers or ASHP.	The most up to date information available for planned developments has been used. High level assumptions have been made for network phasing and the potential timing of network connections. The phasing and timing of the network should be further considered once additional information becomes available for developments
		Mitigated risk rating: 3	4	12		

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
Energy centre	**EC1** Energy centre design does not allow for connection of potential future heat sources, meaning there is little futureproofing measures	Risk Rating			Consideration should be given to futureproofing to ensure the energy centre could connect to a large low carbon heat source.	The site boundary is well defined with limited scope for future connection outside of the boundary to connect to the network. The current energy centre options include future proofing to allow for expansion.
		4	4	16		
		Mitigated risk rating				
		4	2	8		
	EC2 Heat pump working fluids require consideration.	Risk rating			R134a has a high GWP (global warming potential) may increase in cost as a result of the Kigali amendment. If ammonia or HFOs are used, then there is a safety risk that needs to be mitigated through design and operation.	Refrigerant choice needs to be considered in design measures and risk assessments as the project progresses.
		4	3	12		
		Mitigated risk rating				
		4	2	8		
	EC3 Not securing suitable energy centre locations	Risk rating			The network is reliant on suitable energy centre locations being secured. An energy centre location has been identified outside the current assessment boundary but is owned by the development landowner.	Potential energy centre locations have been assessed and selected based on land ownership, proximity to heat demands and discussions with Buckland Development. The proposed location is outside of the development boundary. Continued liaison will be required to ensure authorisation for an energy centre at the prioritised site.
		5	4	20		
		Mitigated risk rating				
		5	3	15		
	EC4 The visual impact of energy centres is deemed significant.	Risk rating			This could potentially increase design costs or limit the energy centre size. The visual impact of the proposed energy centre could be significant as it will be in a rural area without other similar industrial buildings	If the project progresses, further liaison will be required with FBC planning officers and other stakeholders to ensure the design and visual impact of the energy centres is acceptable. Sensitivity analysis has been undertaken to show the impact of an increase in energy centre costs, this is shown further in this section. Appropriate costings have been allocated to the energy centre in line with site specific risks. Costs for EC are given in Appendix 6 and risks discussed in 6.1.4
		5	3	15		
		Mitigated risk rating				
		5	2.5	12.5		

	Risk / issue	Impact	Likelihood	Rating	Rationale	Mitigating measure / action
	EC5 Air quality restrictions and considerations may restrict gas boiler options.	Risk rating: 5 Mitigated risk rating: 4	4 3	20 12	The proposed energy centre location is not within an AQMA. A detailed assessment of the flue design and emissions dispersion may be required to assess the impact if the project is progressed with gas boilers.	The CAPEX includes costs for electric boilers and therefore there will be no local emissions. If the project is progressed with gas boilers, emissions dispersion model, air quality impact and flue height assessment should be carried out at the detailed project development stage if required. Further assessment of the preferred backup boiler option is required. As discussed in 6.1.4
	EC6 Electric boiler option may not be economic and/or risk of extended operation not acceptable to any party	Risk rating: 5 Mitigated risk rating: 5	4 3	20 15	In the base case, the variable heat sale tariff is 8.37 p/kWh and the cost of heat from electric boilers is on average 12 p/kWh. If electric boilers are required to run for an extended period, this could significantly impact the economics of the scheme.	ASHPs are the main heat source for this network. A modular approach to the heat pumps has been selected to reduce the risk that if any one of the heat pumps fail then it will not impact the overall heat supply. Further assessment of the preferred backup boiler option is required. See Figure 45 for effect of gas and electric boiler on CO_2e emission.
Heat network and connections	**N1** Network options presented do not allow connection of additional heat demands.	Risk rating: 4 Mitigated risk rating: 4	4 2	16 8	Network options should, where possible, include futureproofing to allow additional heat demands to connect in the future, otherwise long-term success of the network may be damaged. Consideration should therefore be given to futureproofing to ensure the network has the capacity to serve future network phases and planned developments.	The site boundary is well defined with limited scope for future connections outside of the boundary to connect to the network.
Heat network and connections	**N2** Planned developments progress without futureproofing	Risk rating: 4 Mitigated risk rating: 4	4 3	16 12	It has been assumed that the cost of reinstatement of the road surface is not included. If a planned development is built without installing the pipes, this will significantly increase the cost of the network.	Continued liaison with Highways and developers will be required to ensure coordination when installing road surfaces. Network routes also need to be safeguarded.

	measures for network infrastructure.					
	N3 Project economics and scheme CO_2e intensity impacted by operation of temporary heating plant	Risk rating			Planned developments built out prior to network and so require short term heating solution such as temporary gas or electric boilers, or temporary ASHPs.	Details techno economic and financial work needs to account for this and if this proves to be significant, temporary ASHPs may be an option. The development is being progressed in the same time frame as the heating options and will be coordinated.
		4	4	**16**		
		Mitigated risk rating				
		4	2	**8**		
Economic assessment	**EA1** Capital costs are significantly higher than estimated.	Risk rating			Higher capital costs can have a significant impact on the viability of all network phases. If the economic assessment does not include robust project CAPEX, the likely financial benefits or does not provide sufficient information to secure funding, then the network plan will not progress.	All project costs have been based on a combination of previous project experience and recent quotes for similar projects. The consultant team have a large database the of actual costs of installing district energy schemes including costs for equipment supply and installation, distribution pipework supply and installation, trench excavation and re-instatement. Sensitivity analysis has been undertaken for network options to show the effect of a variance in capital costs, this is shown in the "Sensitivity and Risk" section of the relevant schemes.
		5	4	**20**		
		Mitigated risk rating				
		5	2	**10**		
	EA2 Variation in heat sales tariffs significantly affects economics.	Risk rating			Variation in heat sales tariffs have a significant impact on the viability of all network options. Decrease of 10% in heat sales tariff for phase 1 will lower the 40 year IRR from 1.8% to -0.2%.	Baseline tariffs have been based on the cost of heat to end users with an Air Source Heat Pump counterfactual. Tariff calculations have included unit rates for electricity tariffs (estimated using data from previous projects), ASHP efficiency, and maintenance and replacement costs. Sensitivity analysis has been undertaken to show the effect of heat sale tariff variation, this is shown in the "Sensitivity and Risk" section of the relevant schemes.
		5	4	**20**		
		Mitigated risk rating				
		5	2	**10**		
	EA3 Variation in electricity import tariffs significantly affects economics.	Risk rating			Variation in electricity import tariffs have a significant impact on the viability of network options. An increase in electricity purchase price of 30% will lower the phase 1 40 year IRR from 1.8% to 0.1%	Import tariffs have been based on current tariffs for existing energy centres from similar projects. Sensitivity analysis has been undertaken to show the effect of electricity import tariff variation, this is shown in the "Sensitivity and Risk" section of the relevant schemes. Any heat supply contracts should include indexing of the variable element of customer tariffs to mitigate this risk.
		5	4	**20**		
		Mitigated risk rating				
		5	3	**15**		

	EA4 Energy centre gas or electricity connection charges are higher than estimated.	Risk rating 5 | 4 | **20** Mitigated risk rating 5 | 3 | **15**			There is a risk that utility connection costs will be higher than those estimated for the assessment. There is a potential that upgrades to the electricity infrastructure would be required which would result in a significant increase in connection costs.	All project costs have been based on a combination of previous project experience and recent quotes for similar projects. The electricity substation where power is expected to be taken from is being installed as part of the planned development and will be sized accordingly.
General	**G2** Local planners are not fully engaged / aware of the study outputs.	Risk rating 5 | 4 | **20** Mitigated risk rating 5 | 3 | **15**			Planning officers within FBC have a key role to play in ensuring the viability of the project. The role of planners in district heating is to provide appropriate policy and supporting guidance to developers in the development or extension of networks.	Engagement with planning officers is ongoing and will be further strengthened as the project progresses. The energy centre preferred location is located outside of the current assessment area and will require a separate planning application. If the thermal network is the preferred option, then the local planners should be engaged as soon as possible.
General	**G3** Planned developments are brought forward prior to network development.	Risk rating 4 | 4 | **16** Mitigated risk rating 4 | 3 | **12**			Developers may install alternative heating systems within planned developments if DHN is not in place prior to construction.	Network phases have been assessed based on information currently available on timing of planned developments. This should be reassessed as networks are progressed and more information on planned developments becomes available.

6.2.9 Thermal Network Summary

The proposed network has been assessed over 5 phases. Phase 1 will connect the initial development of ~600 dwellings and install the network spine from the energy centre to the phase 1 demands. The future phases will build out the spine as required and build out the development parcels.

Phase 1 of the scheme is not economically viable without grant funding, and it may not attract private sector investors. However, as the development increases in size the returns improve dramatically. As the site is being built out by a single developer the future phases may be deemed more secure. The private sector may take a longer-term view of the site as the yields are higher however the risk of the site not being developed at the planned rate may limit the interest.

6.3 Ambient Cluster Network

Ambient cluster networks could be built out to correspond with the wider development and be sized based on a combination of site build out rate and the estimated optimum number of houses per cluster. The Ambient cluster network would consist of GSHP in each dwelling and commercial building and local pumping station.

Table 30 shows a summary of the proposed cluster sizes and build out rates for the development.

Table 30: Proposed cluster sizes

Parcel Name	Assumed build year	Phase	No. of dwellings
Chesterfield	2023	1	180
Dashwood	2023	1	220
Heytesbury	2023	1	185
Chesterfield+ Park Village East	2025	1	105
Park Village East	2026	2	210
Dashwood	2026	2	186
Chesterfield	2026	2	128
Heytesbury	2026	2	236
Park Village East	2028	2	240
Park Village East	2029	2	220
Norton	2030	2	100
Park Village West	2030	2	100
Heytesbury	2031	3	127
Park Village West	2031	3	110
Norton	2031	3	222
Park Village West	2032	3	230
Park Village West	2033	3	200
Welborne	2033	3	185
Park Village West	2034	3	121
The Ride	2034	3	155
Welborne	2035	3	200
Blakes Copse	2036	4	190
Welborne	2036	4	120
Welborne	2037	4	200
The Ride	2036	4	90
Albany	2038	4	115
Blakes Copse	2038	4	125
Welborne	2038	4	141
Albany	2039	4	165
Highstead	2039	4	129
Albany	2040	4	122
Blakes Copse	2040	4	103
Highstead	2041	5	210
Albany	2042	5	250
Highstead	2042	5	181
Albany + Sawmills	2043	5	199

Parcel Name	Assumed build year	Phase	No. of dwellings
Care Home Site (Phase 1a) 2023	2023	1	Commercial connections
Northern Nursery (Phase 1a) 2023	2023	1	
Northern Primary School (Phase 1a) 2023	2023	1	
Phase 1 Commercial	2023	1	
District Centre Primary School 2029	2029	2	
M1 parcel total	2030	2	
Norton commercial	2030	2	
District Centre Secondary School 2031	2031	3	
Park Village West commercial	2031	3	
M2 parcel total	2033	3	
Welborne Commercial	2034	3	
Western Primary School	2034	3	

6.3.1 Concept design

This section describes the scheme concept design and includes details of the primary heat sources, pumping station and other associated equipment, utilities connection requirements and metering for the proposed ambient cluster networks.

Ambient Cluster Design

An ambient cluster network will consist of a shared ground loop utilising boreholes as the energy source. Each property will have a ground source heat pump installed internally, with a connection to this ground loop. A pumping station will be required to maintain a differential pressure across the branches of the ambient network to allow the individual heat pumps to operate effectively. Figure 46 shows a Process flow diagram (PFD) for the proposed ambient clusters.

Boreholes

Closed loop boreholes will provide the heat source for the ambient clusters. A borehole consists of a hole drilled between 60 to 200m deep. The diameter of a borehole is typically around 110 to 150mm, although this may change depending on each individual cluster design.

The first few metres of a borehole shall be sleeved with a casing to prevent the sides from collapsing. The depth of this casing depends on the material that the borehole is drilled into and the depth of soil. Boreholes must be separated from each other to prevent interference. They are generally placed 5 to 6m apart. However, for these larger clusters, the interference from one borehole to another must be calculated to ensure there is adequate spacing and sufficient depth between them. This ensures the ground can recover its heat and stops the ground from freezing. If surface space is limited co-axial boreholes may be used as they allow surface level grouping because they use inclined borehole drilling, however they tend to be more expensive than U-tube.

The boreholes will be connected together with a manifold to ensure equal distribution of flow across each borehole. Manifolds can be located at the pumping station building or the pipes can be connected in a subterranean manifold within a trench at the edge of the bore field.

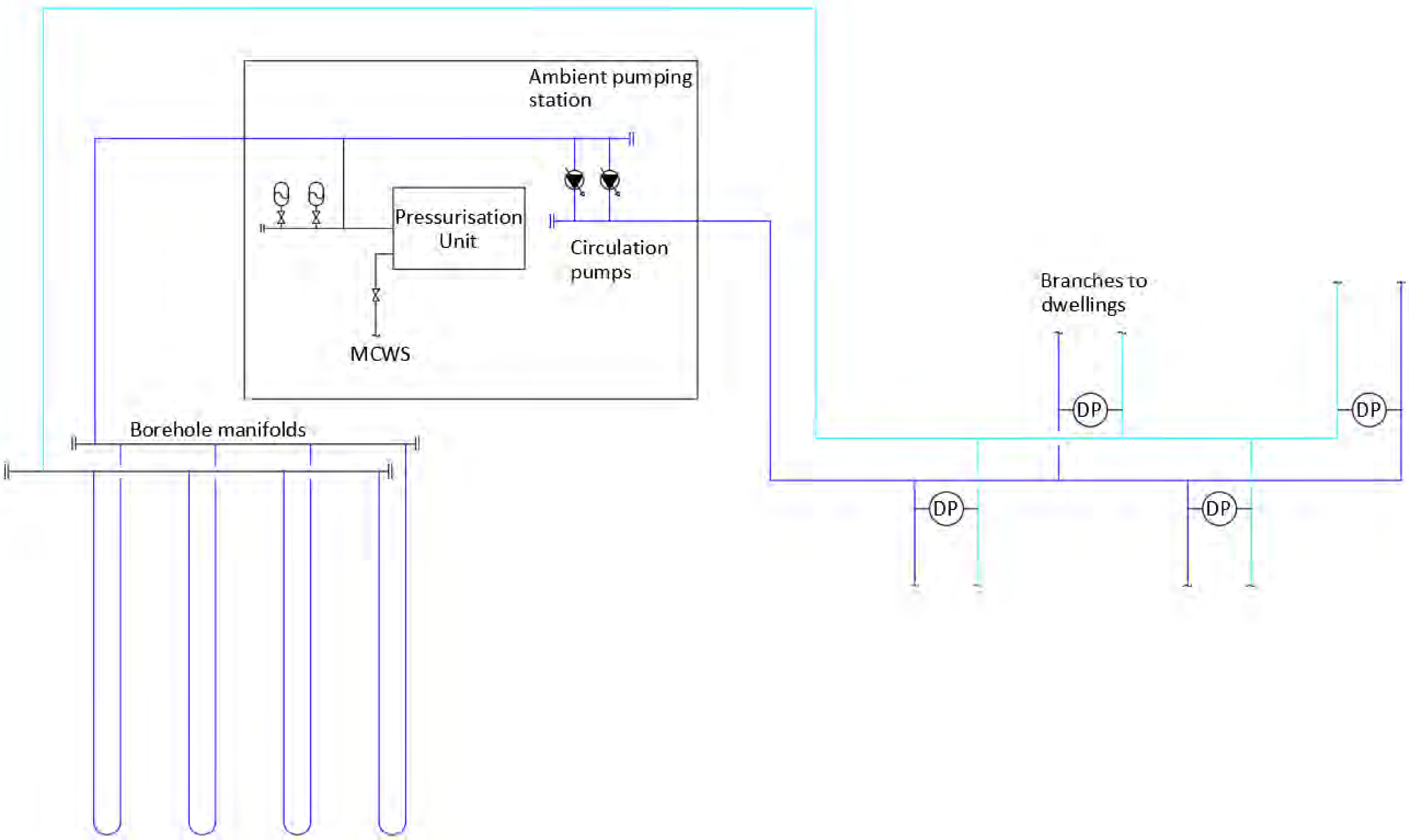


Figure 46: Ambient cluster concept PFD

Network pipework

The ambient cluster network shall consist of non-insulated medium density polyethylene (MDPE). For pipe sizes smaller than 90 OD these can be supplied in coils up to 150m and pipes up to 180 OD can be supplied in coils up to 100m. Larger pipes are supplied in 6m or 12m sections. For connecting each branch or house either mechanical compression fittings or electrofusion fittings shall be used.

Cluster sizes

As the number of dwellings increases the peak demand required per dwelling from the ambient loop decreases sharply but reaches a minimum at around 100 houses (see Figure 47). This is due to the increased diversity with the greater number of dwellings connected. The diversity has been calculated using a combination of the space heating diversity demand from Heat Network CP1 and DHW from Hot Water Association: Stored Hot Water in Heat Networks HWA:DG1.

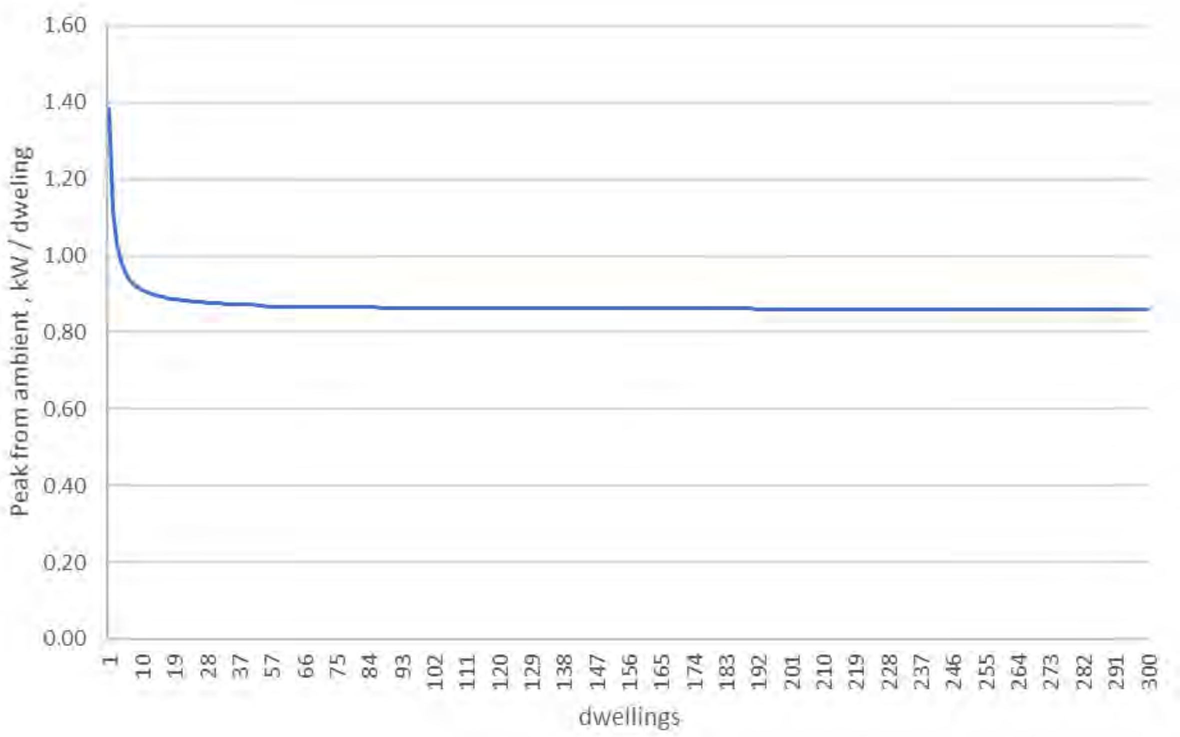


Figure 47: Peak per dwelling from ambient loop

The upper cluster size threshold has been estimated on a cost basis. As more dwellings are connected, the ambient network spine will need to increase in diameter to meet the increase in peak demand. Figure 48 summarises the relationship between the cost and size of plastic pipes.

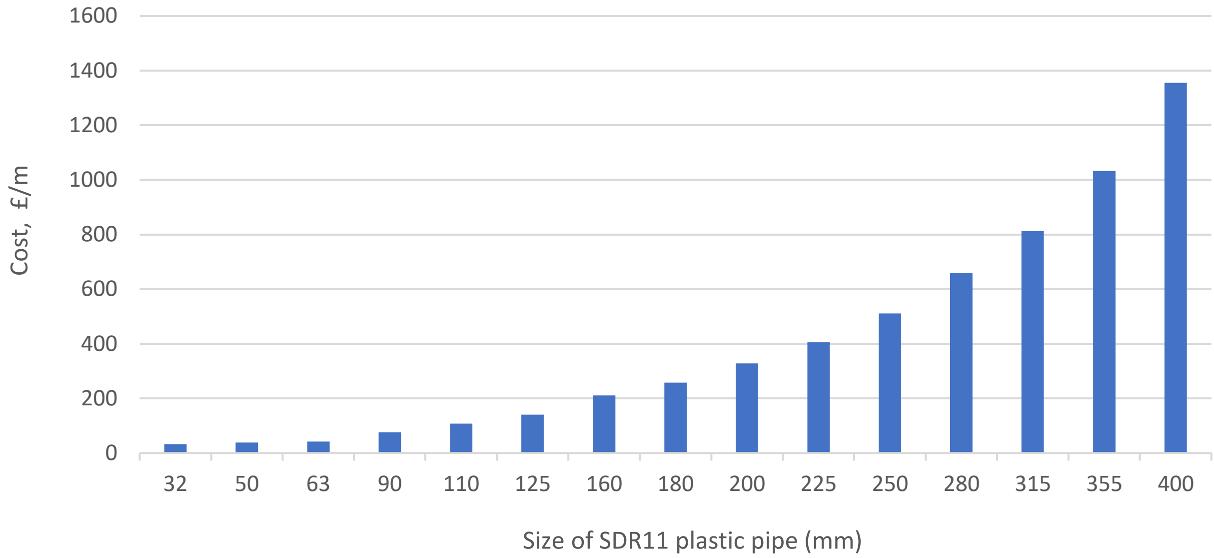


Figure 48: Cost of plastic pipes

From these two figures, the cost of a cluster ambient network (including boreholes) per dwelling is estimated (see Figure 49). The greater the number of connected dwellings, the greater the demand, and the larger the diameter of pipe required. As a result, the recommended number of dwellings in a cluster is between 100 and 400, ensuring that the energy from boreholes is efficiently utilised, network cost and length is minimised, and demand diversity fully considered.

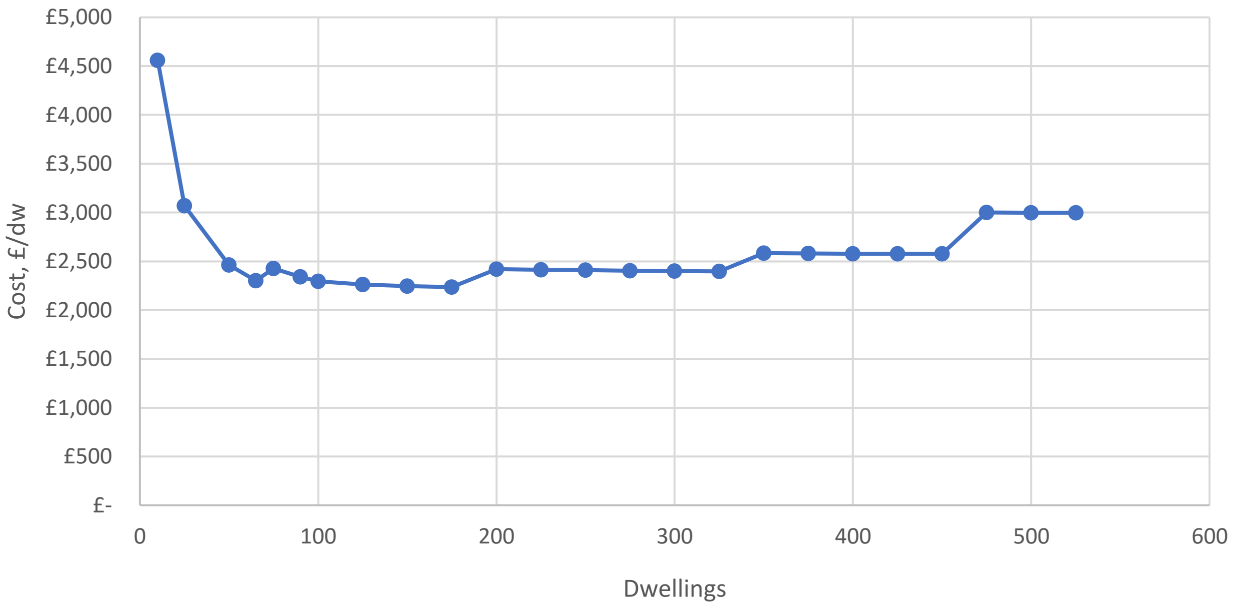


Figure 49: Cost of ambient network per dwelling in ambient cluster option

Pumping station

A pumping station is required for each ambient cluster loop. Individual heat pumps located in each dwelling also require an extraction pump connected to the ambient loop. There will be a detrimental effect on the performance of these heat pumps if the differential pressure in the ambient loop is greater than ~70 kPa (which would be possible in the larger networks). The ambient network should include strategically placed differential pressure sensors on the network branches (where they leave the spine). The pumping station will then be controlled to maintain the required differential pressures and ensure efficient heat pump operation. An example of a typical pumping station layout is given below in Figure 50.

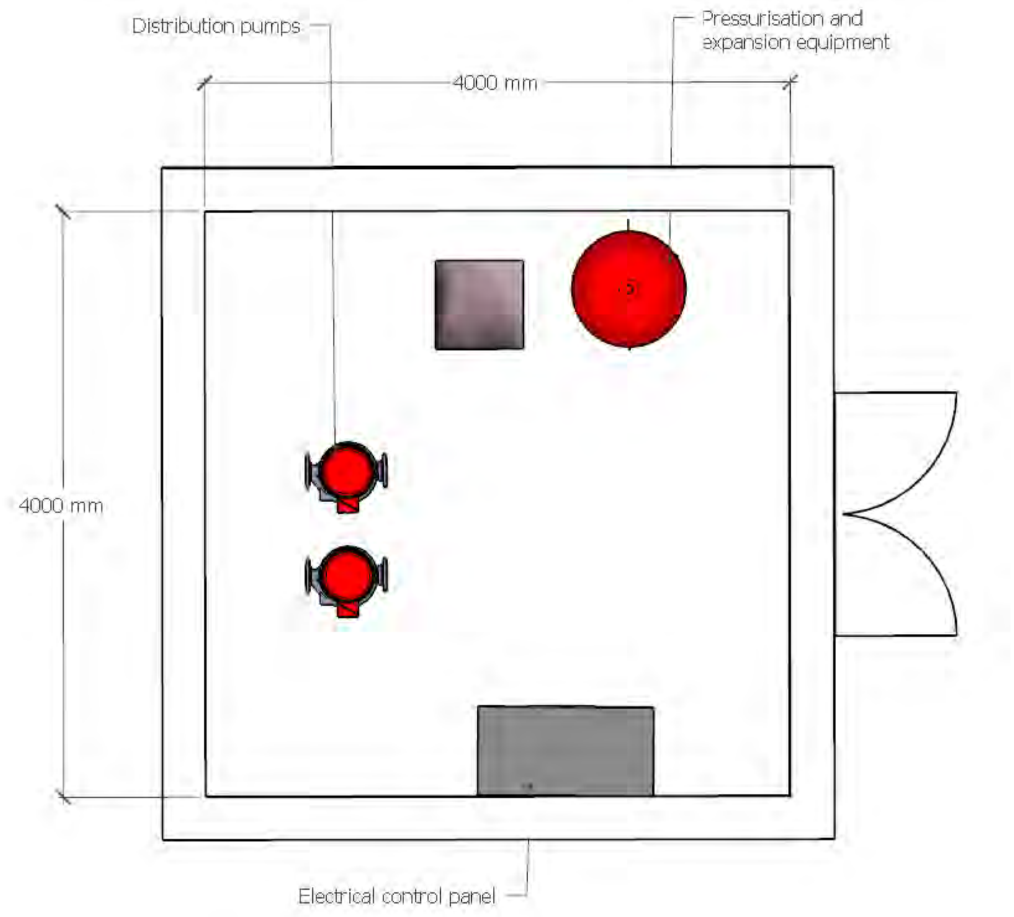


Figure 50: Typical pumping station layout

Futureproofing

By installing ambient networks on a cluster-by-cluster basis the overall network is futureproofed by the nature of the build-out and upfront CAPEX associated with futureproofing is minimised.

Utilities Connections

An electricity connection will be required to supply the circulation pumps. Each pumping station will require 3-5 kVa 3 phase connection.

A mains water supply and drainage will be required for each pumping station.

Metering

All metering should be specified with suitable accuracy class in accordance with the Measurement Instrumentation Directive to satisfy the utility requirements for the purchase and sale of heat, water, and electricity for the energy centre.

- ***Water***

There should be water meters to determine the cumulative use by each of the system pressurisation units, water treatment plant and the overall incoming mains water to each pumping station. All data should be collected by the control system.

- ***Electricity***

Electricity meters should be fitted to measure the import electricity from the grid.

Variable Speed Pumps

The designs utilise variable speed pumps in a multi-pump arrangement (2 pumps – 1no. duty and 1no. standby). They should be controlled to maintain a minimum pressure difference at specific locations using index differential pressure sensors within the network. The pump set will be speed controlled to maintain a set point differential pressure at the systems pressure index. The pumps should be sized to operate as duty/standby - allowing for modulation in the full range of required supply.

The benefits of the variable speed function will be realised as peak flow rate conditions will typically only occur for brief periods during a heating season, with average demands being much lower.

6.3.2 Building Connections

When connecting the ambient network to individual dwellings, the boundaries of responsibility must be considered (see Figure 51).

The house builder will be responsible for the property's electricity connection, distribution board, main electric meters, heat emitters, DHW outlets and the building penetrations.

The network provider will be responsible for providing and installing heat pumps, hot water cylinders, electric sub-meters, connection to the internal heating and DHW circuits, and final connection to the network.

It is important to establish responsibility boundaries as these will significantly impact economics of the project if they differ to the boundaries shown in Figure 51.

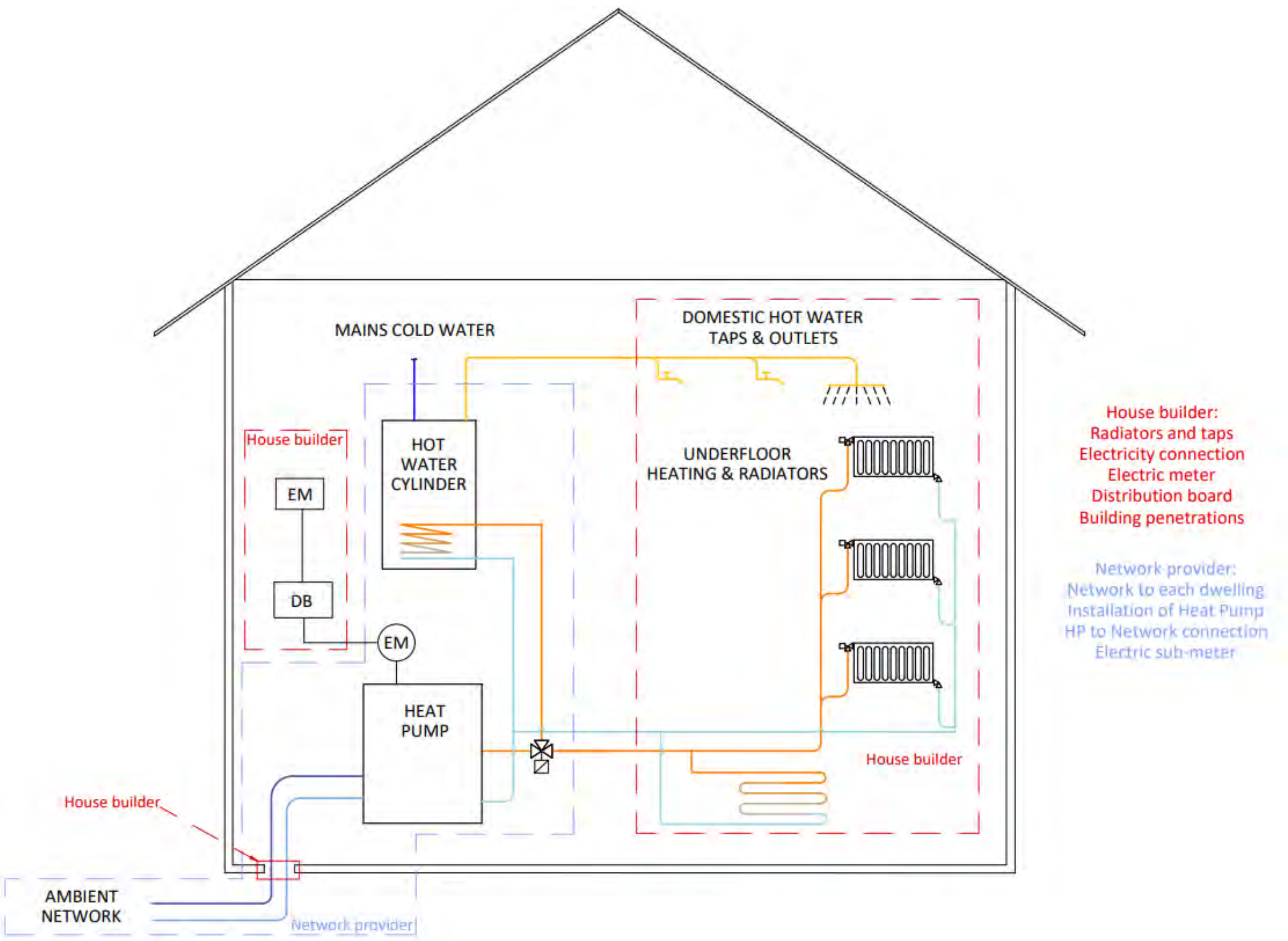


Figure 51: Domestic heat pump installation boundaries

6.3.3 Economic Assessment

The economic model for the ambient network option is not directly comparable to that of a thermal network; there is no variable heat sales income from the ambient network, and we have assumed it relies on a fixed annual service charge. In this techno-economic model the initial connection fee has been split between the cost of heat pump purchase and installation and the cost of the network installation.

To fully assess risk, the economic assessment of the ambient cluster model should be considered as two economic assessments:

1. The sale/purchase and installation of HPs, assessment of network including HPs
2. The operation and maintenance of the network, or a network only economic assessment

The economic assessment results below show the overall project economics (including HP CAPEX, their installation, and network operation),see Table 31 and network only economics (including network CAPEX and revenue from fixed tariff),see Table 32.

Details of the assumptions used in techno-economic modelling are shown in Appendix 6: Techno Economic Modelling - Key Parameters and Assumptions.

The 25 year, 30 year and 40 year economic assessments for each phase the network are shown in Table 31. The capital cost does not include connection charges, however the IRR, NPV and net income account for connection charges from developer of £6000/dwelling and £450/kWh for commercial connections.

Table 31: Economic assessment with HP CAPEX

		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs for each phase (including contingency)		£6,753,651	£14,604,994	£17,190,420	£11,554,856	£6,551,611
Total cumulative capital costs (including contingency)			£21,358,646	£38,549,066	£50,103,922	£56,655,533
25 years	IRR	-4.6%	-9.4%	N/A	N/A	N/A
	NPV	£214,974	-£91,161	-£1,596,506	-£1,284,636	-£1,521,302
	Simple payback	16	18	22	22	23
	Net income	£1,502,331	£3,378,355	£2,982,110	£4,206,532	£3,921,991
30 years	IRR	-0.1%	-2.6%	-7.0%	-5.8%	-6.2%
	NPV	£503,764	£816,954	£8,001	£921,267	£1,019,282
	Simple payback	16	18	22	22	23
	Net income	£2,258,627	£5,756,569	£7,184,069	£9,983,453	£10,575,391
40 years	IRR	3.7%	2.6%	1.0%	2.0%	2.2%
	NPV	£951,572	£2,225,111	£2,496,011	£4,341,822	£4,958,806
	Simple payback	16	18	22	22	23
	Net income	£3,771,219	£10,512,997	£15,587,988	£21,537,295	£23,882,190

The capital costs, operational expenditure, revenue, and cumulative cash flow for the 40 year case for the full network is shown in Figure 52 for the ambient cluster network including HP CAPEX.

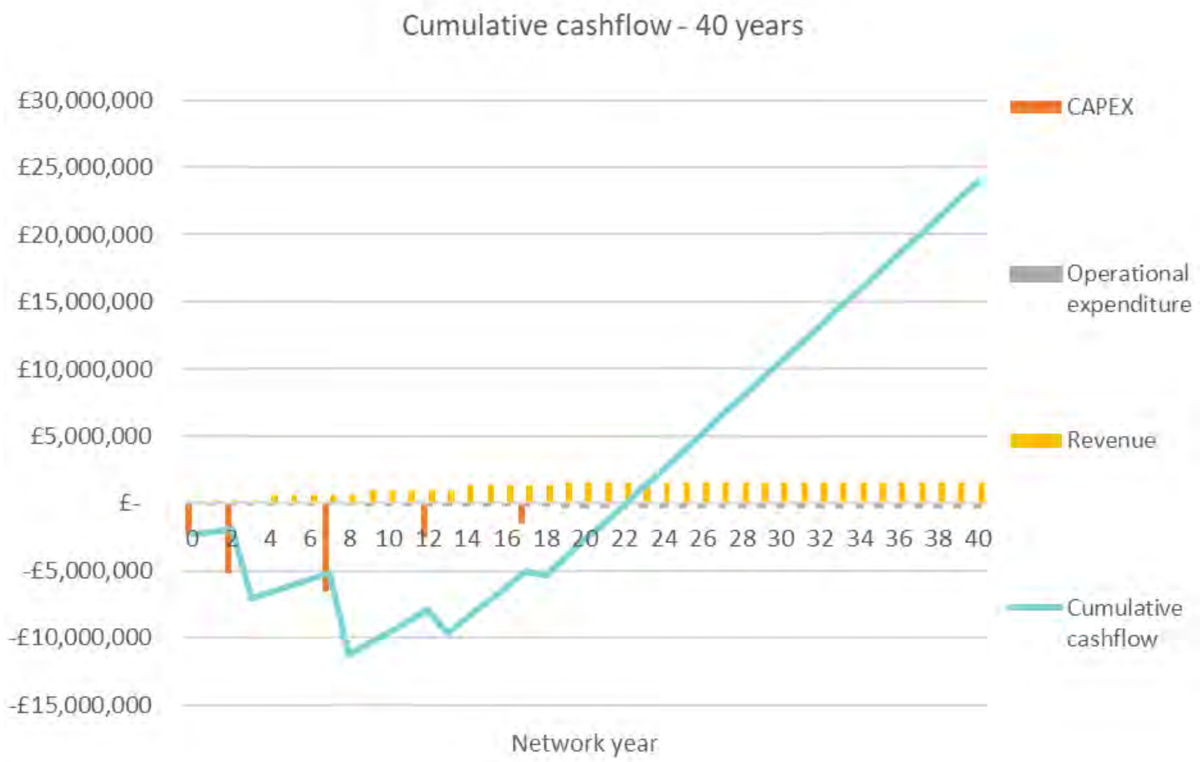


Figure 52: Cumulative cash flow- including HP CAPEX - 40 years

Table 32 shows 25 year, 30 year and 40 year economic assessments for network only for each phase of the ambient cluster networks option. The capital cost does not include connection charges, however the IRR, NPV and net income account for connection charges from developer.

Table 32: Economic assessment for network only

		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs for each phase (including contingency)		£2,530,308	£5,466,226	£6,757,767	£3,864,789	£2,245,173
Total cumulative capital costs (including contingency)			£7,996,534	£14,754,301	£18,619,090	£20,864,263
25 years	IRR	1.0%	-1.3%	-6.5%	-6.9%	-8.3%
	NPV	£682,318	£1,542,796	£1,196,287	£1,629,653	£1,450,262
	Simple payback	12	15	18	19	20
	Net income	£1,969,675	£5,139,267	£6,269,274	£7,683,764	£7,505,661
30 years	IRR	4.0%	2.8%	0.1%	0.5%	0.2%
	NPV	£971,107	£2,450,911	£2,800,795	£3,835,556	£3,990,846
	Simple payback	12	15	18	19	20
	Net income	£2,725,971	£7,517,481	£10,471,234	£13,460,685	£14,159,061
40 years	IRR	6.6%	6.1%	4.9%	5.6%	5.6%
	NPV	£1,418,915	£3,859,068	£5,288,804	£7,256,111	£7,930,370

		Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
	Simple payback	12	15	18	19	20
	Net income	£4,238,563	£12,273,909	£18,875,153	£25,014,527	£27,465,860

The capital costs, operational expenditure, revenue, and cumulative cash flow for the 40 year case for the full network is shown in Figure 53.

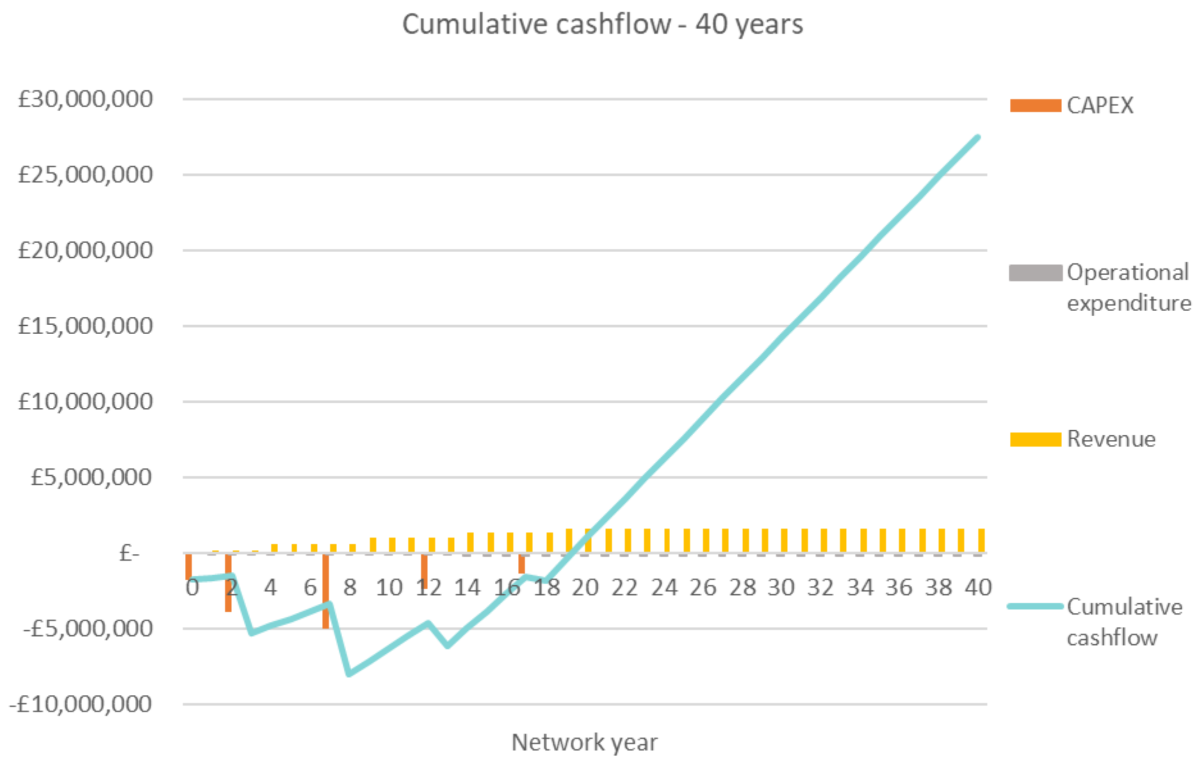


Figure 53 : Cumulative cash flow for network only - 40 years

Green Heat Network Fund core metrics

Table 33 shows GHNF criteria and Ambient cluster network parameters.

Table 33: Green Heat Network Fund core metrics

Metric	Minimum score	Ambient cluster scheme
Carbon gate	100 gCO_2e/kWh thermal energy delivered	The maximum intensity is 79 gCO2e/kWh, which is reached in year 1 of operation but then decreases as the electric grid decarbonises
Customer detriment	Domestic and micro-businesses must not be offered a price of heat greater than a low carbon counterfactual for new buildings and a gas/oil counterfactual for existing buildings	Customer service charges have been calculated using an ASHP counterfactual
Social IRR	Projects must demonstrate a Social IRR of 3.5% or greater over a 40-year period	The 40 year social IRR is 19.3% for phase 1 and 17.6% for phase 5 (based on carbon savings against gas boiler)

Metric	Minimum score	Ambient cluster scheme
Minimum demand	For urban networks, a minimum end customer demand of 2GWh/year. For rural networks, a minimum number of 100 dwellings connected	End customer demand is 4.3 GWh/year for phase 1 and 34 GWh/year for the fully built network
Maximum capex	Grant award requested up to but not including 50% of the combined total capex + commercialisation costs	Grant funding request amount to be determined
Capped award	The total 15-year kWh of heat/cooling forecast to be delivered will not exceed 3.33 pence of grant per kWh delivered (subject to review by GHNF)	The maximum grant funding available according to this metric is £8,686,460, which is 15% of total capex + commercialisation cost, but significantly more than 50% of phase 1
Non-heat/cooling cost inclusion	For projects including wider energy infrastructure in their application, the value of income generated/costs saved/wider subsidy obtained should be greater than or equal to the costs included.	No non-heat/cooling infrastructure included

GHNF considers cluster ambient network option as aggregation of communal heating systems, under point 2.3 from "Green Heat Network Fund Transition Scheme" [5] as long the applicant can prove that the communal heating system is a part of wider heat decarbonisation strategy, and the heating system is designed to enable future connections.

The ambient cluster network also fulfils criteria of point "2.6 Shared Ground Loops vs Ambient Loops", which states that the network will be classified as ambient loop if it will distribute 2 GWh/year or more thermal energy and is a centrally managed network. Individual clusters may be aggregated into a single application to enable the required target for distribution of thermal energy. This will allow the clusters to be optimised based on pipe sizes and build-out while still be eligible for grant funding.

Table 34 shows impact of grant funding for phase 1 on 40 year IRR.

Table 34: Impact of grant funding

Grant funding for phase 1	Phase 1 40 year IRR	Phase 2 40 year IRR	Phase 3 40 year IRR	Phase 4 40 year IRR	Phase 5 40 year IRR
0%	3.7%	2.6%	1.0%	2.0%	2.2%
10%	7.5%	3.8%	1.8%	2.7%	2.8%
20%	13.7%	5.2%	2.7%	3.5%	3.6%
25%	19.5%	6.0%	3.1%	3.9%	4.0%

6.3.4 Environmental benefits and impact

Network emissions

Planned developments have been assessed with individual air source heat pumps as the base case BAU. Individual ASHPs CO_2e emissions, network CO_2e emissions and CO_2e savings for the network are shown in Figure 54 and Table 35. The green line shows the difference between CO_2e emissions in the BAU emissions and the network emissions. The individual ASHP emissions

[5] Green Heat Network Fund Transition Scheme guidance (publishing.service.gov.uk)

decrease due to the reduction in emissions factor for grid electricity used in assessments and increases with the increase in heat demand with each network phase. The ambient network emissions reduce over time as the grid decarbonises.

Choice of refrigerant for commercially available heat pumps influence the CO_2e emissions from GSHP used in ambient network as well as individual ASHP used as counterfactual option. Data and leakage rates of the refrigerants can be found in Appendix 5: Heat Pump refrigerant.

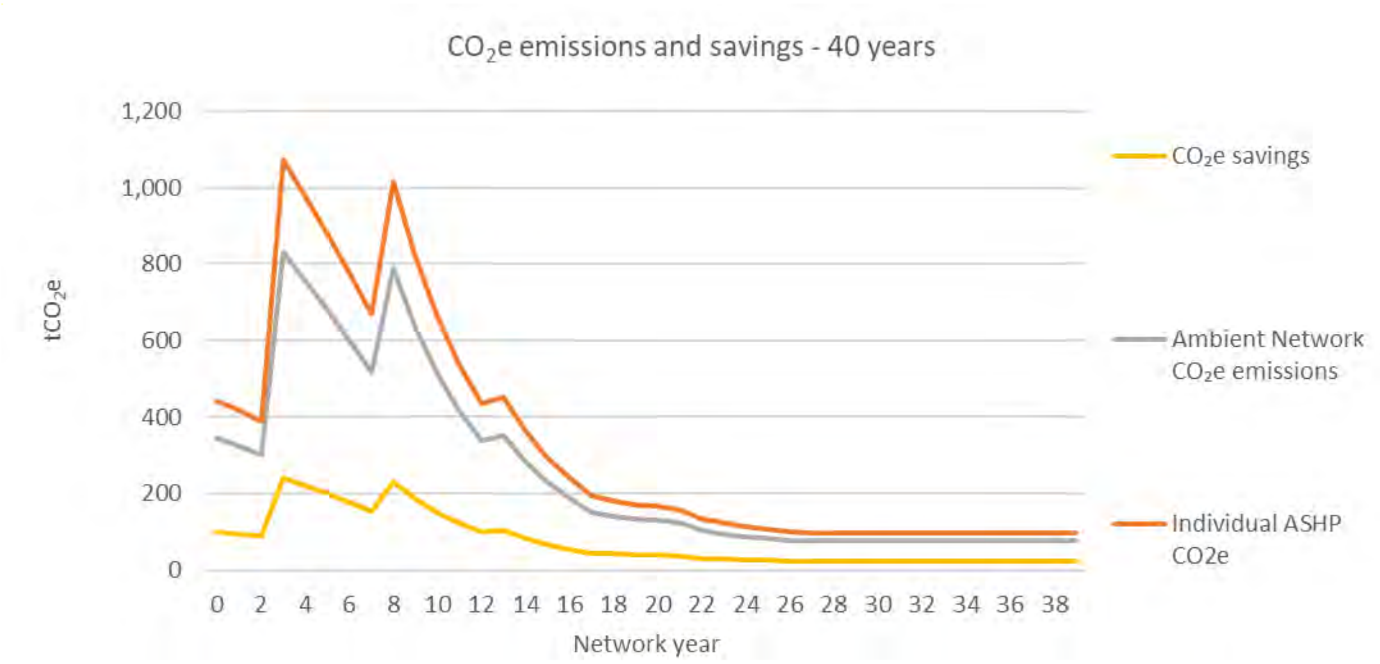


Figure 54: Network CO2e emissions and savings

Table 35: Network CO_2e emissions and savings

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Network CO_2e emissions (25 years), tCO_2e	2,856	6,600	8,548	8,971	9,060
Total CO_2e savings (25 years), tCO_2e	833	1,922	2,494	2,615	2,640
Network CO_2e emissions (30 years), tCO_2e	2,904	6,743	8,816	9,314	9,445
Total CO_2e savings (30 years), tCO_2e	847	1,964	2,573	2,715	2,752
Network CO_2e emissions (40 years), tCO_2e	2,998	7,023	9,339	9,985	10,199
Total CO_2e savings (40 years), tCO_2e	874	2,045	2,726	2,910	2,971
Annual CO_2e savings (year 1), tCO_2e	100				
CO_2e intensity of heat delivered (year 1), gCO_2e/kWh	79				
CO_2e intensity of heat delivered (40 year average), gCO_2e/kWh	17	17	17	17	17
CO_2e intensity of heat from individual ASHPs (year 1), gCO_2e/kWh	102				
CO_2e intensity of heat from individual ASHPs (40 year average), gCO_2e/kWh	22				

The CO_2e intensity of heat delivered in the first year of network operation is significantly lower than the current SBEM/SAP (2012) figure for notional building connected to a district heat network of 190 gCO_2e/kWh. And is lower than proposed 350 gCO_2e /kWh threshold for existing network in the Part L 2022 uplift.

Visual and acoustic impact

There will be minimal visual and acoustic impact on the surrounding character of the development. For every cluster there will need to be a pumping station, but these will be small as they only contain pressurisation equipment, pumps and water treatment equipment.

Social IRR and NPV

The environmental benefits of the scheme can be quantified by monetising the CO_2e savings and the improvements in air quality against the use of individual gas boilers. The economic value of the CO_2e and air quality improvements are included in the project cashflow to generate a social IRR and NPV. Assessment including HP CAPEX and network only are shown in Table 36 and Table 37 respectively. The social IRR helps to identify the wider benefits of the scheme for the community and is a vital consideration for local authorities. Social IRR calculations were based on the carbon savings of the network against gas boilers. The large increase in social IRR is due to the new BEIS CO_2e emission projections, which predicts rapid decarbonisation of electricity grid from 2030.

Table 36: Social IRR and NPV with HP CAPEX included

		IRR	Social IRR	NPV	Social NPV
Phase 1	25 years	-4.55%	19.07%	£214,974	£9,193,444
	30 years	-0.07%	19.19%	£503,764	£10,165,269
	40 years	3.73%	19.26%	£951,572	£11,686,191
Phase 2	25 years	-9.44%	16.68%	-£91,161	£16,021,820
	30 years	-2.60%	16.95%	£816,954	£18,965,846
	40 years	2.60%	17.12%	£2,225,111	£23,572,613
Phase 3	25 years	N/A	16.30%	-£1,596,506	£21,775,092
	30 years	-6.97%	16.71%	£8,001	£27,191,637
	40 years	1.03%	16.96%	£2,496,011	£35,668,719
Phase 4	25 years	N/A	16.71%	-£1,284,636	£25,102,176
	30 years	-5.78%	17.18%	£921,267	£32,191,709
	40 years	2.04%	17.46%	£4,341,822	£43,284,911
Phase 5	25 years	N/A	16.75%	-£1,521,302	£25,813,237
	30 years	-6.18%	17.27%	£1,019,282	£33,837,542
	40 years	2.17%	17.57%	£4,958,806	£46,392,516

Table 37: Social IRR and NPV for network only

		IRR	Social IRR	NPV	Social NPV
Phase 1	25 years	0.96%	22.51%	£682,318	£9,660,787
	30 years	3.97%	22.59%	£971,107	£10,632,613
	40 years	6.58%	22.63%	£1,418,915	£12,153,534
Phase 2	25 years	-1.28%	20.91%	£1,542,796	£17,655,778
	30 years	2.76%	21.07%	£2,450,911	£20,599,804
	40 years	6.08%	21.16%	£3,859,068	£25,206,571
Phase 3	25 years	-6.50%	20.76%	£1,196,287	£24,567,886
	30 years	0.12%	21.02%	£2,800,795	£29,984,431
	40 years	4.92%	21.15%	£5,288,804	£38,461,513
Phase 4	25 years	-6.94%	21.07%	£1,629,653	£28,016,465
	30 years	0.50%	21.37%	£3,835,556	£35,105,998
	40 years	5.55%	21.52%	£7,256,111	£46,199,200
Phase 5	25 years	-8.27%	21.09%	£1,450,262	£28,784,801
	30 years	0.18%	21.43%	£3,990,846	£36,809,106
	40 years	5.60%	21.59%	£7,930,370	£49,364,080

6.3.5 Sensitivity Analysis

Sensitivity analysis has been undertaken for the prioritised network based on the key network risks and key parameters and variables for each network. The base case 40 year IRRs are shown in grey cells in tables.

Key risks for the network include:

- Capital costs
- Connection charges
- Annual service charge

These sensitivities have been performed on both economic assessments: including HP CAPEX and the network only option.

1. Including HPs CAPEX Option

Ambient clusters CAPEX

The effect of a variance in capital costs is shown in Figure 55 for each network phase. A decrease in capital costs of approximately 10% would be required for phase 1 to achieve 40 year IRR of 8%.

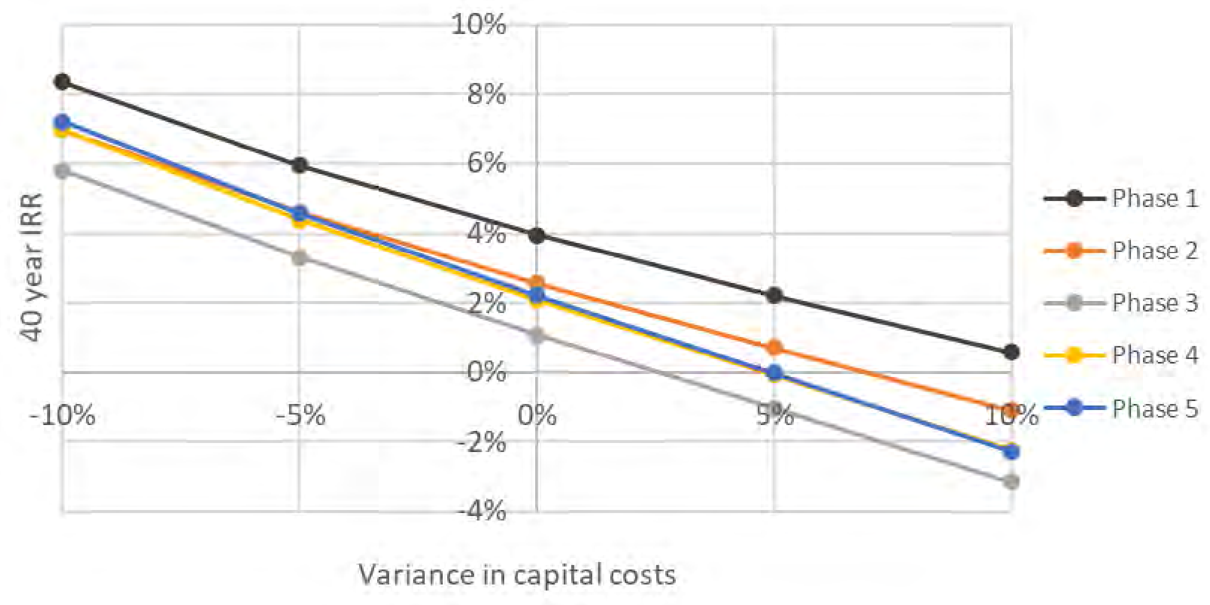


Figure 55: Effect of variance in capital costs including HP costs

Table 38 shows the 40 year IRR for each network phase if the capital costs do not include contingency.

Table 38: Contingency applied to capital costs

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs including contingency (including previous phases)	£6,753,651	£21,358,646	£38,549,066	£50,103,922	£56,655,533
40 year IRR including contingency	3.7%	2.6%	1.0%	2.0%	2.2%
Capital costs not including contingency (including previous phases)	£6,003,246	£18,985,463	£34,265,836	£44,536,820	£50,360,474
40 year IRR not including contingency	8.7%	7.6%	6.4%	7.6%	7.8%

Connection charges

Sensitivity of connection charges from developers towards HP and network cost is shown in Figure 56. Table 39 shows monetary values of the percentage variance used in the sensitivity. Connection charge of £6000 has calculated based on the cost of the counterfactual solution - individual ASHP. £450/kW connection charge for commercial buildings has been assumed based on the data taken from operational district heating schemes. Base case assumes that connection charge of £5000/dwelling and £400/kW will go towards purchase and installation of HPs and £1000/dwelling and £50/kW will go towards network capital and operation cost.

Table 39: Values of connection charges after variance

Variance	Residential £/dwelling	Commercial £/kW
-30%	4200	315
-15%	5100	382.5
0%	6000	450
15%	6900	517.5
30%	7800	585

Connection charges are required for the project to be economic. Increasing connection charges by 15% increases 40 year IRR from 2.2% to 6.7%. A decrease of less than 5% means the project is no longer economic. The project is particularly sensitive to HP cost, therefore as long as the connection charges recover the cost of HPs and a contribution is made towards network CAPEX, the project will have positive IRR.

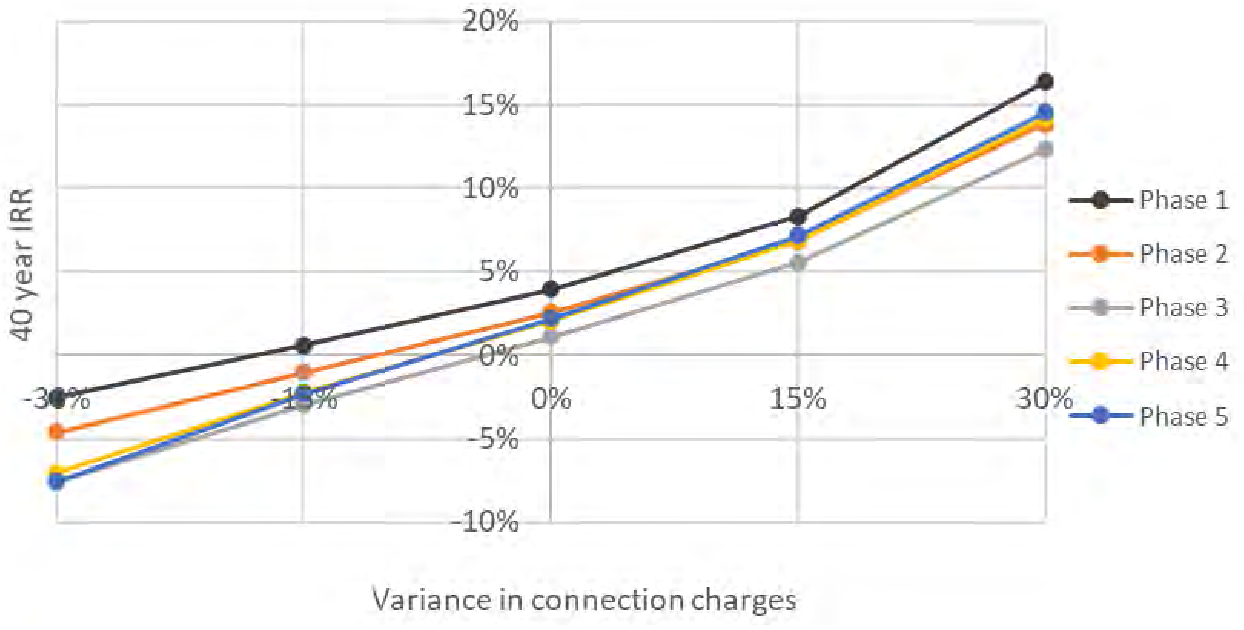


Figure 56: Variance in connection charges including HP costs

Service charge

Table 40 shows values of service charge after percentage variance has been applied. Sensitivity on service charge is shown in Figure 57. A service charge of £240/pa was selected based on the savings from better SPF an ambient network offers in comparison to ASHPs in each dwelling. Commercial tariffs have also been calculated based on the SPF and have been modelled based on the heat pump capacity installed.

Table 40: Values of annual service charge after variance

Variation	Residential £/year/dwelling	Commercial £/year/kW
-30%	168	13
-15%	204	16
0%	240	19
15%	276	22
30%	312	24

The effect of a variance in service charge is shown in Figure 57Figure 59 for each network phase.

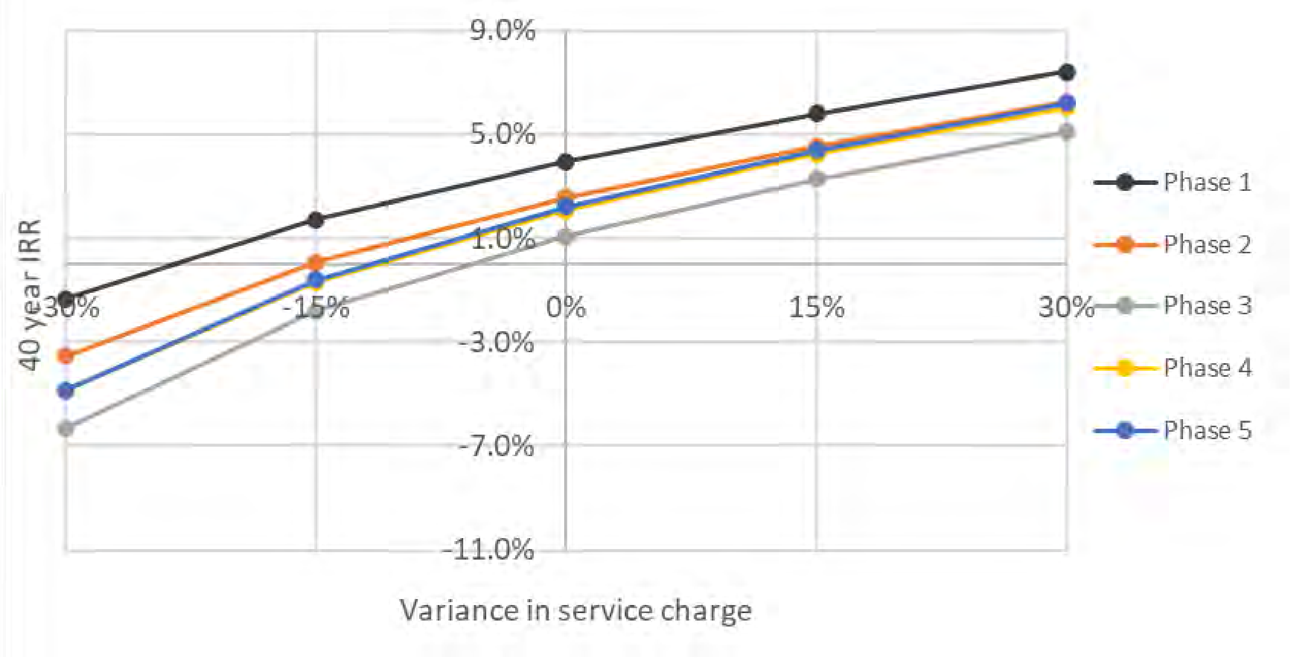


Figure 57: Variance in service charge including HP costs

2. Excluding HPs cost

Following sensitivity analysis is based only on the network economic assessment. Connection charges towards network cost for economic assessment have been assumed to be £1000/dwelling and £50/kW for commercial connections. Service charge per dwelling has been assumed to be £240/year and £18.75/kW/year for commercial connections.

Ambient clusters CAPEX

Figure 58 shows sensitivity analysis on the capital cost of network only for each network phase. 10% reduction in capital cost would results in 40 year IRR of 7.8%.

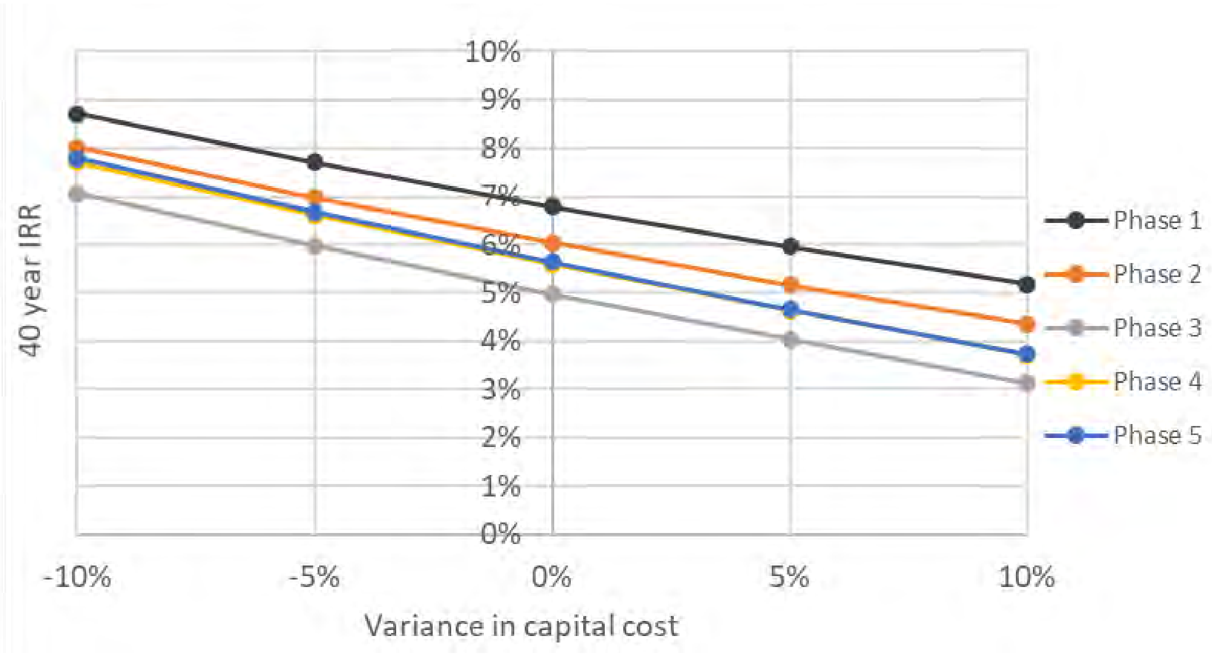


Figure 58: Variance in capital cost - network only

Connection charges

The effect of a variance in connection charges is shown in Figure 59 for each network phase.

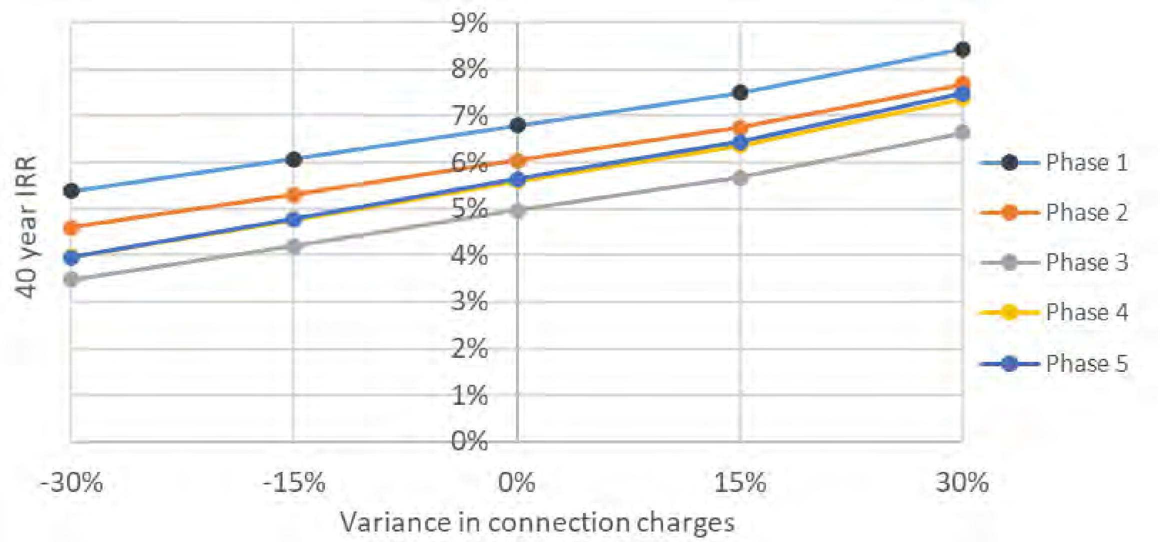


Figure 59: Variance in connection charges - network only

The value of domestic and commercial connection charges (per building) that contribute to the network CAPEX after variance are shown in Table 41.

Table 41: Values of connection charges after variance- network only

Variance	Residential £/dwelling	Commercial £/kW
-30%	700	35
-15%	850	42.5
0%	1000	50
15%	1150	57.5
30%	1300	65

Network service charge

The sensitivity on service charge for network only economic assessment for each phase is shown in Figure 60.

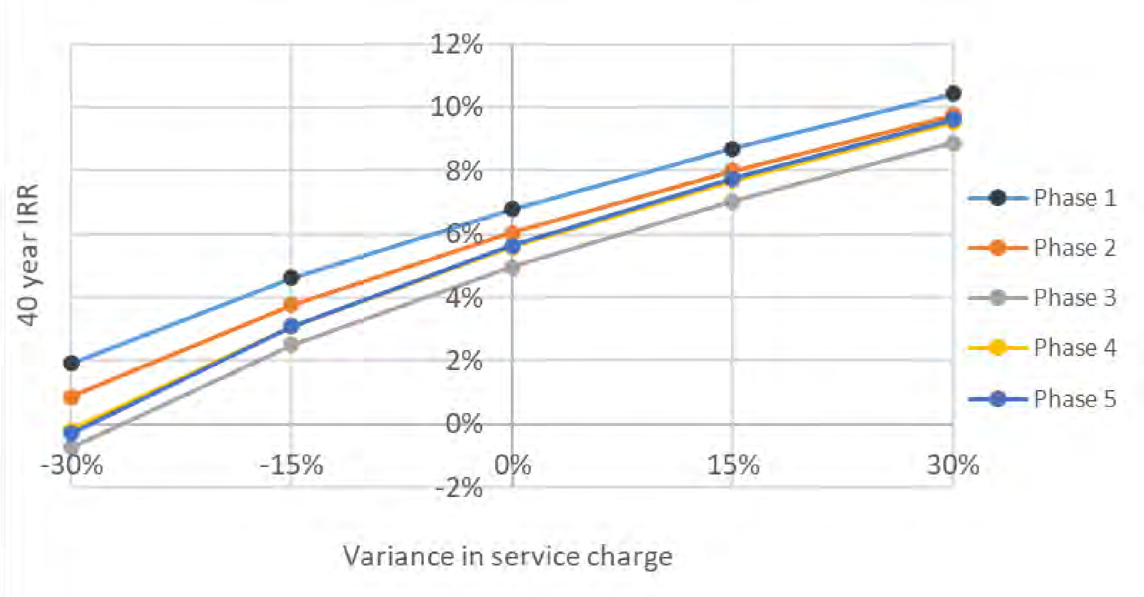


Figure 60: Variance in service charge - network only

The values of network service charges per unit after variance are shown in Table 42.

Table 42:Values of annual service charge after variance

Variation	Residential £/year/dwelling	Commercial £/year/kW
-30%	168	13
-15%	204	16
0%	240	19
15%	276	22
30%	312	24

Energy Price Indexing

Energy indexing has no effect on cluster ambient network.

6.3.6 Risks

The main risks and constraints for the implementation of the proposed ambient network options have been considered and assessed in Table 44.

Risk ratings are the product of impact and likelihood. The impact measures how much of an affect the risk being realised would have, and the likelihood is a measure of how probable the risk realisation is. The score associated with current risk is the level of risk present if no further action is taken, and mitigated risk levels are a measure of the risk present once the mitigating measures have been carried out.

A key showing the level of risk is shown in Table 43.

Table 43: 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 44: Summary of risks and issues – Ambient cluster

	Risk / issue	Risk rating: Impact	Likelihood	Rating	Rationale	Mitigating measure / action
Heat Source	**HS1** Thermal availability of boreholes.	Risk rating: 5	4	20	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.
		Mitigated risk rating: 5	3	15		
	HS2 Positioning of boreholes.	Risk rating: 5	4	20	If boreholes are too close together, the ground may not be able to sustain thermal requirements as losses will be greater than gains, resulting in localised cooling of the ground. The number of boreholes required per dwelling will influence distance between boreholes.	The optimal number of dwellings to connect has been determined. This reduces the number of boreholes per dwelling, assuring the smallest number of boreholes and, as a result, maximises space between them. Detailed calculations should be carried once thermal response of the boreholes and regeneration rates are known.
		Mitigated risk rating: 5	3	15		
Energy demand assessment	**ED1** Energy demands for the whole site are planned developments and are based on high level information.	Risk rating: 3	4	12	Energy demands for planned developments have been based on high level information that is likely to change as development plans are progressed.	Energy demands for all planned developments have been estimated based on the most recent information available. Energy demands should be re-considered as development plans progress and more information becomes available.
		Mitigated risk rating: 3	3	9		
	ED2 Planned developments are not brought forward. This can cause network demands to change from those assessed.	Risk rating: 4	2	8	Volume risk is likely to sit with the network operator. Heat demand do not impact network viability. If planned developments are either not built out or are built out in different clusters.	The nature of the ambient cluster design allows for the networks to be phased in lines with the build out rate, therefore it mitigates the risk of impacting network viability.
		Mitigated risk rating: 4	1	4		
	ED3	Risk rating				

	Risk / issue	Risk rating			Rationale	Mitigating measure / action
		Impact	Likelihood	Rating		
	Engagement with developers is not achieved and developments do not connect to network.	5	4	20	All of the network demand is provided from planned developments.	Master developer is clear that one of the conditions for building on the site will be to connect to the proposed network. Planning policy / developer conditions are sufficiently robust and appropriate developer engagement will be required.
		Mitigated risk rating				
		5	1	5		
	ED4 The estimated timing of the planned developments is not currently known.	Risk rating			If planned developments are brought forward sooner than expected, or are delayed, this will impact the network timing, phasing and also the network viability.	The most up to date information available for planned developments has been used. High level assumptions have been made for network phasing and the potential timing of network connections. The phasing and timing of the network should be further considered once additional information becomes available for developments.
		4	4	16		
		Mitigated risk rating				
		3	4	12		
Heat network and connections	**N1** Network options presented do not allow connection of additional heat demands.	Risk rating			Network options should, where possible, include futureproofing to allow additional heat demands to connect in the future. Consideration should therefore be given to futureproofing to ensure the network has the capacity to serve future network phases and planned developments.	The nature of the ambient cluster design allows for the networks to be phased in line with the build out rate, therefore if additional heat demands would like to connect, they could be included onto a separate cluster or connect to a smaller cluster near-by
		4	4	16		
		Mitigated risk rating				
		4	2	8		
	N2 Planned developments progress without futureproofing measures for network infrastructure.	Risk rating			It has been assumed that the cost of reinstatement of the road surface is not included. If a planned development is built without installing the pipes, this will significantly increase the cost of the network.	Liaison with the master developer required to ensure coordination when installing road surfaces. Network routes need to be safeguarded.
		4	4	16		
		Mitigated risk rating				
		4	3	12		

	N3 Networks are built and operated and maintained by different contractors leading to variations in price and service levels between clusters	Risk rating 4 | 4 | 16 Mitigated risk rating 4 | 3 | 12	If separate contactors are employed to deliver and operate different network clusters, even if the commercial conditions are the same then this may lead to differences in service levels between neighbouring clusters which may cause controversy and complaint. Economies of scale may not be realised if different contractors are responsible for separate clusters.	A full commercial assessment is required to develop a delivery strategy; however, it is likely that there are significant benefits associated with contracting a single contractor to deliver the networks as part of a long-term contract with relevant break clauses etc.
Economic assessment	**EA1** Capital costs are significantly higher than estimated.	Risk rating 5 | 4 | 20 Mitigated risk rating 5 | 2 | 10	Higher capital costs can have a significant impact on the viability of all network phases. If the economic assessment does not include robust project CAPEX, the likely financial benefits or does not provide sufficient information to secure funding, then the network plan will not progress.	All project costs have been based on a combination of previous project experience and recent quotes for similar projects. The consultant team have a large database the of actual costs of installing district energy schemes including costs for equipment supply and installation, distribution pipework supply and installation, trench excavation and re-instatement. Sensitivity analysis has been undertaken for network options to show the effect of a variance in capital costs, this is shown in the "Sensitivity and Risk" section of the relevant schemes. Significant increase in CAPEX will deem project uneconomic unless the increase in CAPEX is covered by connection charges.
	EA2 Variation in connection charges from developer significantly affects economics.	Risk rating 5 | 2 | 10 Mitigated risk rating 5 | 1 | 5	Variation in connection charges have a significant impact on the viability of all network options.	Connection charges should cover a cost of the HP and their installation as well as contribute at least £1000/dwelling towards a network and £50/kW heat pump capacity installed for commercial connection to ensure that be project is economically viable. Sensitivity analysis has been undertaken to show the effect of connection charges, this is shown in the "Sensitivity and Risk" section of the relevant schemes.
	EA3 Variation in service charge significantly affects economics.	Risk rating 5 | 2 | 10 Mitigated risk rating	Variation in network service charge have a significant impact on the viability of all network options.	Network service charge is the only revenue in the ambient cluster network economic model. Service charge should cover network O&M cost and replacements cost of the network. However, it should be maintained below

		5	1	5		£250 to ensure that cost to customer is lower than the cost of counterfactual option.
General	**G1** Local planners are not fully engaged / aware of the study outputs.	Risk rating			Planning officers within FBC have a key role to play in ensuring the viability of the project. The role of planners in district heating is to provide appropriate policy and supporting guidance to developers in the development or extension of networks.	Engagement with planning officers is ongoing and will be further strengthened as the project progresses.
		5	4	**20**		
		Mitigated risk rating				
		5	3	**15**		
	G2 Planned developments are brought forward prior to network development.	Risk rating			Developers may install alternative heating systems within planned developments if DHN is not in place prior to construction.	Network phases have been assessed based on information currently available on timing of planned developments. This should be reassessed as networks are progressed and more information on planned developments becomes available.
		4	4	**16**		
		Mitigated risk rating				
		4	3	12		
	G3 Project will require grant funding	Risk rating			If cluster option is unable to fulfil criteria mentioned in section 6.3.3 in Table 33, the overall economics of the project will not be attractive to private sector.	An engagement with GHNF committee showed that ambient cluster network potentially fulfilling grant funding criteria. Necessary adjustments to the application for ambient network will be required.
		4	4	**16**		
		Mitigated risk rating				
		4	2	8		

6.3.7 Ambient Network Summary

The proposed network has been assessed over 5 phases. Phase 1 will connect the initial development of ~600 dwellings and is proposed to consist of four clusters. Clusters can be phased out in future phases based on the development build out rate. However, it is critical to ensure that boreholes provide enough thermal energy for individual clusters and that clusters are constructed for optimal numbers.

7 CONCLUSIONS

The conclusions for Welborne Garden Village Heat Network Feasibility Study are outlined and discussed below. The main driver for this project is to help ensure Welborne Garden Village becomes a sustainable community development, delivering low / zero carbon and energy efficient heat. This project should form a key part of the overall carbon reduction and heating strategy for the Welborne Garden Village.

The Future Homes Standard sets out the commitment that fossil fuel heating systems will not be installed in new homes from 2025. The counterfactual heating solution for this development is ASHPs in each property which are potentially costly and have visual, spatial and acoustic impacts. Either of the two priority scheme options will enable renewable heating to be delivered to all new homes in a way that is technically and economically viable and maximises environmental and social benefits.

7.1 Energy Demand Assessment

Most of the heat demand comes from the planned 6,000 domestic dwellings. These account for 78% of the estimated 34 GWh of heat demand and 86% of the estimated 2.9 GWh of cooling demand. The commercial energy demand assessment has been performed using high level of information and will be subject to change.

The heat demand of the houses will be determined by the master developer requirements and the FHS coming into effect in 2025. The heat demand assessment has used notional values from the FHS. As more information is available from the house builders, the heat demand assessment should be re-visited.

7.2 Energy Supply Assessment

Heat pump (air, ground, water), energy from waste, geothermal, waste heat, biomass and gas CHP technologies were assessed as options to supply heat network options. Potential water sources identified for water source heat pumps (WSHPs) were the 3 Portsmouth Water reservoirs located to the Northeast of the development.

In discussions with the development team, it was agreed that an energy centre utilising ASHPs or WSHPs could be located to the northeast of the development if a thermal network was selected as the preferred option. This would be subject to a local planning application which could have a significant impact on the network timing and project CAPEX.

The ambient loop option assessed an open loop connection to Portsmouth Water Hoads Hill reservoirs and a closed loop ground source clustered option which would use a series of closed loop boreholes. The closed loop cluster model was deemed as potentially the most beneficial as it would allow the networks to be built to correspond with the build-out rate of the site.

7.3 Thermal Network Scheme

A sitewide energy network and a cluster-based network were both assessed. The sitewide networks were phased over 5 phases. Phase 1 includes most of the network spine and needs to be futureproofed to serve the fully developed site.

Potential network barriers and constraints were assessed, and network route selection methodology also involved consideration of linear heat density (net demand divided by spine trench length).

For the sitewide thermal network, technology sizing scenarios have been assessed to determine the optimal sized ASHP and thermal store. The optimised solutions are summarised in Table 45.

Table 45: Technology sizing summary

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
ASHP capacity	2.3 MW	3.4 MW	4.3 MW	6.8 MW	7.9 MW

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Peak boiler capacity	1.0 MW	4.0 MW	8.0 MW	10.0 MW	10.0 MW
Thermal store capacity	200,000 l	200,000 l	200,000 l	200,000 l	200,000 l
Energy centre footprint	1,271 m^2	1,271 m^2	1,271 m^2	1,271 m^2	1,271 m^2

The scheme will also require peak and reserve boilers for times of peak demand (e.g., during coldest weather). The selected peak and reserve boilers are electric to help minimise CO_2e emissions for the development. Therefore, it is recommended that the installed heat pumps are modular so that maintenance activities on one heat pump will not affect the required supply capacity.

It has been assumed that the network operator will own all substations or HIUs within each dwelling. Each connection will be an indirect connection with the HIU/substation being the demarcation line for ownership.

A TEM was constructed to assess the economics of the thermal network and allow key variables to be revised and the associated impact assessed. The 40 year economics and carbon savings are shown in Table 46.

Table 46: Economic and CO_2e saving summary of thermal network

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs (incl. contingency)	£11,209,960	£24,106,033	£40,864,822	£53,940,964	£60,651,605
40 year IRR	1.8%	7.1%	7.5%	8.2%	8.8%
40 year social IRR	6.3%	11.9%	12.4%	13.8%	14.2%
40 year Carbon savings (vs individual ASHP), tCO_2e	-363	-2,198	-3,986	-3,930	-3,775

While the thermal network option is potentially economic, the heat has a higher CO_2e intensity than the counterfactual (ASHPs in each building/dwelling).

7.4 Ambient Cluster Network Scheme

The cluster-based ambient network options were assessed to find the optimum cluster size based on a combination of peak diversity and pipe sizes. The optimum cluster size was found to be between 100-300 dwellings per cluster which matches well with the proposed build-out rate of the development.

The boreholes will serve as the heat source to the ambient loop and a heat pump located in each connection will connect to the loop. The required boreholes have been minimised based on diversity of load.

The heat pump will be installed by the network developer, but ownership will revert to the dwelling owner on completion of the housing sale. It will then be the responsibility of the homeowner for operation and maintenance costs for the heat pump.

A TEM was constructed to assess the economics of the ambient network and allows key variables to be revised and the associated impact assessed. The presented economics cover the ambient network only without the cost of heat pumps. This assumes that the heat pump can be bought and installed for the connection fee and the network operator will receive a £1000 of the total connection fee. The 40 year economics and carbon savings are shown in Table 47.

Table 47: Economic and carbon saving summary of ambient network

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Capital costs (incl. contingency)	£2,530,308	£7,996,534	£14,754,301	£18,619,090	£20,864,263
40 year IRR	6.6%	6.1%	4.9%	5.6%	5.6%
40 year social IRR	22.6%	21.2%	21.2%	21.5%	21.6%

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
40 year Carbon savings (vs ASHP), tCO_2e	874	2,045	2,726	2,910	2,971

7.5 Comparison of Potential Low Carbon Heating Options

7.5.1 Techno-economic Comparison

Table 48 shows 40 year costs and CO_2e intensity of DHN option, ambient option and ASHPs in each building.

Table 48: 40 year costs and CO_2e intensity of DHN option, ambient option and ASHPs in each building

	LTWH ASHP network	Ambient cluster network	Individual ASHPs
40-year net present cost	£97,642,404	£119,902,811	£123,614,880
CO_2e emissions (40 years), tCO_2e	18,255	10,199	13,170
CO_2e intensity of heat delivered (40 year average), gCO_2e/kWh	30	17	22

40 year net present costs have been calculated based on the total CAPEX and OPEX for each option. For the decentralised option of individual ASHPs the CAPEX includes the cost of the heat pumps, hot water cylinders, and installation. The OPEX for this option is the cost for operating the heat pumps, which will be paid by the customers.

For the decentralised ambient cluster network, the CAPEX includes the cost of the network, boreholes, pumping stations, heat pumps, hot water cylinders, and installation. The OPEX for this option is the cost for operating the heat pumps, which will be paid by the customers.

The CAPEX allocated to the purchase and install of ASHPs and associated equipment is conservative to reflect the reported economies of scale from which developers benefit. The cost does not reflect the additional cost of warrantied items for high-end low GWP refrigerant domestic ASHPs.

7.5.2 CO_2e intensity comparison

Figure 61 shows CO_2e intensity of heat delivered (40 year average) for all options. The ambient network has the lowest CO_2e intensity.

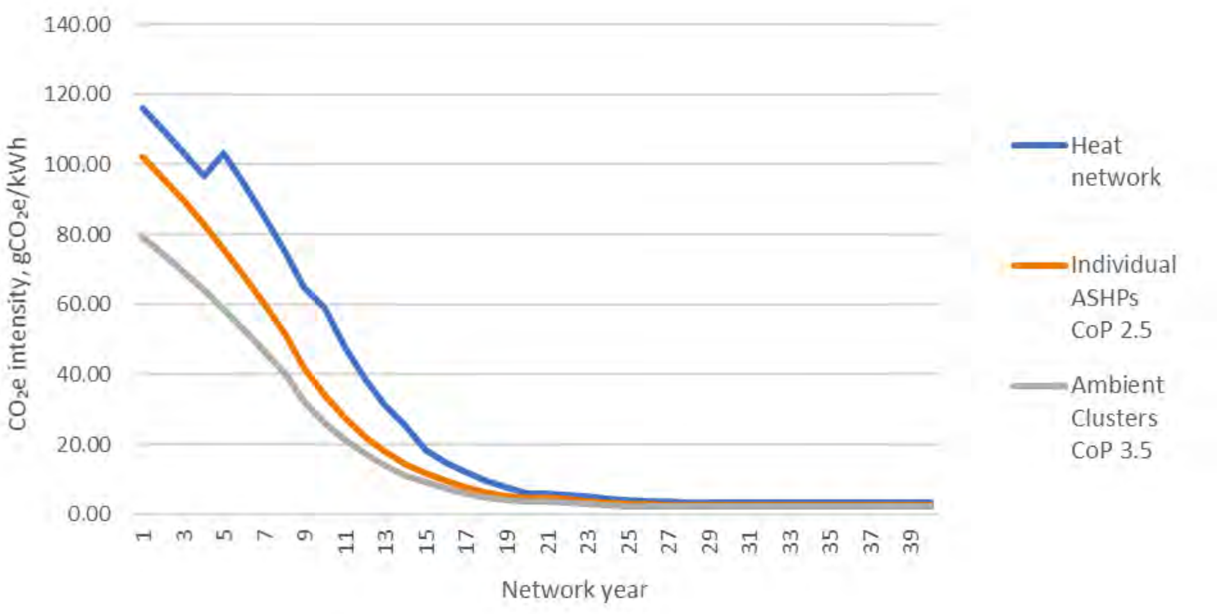


Figure 61: CO_2e intensity of heat delivered (40 year average), gCO_2e/kWh

Some of the refrigerant can leak into the atmosphere during the operation of the heat pump. Often CO_2e saving estimates do not consider this, and if they did, CO_2e savings would be reduced for many heat pump schemes using high GWP refrigerants.

Table 49 shows the refrigerant leakage rates identified in the 'Impacts of Leakage from Refrigerants in Heat Pumps' study by the Department of Energy & Climate Change[6].

Table 49: Refrigerant leakage rates

Scenario	Annual leakage rate		Leakage rate during decommissioning
	Domestic	Non-domestic	
Low	1.82%	1.81%	10%
Central	3.48%	3.77%	15%
High	10%	7.63%	20%

The annual CO_2e emissions with emissions from refrigerant leaks in individual HPs for different refrigerants and central leakage scenario are shown in Table 50. Detailed information on refrigerants can be found in Appendix 5: Heat Pump refrigerant. R410a is currently the most common refrigerant in domestic heat pumps, however it is currently being phased out and replaced with R32 systems. These two refrigerants have been used in the assessment.

Table 50: Effect of refrigerant leakage in domestic HPs on CO_2e emissions and CO_2e intesivity (central scenario)

Summary	ASHP thermal network	Ambient cluster network	Individual ASHPs
CO_2e emissions (40 years), tCO_2e	18,255	10,199	13,170
CO_2e intensity of heat delivered (40 year average), gCO_2e/kWh	29.9	17.3	22.3
CO_2e emissions with R32 emission (40 years), tCO_2e	18,255	12,026	14,997

[6] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/303689/Eunomia_-_DECC_Refrigerants_in_Heat_Pumps_Final_Report.pdf

Summary	ASHP thermal network	Ambient cluster network	Individual ASHPs
CO_2e intensity of heat delivered with R32 (40 year average), gCO_2e/kWh	29.9	19.6	24.6
CO2e emissions with R410a emission (40 years), tCO_2e	18,255	16,689	19,660
CO2e intensity of heat delivered with R410a (40 year average), gCO_2e/kWh	29.9	25.7	30.7

Figure 62 shows the CO_2e intensity of heat network as previously shown, along with ambient cluster network and individual ASHPs that use the R32 refrigerant with a central leakage rate.

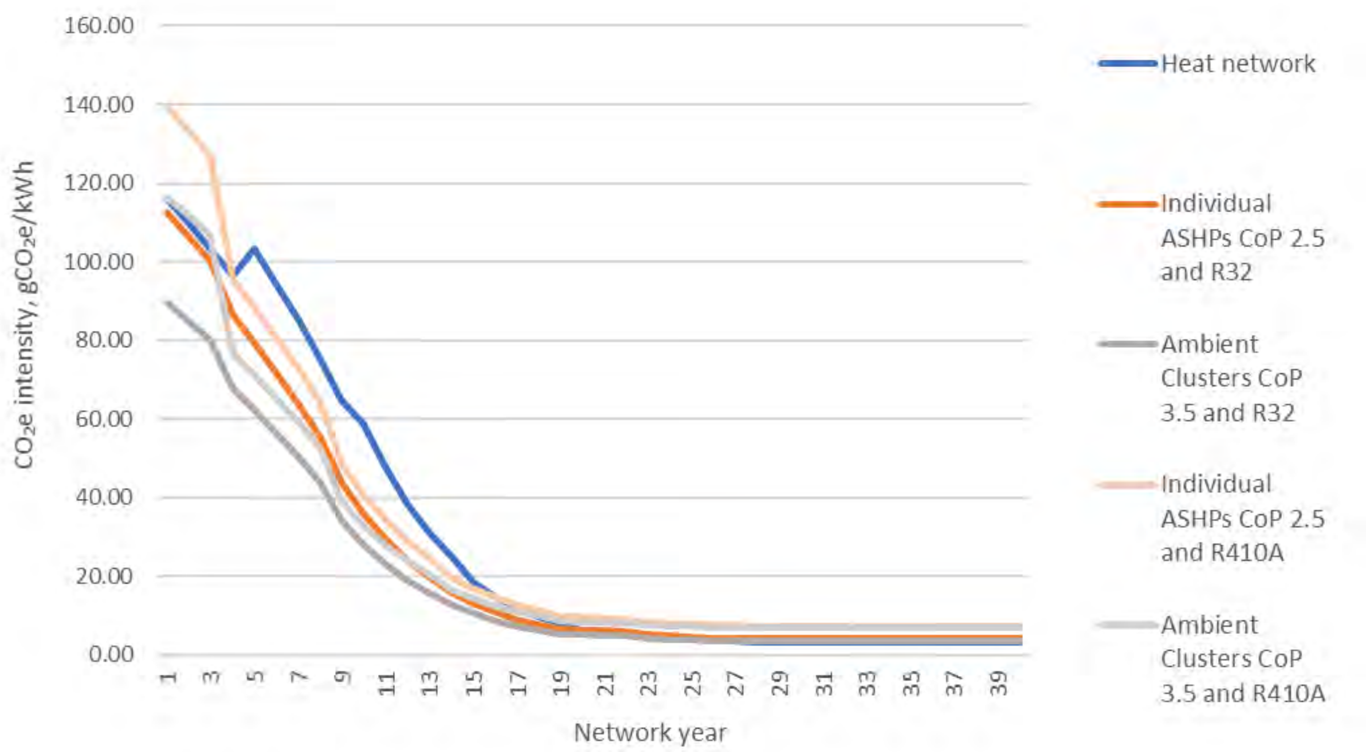


Figure 62: CO_2e intensity of heat delivered with R32 and R410A central scenario emissions (40 year average), gCO_2e/kWh

7.5.3 Electricity Capacity Requirements

The electricity capacity for the centralised energy centre and the decentralised options are summarised below. The energy centre design allows for electric boilers to meet peak network heat demands (row 16). Due to the heat pump sizing strategy which includes smaller, modular heat pumps, it is unlikely that all heat pump equipment will fail at the same time.

For ASHPs and the ambient network, the electrical connection to the site needs to be designed for the realistic worst case after diversity maximum demand (ADMD). The "cold load" worst case is the peak that occurs during a 1/20 winter in the UK coupled with a significant power cut at this time. When the fault is remedied and the heat pump systems come back online there is consequently no diversity as everyone on the feeder is attempting to warm their houses at an increased rate at the same time. For an ASHP, the heat pumps will be operating at a much lower COP as this load is assumed to be during winter. For the ambient network, the COP will be much higher as the ambient network is not affected by outside air temperature.

Table 51 compares the site electricity capacity requirements for different scenarios.

Table 51: Electricity capacity requirements for DHN and ASHPs in each building

Summary	ASHP Network	Ambient Network	Individual ASHPs
Installed heat pump capacity, MW	7.9	42.8	42.8
Installed electric boilers, MW	10	-	-
Assumed "Cold Load" COP	1.5	2.0	1.5
Overall connection capacity, MVA	15.2	21.4	28.5

The district heating option has the lowest overall capacity requirements and will allow additional capacity to be utilised in the Garden Village.

7.5.4 Risks, Benefits and Disbenefits

Table 52 shows risks, benefits and disbenefits comparing the two preferred network options and counterfactual individual ASHPs option.

Table 52: Risk, benefits and disbenefits of all potential options

	ASHP thermal district heat network	Cluster based ambient network using closed loop boreholes	ASHPs in each dwelling
Risks	• Upfront CAPEX associated with network future proofing may cause commercial complications and planned developments might not come forward or be built out • Heat network feeds need to be installed in coordinated manner in line with best practice to minimise length, costs and heat losses or scheme will be unviable • Is reliant on a suitable energy centre location being secured	• Highly reliant on the ability to source and install heat pumps • Ambient network feeds need to be installed in coordinated manner in line with best practice to minimise length and cost • Thermal response from boreholes may be lower than expected and more boreholes may be required • Higher capacity of heat pumps required and increase to the electricity grid connection and distribution capacity which may result in significant additional CAPEX • May not be operated and maintained in most efficient manner • Higher GWP refrigerants such as R32 often used in domestic heat pumps	• Lower CoP will increase costs to customers and decrease CO_2e savings • Higher GWP refrigerants such as R32 often used in domestic heat pumps • Higher capacity of heat pumps required and increase to the electricity grid connection and distribution capacity which may result in significant additional CAPEX • May not be operated and maintained in most efficient manner
Benefits	• Network operator able to maximise CO_2e and cost savings through utilising thermal stores and operating technologies at times of lowest electricity price and CO_2e emissions • Potential for grant funding through GHNF • Potentially lower cost of heat to customers • Access to more competitive non-domestic energy tariffs that can be exploited through smart operation	• Potentially greatest CO_2e savings if operated and maintained efficiently • Not impacted by development build out rate or changes to development plans • Potential for grant funding through GHNF • Low acoustic and visual impact • Availability to provide comfort cooling	• Potentially high CO_2e savings (if good quality heat pump operated and maintained efficiently) • Not impacted by development build out rate or changes to development plans • Availability to provide comfort cooling
Disbenefits	• Space requirements for energy centre • Low linear heat density resulting in high network heat losses and lower CO_2e savings than high density network • Acoustic and visual impact of energy centre • May require peak and reserve (back up) gas boilers resulting in higher CO_2e intensity and local air quality impacts • Unable to provide comfort cooling	• Additional space required at each dwelling (internal unit, DHW cylinder, buffer vessel and controls) • May not be operated and maintained in most efficient manner	• Additional space required at each dwelling (external and internal unit for heat pump, DHW cylinder, buffer vessel and controls) • May not be operated and maintained in most efficient manner • Higher cost of heat to customers (under modelled assumptions) • Higher cost to developers (under modelled assumptions) • Acoustic and visual impact resulting from numerous outdoor units

Key Sensitivities and Risks

Key sensitivity parameters for the thermal network:

- Capital costs
- Network heat demand
- Energy tariffs including heat sales tariffs, energy centre electricity purchase tariffs
- Subsidy and grant funding

Key sensitivity parameters for the ambient network

- Capital costs
- Connection charges
- Annual service charge

Key Risks

The key risks for the thermal network have been identified and summarised below.

- Heat demand significantly impacts on network viability. If part of the development does not come forward then the energy centre and network will be oversized and will take longer to pay back the initial CAPEX. If heat demand is significantly greater then more heat will be required from the peak electric boilers costing more than the heat sales tariff unless the heat pumps out pump can be increased.
- The network is reliant on a suitable energy centre location being secured. The proposed energy centre location is currently outside of the development boundary. However, the proposed location for the energy centre is under the same ownership as the development. The main concern would be obtaining planning permission for a large industrial application in the rural location. To ensure the energy centre location is secured, continued engagement with FBC planners is required.
- The scheme will require grant funding. It has been assumed that network start year for phase 1 is 2023, which is after the closure of the HNIP scheme (2022). Phase 1 options are marginally economic as they include futureproofing measures for later network phases. These projects are likely to be eligible for The Green Heat Network fund. This fund requires networks to generate heat with low CO_2e intensity, which this scheme should achieve.

The key risks for the ambient network have been identified and summarised below.

- The cluster ambient option will be most affected by the ability to source and install ground source heat pumps within each dwelling. If the cost of the heat pump and installation is greater than the connection fee received then the scheme will be marginally economic.
- The ambient network's heat sources are closed loop boreholes. The scheme will be significantly affected if the thermal response of the local area is poor. This will require extra boreholes at a greater cost.
- The ambient loop scheme will not have the same problems with planning as there will be minimal extra building works required and these will all be within the development boundary.

Comparison with Building Level Renewable Heat Generation

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

- Potentially higher SPF for larger heat pumps than smaller heat pumps
- Economy of scale CAPEX and OPEX benefits
- Reduced space requirements
- Potential to purchase electricity more competitively

- Thermal storage, control strategy and multiple heat sources enabling SMART operation
- Potential for grant funding
- A more diversified heat demand and so the centralised heat pump capacity is far lower than at building level
- It is more practical to utilise low or zero GWP working fluids such as ammonia in large heat pumps

In most cases the CO_2e intensity of the heat delivered by the heat network is similar compared to individual ASHPs at building level. However, this figure does not include the higher GWP refrigerants that may be used in the heat pumps at building level.

Commercial and delivery strategy

This requires further discussion with the Buckland Development. Buckland Development would need decide on the contractual roles, and ensure that project maximises social and environmental benefits. For Ambient Cluster network there is a risk if separate contractors are employed to deliver and operate different network clusters, even if the commercial conditions are the same then this may lead to differences in service levels between neighbouring clusters which may cause controversy and complaint. Economies of scale may not be realised if different contractors are responsible for separate clusters. Full commercial assessment is required to develop a delivery strategy; however, it is likely that there are significant benefits associated with contracting a single contractor to deliver the networks as part of a long term contract with relevant break clauses etc.

Green Heat Network Funding

Table 53 shows GHNF metrics and and parameters of both thermal and ambient network option.

Table 53: Green Heat Network Fund core metrics

Metric	Minimum score	Thermal network	Ambient clusters network
Carbon gate	100 gCO_2e/kWh thermal energy delivered	100 gCO_2e/kWh reached in year 4 of operation	The maximum intensity is 79 gCO2e/kWh, which is reached in year 1 of operation
Customer detriment	Domestic and micro-businesses must not be offered a price of heat greater than a low carbon counterfactual for new buildings and a gas/oil counterfactual for existing buildings	Customer sale tariffs have been using an ASHP counterfactual	Customer service charges have been calculated using an ASHP counterfactual
Social IRR	Projects must demonstrate a Social IRR of 3.5% or greater over a 40-year period	The 40 year social IRR is 6.3% for phase 1	The 40 year social IRR is 19.3% for phase 1 and 17.6% for phase 5
Minimum demand	For urban networks, a minimum end customer demand of 2GWh/year. For rural networks, a minimum number of 100 dwellings connected	End customer demand is 4.3 GWh/year for phase 1 and 34 GWh/year for the fully built network	End customer demand is 4.3 GWh/year for phase 1 and 34 GWh/year for the fully built network
Maximum capex	Grant award requested up to but not including 50% of the combined total capex + commercialisation costs	Grant funding request amount to be determined	Grant funding request amount to be determined
Capped award	The total 15-year kWh of heat/cooling forecast to be delivered will not exceed 3.33	The maximum grant funding available according to this metric is £8,686,460 - significantly higher	The maximum grant funding available according to this metric is £8,686,460, which is 15% of total

Metric	Minimum score	Thermal network	Ambient clusters network
	pence of grant per kWh delivered (subject to review by GHNF)	than the 50% maximum in the row above	capex + commercialisation cost, but significantly more than 50% of phase 1
Non-heat/cooling cost inclusion	For projects including wider energy infrastructure in their application, the value of income generated/costs saved/wider subsidy obtained should be greater than or equal to the costs included.	No non-heat/cooling infrastructure included	No non-heat/cooling infrastructure included

Conclusion

The two network options of the sitewide thermal network and a cluster based closed loop ambient network have been compared in detail alongside the counterfactual of individual ASHPs. The sitewide thermal network offers potentially higher returns to an investor. However, this comes with a much larger upfront cost as the energy centre will need to be futureproofed to serve the entire site. There are also higher carbon emissions associated with the thermal network due to the larger heat losses that come from a low density development.

The ambient cluster network does not provide as high returns due to the income only coming from a fixed yearly cost from each connection. The ambient cluster network offers the lowest carbon emissions from the options due to the improved SCOP. Another benefit is that the ambient clusters can be built at the same rate as the housing development lowering the risk and does not need to be futureproofed for the whole development.

If a network approach is to be adopted, the ambient cluster network is the preferred solution to provide heating to the Welborne Garden Village.

Next Steps

If the project is to be progressed, then next steps include:

- Continued engagement with FBC planners and to ensure that all necessary planning permission for an energy centre can be obtained if the centralised thermal network is preferred
- Engagement of ambient loop and heat pump suppliers if the ambient loop option is preferred
- Place conditions on house builders to ensure that roles and responsibilities are agreed and understood and that internal heating systems allow maximum efficiency of heat pump operation
- Apply for GHNF
- Work with all parties to assess roles and responsibilities (including ownership) and delivery strategy for the scheme

APPENDIX 1: ENERGY DEMAND ASSESSMENT

Table 54: Network connections

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
Blakes Copse 2036	Planned development	90	0	508,279	Modelled with in house software based on building layouts based on proposed Phase 1 connections	N/A	N/A	34,939	Modelled with in house software based on building layouts based on proposed Phase 1 connectio ns
Blakes Copse 2037	Planned development	100	0	349,961				38,821	
Blakes Copse 2038	Planned development	70	0	274,970				27,174	
Blakes Copse 2039	Planned development	55	0	519,157				21,351	
Blakes Copse 2040	Planned development	103	0	199,978				39,985	
Heytesbury 2023	Planned development	40	0	399,956				15,528	
Heytesbury 2024	Planned development	80	0	324,964				31,056	
Heytesbury 2025	Planned development	65	0	349,961				25,233	
Heytesbury 2026	Planned development	70	0	84,991				27,174	
Heytesbury 2027	Planned development	17	0	299,967				6,599	
Heytesbury 2028	Planned development	60	0	99,989				23,292	
Heytesbury 2029	Planned development	20	0	344,962				7,764	
Heytesbury 2030	Planned development	69	0	384,958				26,786	
Heytesbury 2031	Planned development	77	0	249,972				29,892	

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
Heytesbury 2032	Planned development	50	0	349,961				19,410	
Dashwood 2023	Planned development	70	0	399,956				27,174	
Dashwood 2024	Planned development	80	0	349,961				31,056	
Dashwood 2025	Planned development	70	0	349,961				27,174	
Dashwood 2026	Planned development	70	0	124,986				27,174	
Dashwood 2027	Planned development	25	0	379,958				9,705	
Dashwood 2029	Planned development	76	0	74,992				29,504	
Dashwood 2030	Planned development	15	0	149,983				5,823	
Chesterfield 2022	Planned development	30	0	349,961				11,646	
Chesterfield 2023	Planned development	70	0	399,956				27,174	
Chesterfield 2024	Planned development	80	0	379,958				31,056	
Chesterfield 2025	Planned development	76	0	349,961				29,504	
Chesterfield 2026	Planned development	70	0	289,968				27,174	
Chesterfield 2027	Planned development	58	0	144,984				22,516	
Park Village East 2025	Planned development	29	0	149,983				11,258	
Park Village East 2026	Planned development	30	0	921,171				11,646	

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
Park Village East 2027	Planned development	180	0	1,208,077				69,877	
Park Village East 2028	Planned development	240	0	1,043,994				93,169	
Park Village East 2029	Planned development	204	0	79,991				79,194	
Park Village East 2030	Planned development	16	0	508,279				6,211	
Park Village West 2030	Planned development	100	0	554,440				38,821	
Park Village West 2031	Planned development	110	0	1,157,740				42,703	
Park Village West 2032	Planned development	230	0	1,023,523				89,287	
Park Village West 2033	Planned development	200	0	609,884				77,641	
Park Village West 2034	Planned development	121	0	274,970				46,973	
The Ride 2034	Planned development	55	0	508,279				38,821	
The Ride 2035	Planned development	100	0	460,586				38,821	
The Ride 2036	Planned development	90	0	269,970				34,939	
Highstead 2039	Planned development	54	0	374,959				20,963	
Highstead 2040	Planned development	75	0	1,057,067				29,115	
Highstead 2041	Planned development	210	0	604,843				81,523	
Highstead 2042	Planned development	120	0	304,966				46,585	

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
Highstead 2043	Planned development	61	0	508,279				23,681	
Norton 2030	Planned development	100	0	569,561				38,821	
Norton 2031	Planned development	113	0	349,961				43,867	
Norton 2032	Planned development	70	0	194,979				27,174	
Norton 2033	Planned development	39	0	304,966				15,140	
Welborne 2033	Planned development	61	0	625,005				23,681	
Welborne 2034	Planned development	124	0	1,023,523				48,138	
Welborne 2035	Planned development	200	0	614,114				77,641	
Welborne 2036	Planned development	120	0	1,023,523				46,585	
Welborne 2037	Planned development	200	0	588,526				77,641	
Welborne 2038	Planned development	115	0	129,986				44,644	
Welborne 2039	Planned development	26	0	588,526				10,093	
Albany 2038	Planned development	115	0	844,407				44,644	
Albany 2039	Planned development	165	0	614,924				64,054	
Albany 2040	Planned development	122	0	460,586				47,361	
Albany 2041	Planned development	90	0	818,819				34,939	

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
Albany 2042	Planned development	160	0	726,702				62,113	
Albany 2043	Planned development	142	0	284,969				55,125	
Sawmills 2043	Planned development	57	0	349,147				8,964	
Shop - A	Planned development	0	1	27,687	Estimated using data for similar sites	28,290	Estimated using data for similar sites	3,092	Estimated using data for similar sites
Bakery - B	Planned development	0	1	8,278		8,459		925	
Shop - C1	Planned development	0	1	6,497		6,639		726	
Café - C2	Planned development	0	1	5,081		5,190		567	
Estate Office - D	Planned development	0	1	12,631		16,373		1,817	
Pub/Hotel - E	Planned development	0	1	149,631		141,595		18,920	
Village Hall - F	Planned development	0	1	29,430		38,150		4,235	
Vet - G	Planned development	0	1	18,360		14,892		1,585	
Pharmacy - H	Planned development	0	1	7,304		7,463		816	
Doctor Surgery - I	Planned development	0	1	26,496		21,491		2,287	
Restaurant - J	Planned development	0	1	13,328		13,616		1,488	
Butcher - K	Planned development	0	1	5,857		5,985		654	
Shop - L	Planned development	0	1	5,649		5,772		631	

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
Hairdresser - M1	Planned development	0	1	5,426		5,544		606	
Takeaway - M2	Planned development	0	1	8,804		8,994		983	
Takeaway - N1	Planned development	0	1	5,130		5,240		573	
Deli - N2	Planned development	0	1	5,130		5,240		573	
Office - O1	Planned development	0	1	3,629		4,704		522	
Office - O2	Planned development	0	1	3,629		4,704		522	
Northern Primary School	Planned development	0	1	271,215		116,235		-	
Care Home Site	Planned development	0	1	542,300		194,700		-	
District Centre Primary School	Planned development	0	1	180,810		77,490		-	
District Centre Secondary School	Planned development	0	1	641,655		324,135		-	
Western Primary School	Planned development	0	1	180,810		77,490		-	
M1 Office Space	Planned development	0	1	672,550		871,824		96,772	
M1 Industry	Planned development	0	1	857,227		3,358,473		-	
M1 Warehouses	Planned development	0	1	369,952		1,250,302		-	
M2 Office Space	Planned development	0	1	898,148		1,164,266		129,234	
M2 Industry	Planned development	0	1	1,144,773		4,485,027		-	

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
M2 Warehouses	Planned development	0	1	494,048		1,669,698		-	
Park Village West Office Space	Planned development	0	1	15,186		19,686		2,185	
Welborne K1 Office Space	Planned development	0	1	34,831		45,151		5,012	
Welborne K2 Office Space	Planned development	0	1	6,089		7,893		876	
Park Village West Shops	Planned development	0	1	94,058		96,107		10,506	
Norton Shops	Planned development	0	1	18,294		18,693		2,043	
Welborne K1 Shops	Planned development	0	1	257,694		263,306		28,783	
Welborne K2 Shops	Planned development	0	1	45,048		46,029		5,032	
Park Village West Restaurant	Planned development	0	1	25,628		26,180		2,861	
Norton Restaurant	Planned development	0	1	4,985		5,092		556	
Welborne K1 Restaurant	Planned development	0	1	70,213		71,727		7,838	
Welborne K2 Restaurant	Planned development	0	1	12,274		12,539		1,370	
Park Village West Fast Food	Planned development	0	1	10,440		10,665		1,166	
Welborne K1 Fast Food	Planned development	0	1	10,440		10,665		1,166	
Welborne K1 GP	Planned development	0	1	168,930		137,021		14,584	
Park Village West Nursery	Planned development	0	1	46,200		19,800		-	

Site name	Status	No of domestic connections	No of commercial connections	Heat demand, MWh	Heat demand data source	Electricity demand, MWh	Electricity demand data source	Cooling demand, MWh	Cooling demand data source
Norton Nursery	Planned development	0	1	46,200		19,800		-	
Welborne K1 Nursery	Planned development	0	1	46,200		19,800		-	
Welborne K2 Nursery	Planned development	0	1	46,200		19,800		-	
Northern Nursery	Planned development	0	1	46,200		19,800		-	

APPENDIX 2: TECHNOLOGY OPTIONS ASSESSMENT

GSHP and Aquifer Assessment

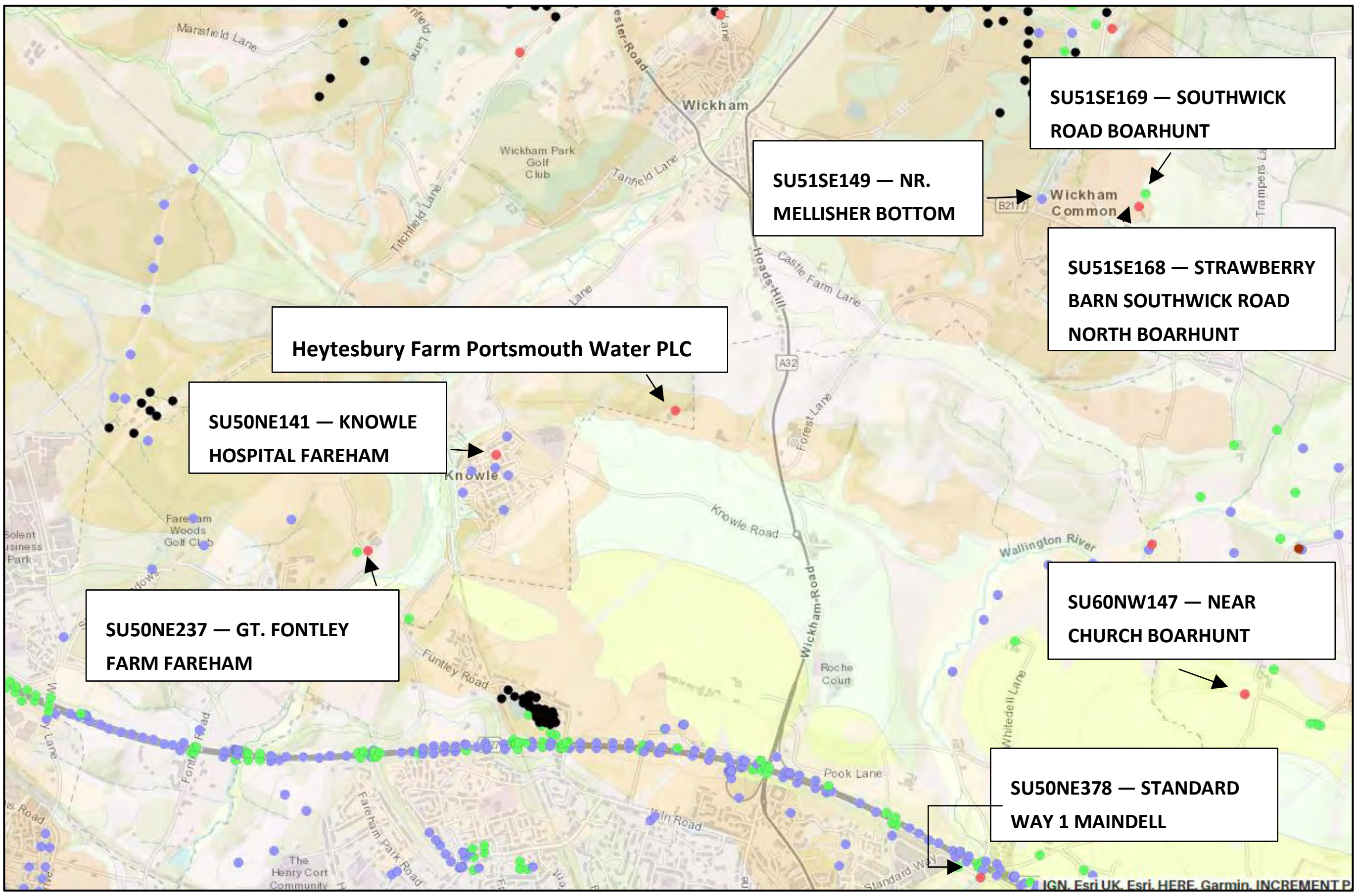


Table 55: Borehole location notes

Borehole name	Depth, m	Water depth, m	Flowrate, l/s	Strata details	Dates
SU571098 – Heytesbury Farm Portsmouth Water PLC no.6a	120.6	33.45	1 (clearance pumping)	0-0.75 m Brick 0.75-12m Yellow Clay 12-20.6 m Upper Chalk- very weathered 20.6-120.6 Upper Chalk	2000
SU51SE149 — NR. Mellisher Bottom Wickham	8.23	6.04	N/A	NO STRATA DATA	1957
SU51SE169 — Southwick Road Boarhunt	19	9	0.33	0-0.5 m top soil 0.5-19m sandy clay with fine sands	2019

Borehole name	Depth, m	Water depth, m	Flowrate, l/s	Strata details	Dates
SU51SE168 — Strawberry Barn Southwick Road North Boarhunt	33	21	N/A	0-33 m Light Brown Clay with interbedded fine sands	2017
SU50NE378 — Standard Way Maindell	30.3	8.1 below datum	N/A	0-0.8 m Gravel 0.8-8 m Brown sandy clay with gravel 8- 30.3 m Chalk and Flints	2005
SU50NE141 — Knowle Hospital Fareham Hants	36.57	34.74	3.7	0-36.57 m Upper Chalk	1976
SU50NE237 — Gt. Fontley Farm Fareham	30.48	10.46	0.31	NO STRATA DATA Used for cooling and washing down 0.023l/s used Electric pump	1959
SU60NW147 — Near Church Boarhunt	36.58	30.48	N/A	NO STRATA DATA	1957

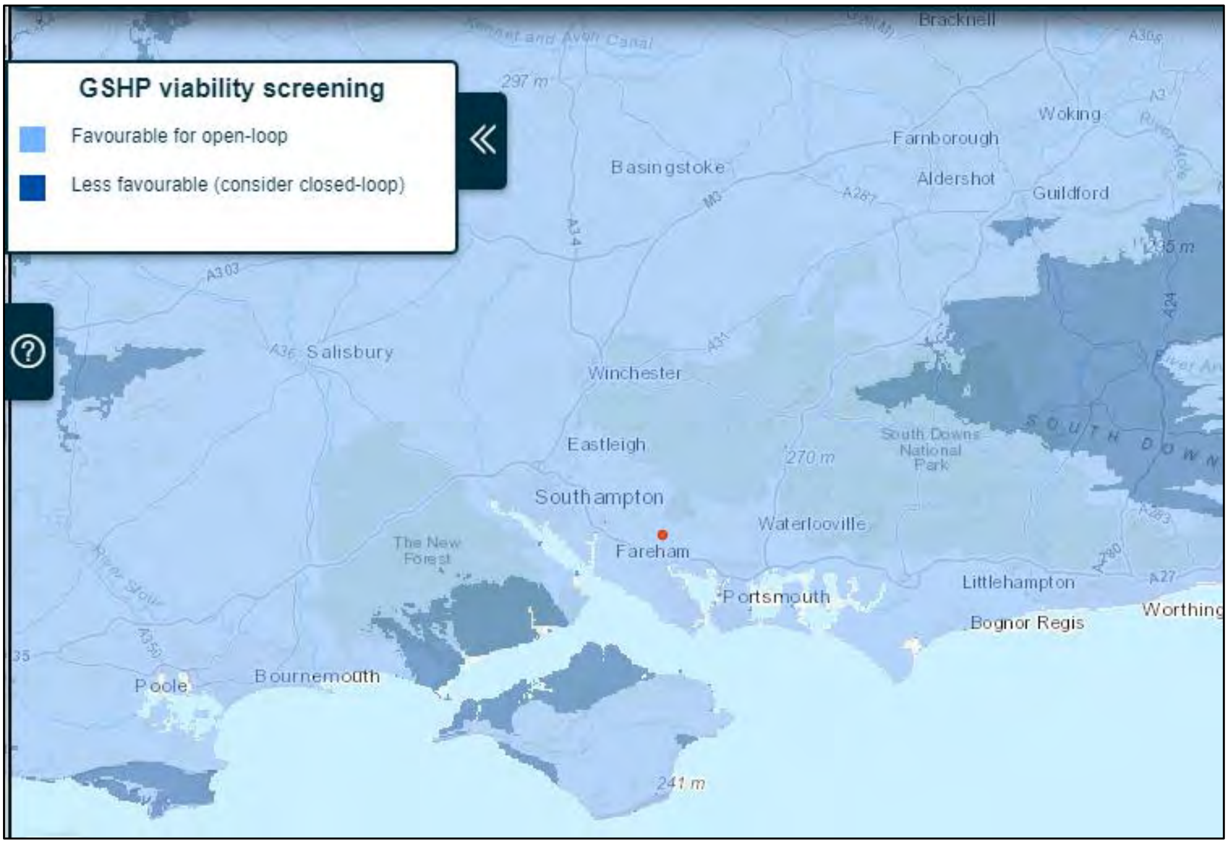


Figure 63: Open source GSHP screening tool[7]

[7] Image reproduced from The British Geological Survey open source GSHP screening tool: http://mapapps2.bgs.ac.uk/gshpnational2/app/index.html

APPENDIX 3: NETWORK ASSESSMENT

The pipe routes have been designed to consider pipe length and barriers such as highways and construction limitations.

Pipe lengths, CAPEX and layouts are based on high level information provided and installing pipes in a coordinated manner and connecting houses in line with best practice. The dwellings on the right in Figure 64 and Figure 65 reflect the assumptions used and show shared feed pipes from the road to the front of the dwelling and heat interface units (HIUs) located at the nearest point to the network branches respectively. If this is not achieved, then additional network length will be required and CAPEX and network heat losses will increase, which will significantly impact the scheme economics as shown in the dwellings on the left in Figure 64 and Figure 65.

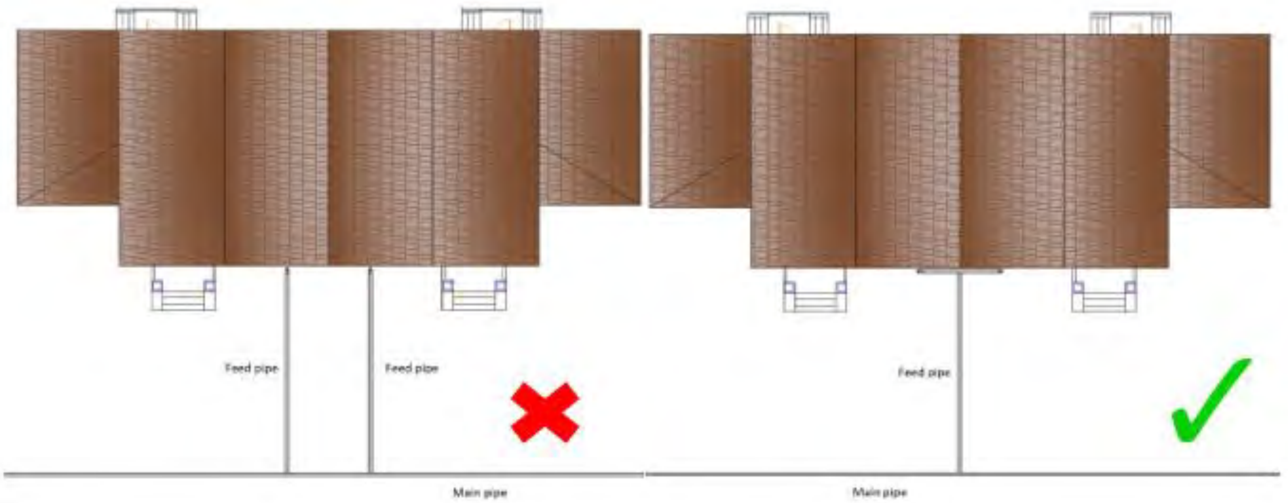


Figure 64: Shared feed pipes to terraced and semi-detached dwellings

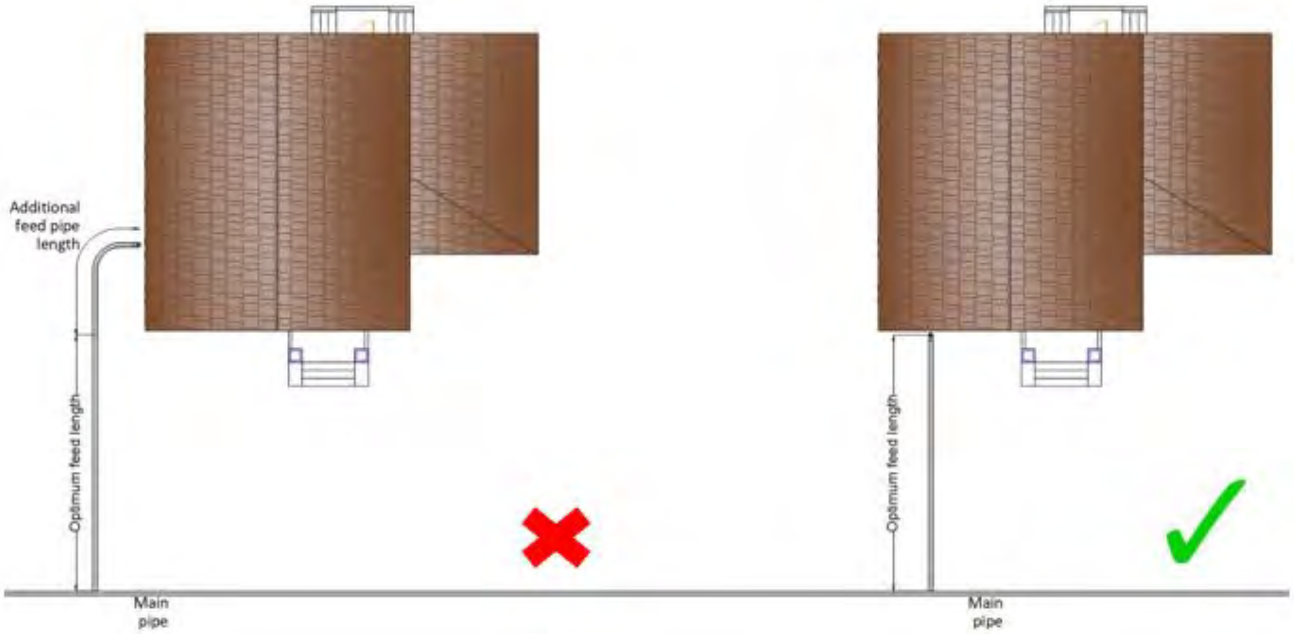


Figure 65:Heat network connection and HIU location

The heat network has been designed as a pre-insulated ridged steel pipe system for larger pipe diameters and where possible flexible pre-insulated polymer pipe for smaller diameters. The pre-insulated pipe will either be installed as single pipe (with a separate pipe for the flow and the return) or twin pipe where both the flow and return pipe are housed within the same casing, see Figure 66.

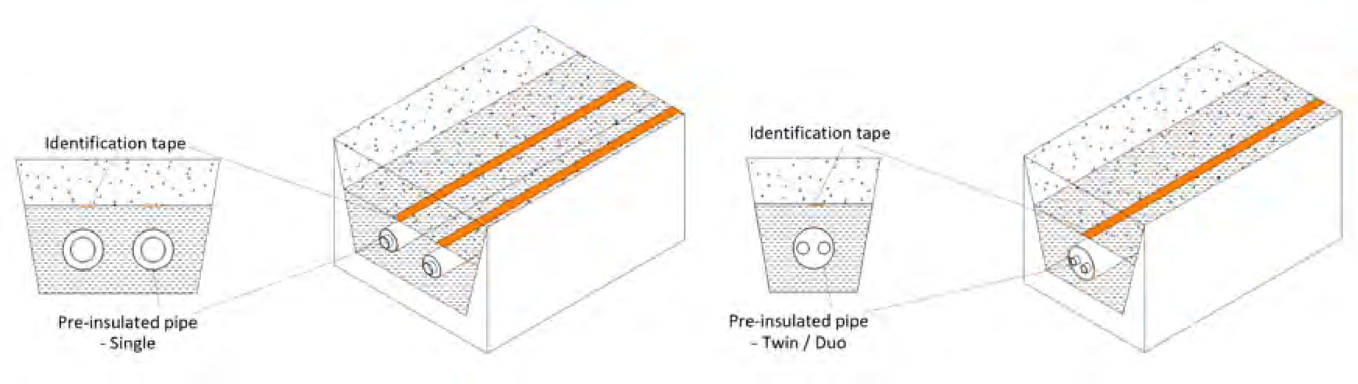


Figure 66: Pipes in trench

The network includes the spine (connecting the energy centre to the development parcels) and the branches and feeds within the parcels network (connecting the spine to the heat users). The spine network dimensions are shown in Table 43 below. The pipework in the parcels is pre-insulated twin/duo plastic pipe ranging from 63+63 / 182 to 25 + 25 /111. Based on the layout images received, there is 6.7 km of spine network and 84.7 km of branches and feeds within the parcels.

Table 56:Spine pipe sizes and lengths

Pipe size	Trench length, m					
	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Total
DN50	144	-	-	-	33	178
DN65	-	-	46	-	-	46
DN80	24	205	37	-	-	265
DN00	123	449	455	1,451	-	2,477
DN125	-	462	405	-	-	867
DN150	75	560	-	-	-	638
DN200	620	606	-	-	-	1,226
DN250	961	-	-	-	-	961
Total	**1,950**	**2,282**	**942**	**1,451**	**33**	**6,658**

Insulation will be CFC free rigid polyurethane foam homogenously filling the space between the service pipe and casing over the total length and in compliance with standard EN 253. The high density polyethylene (HDPE) pipe casing and all fittings and joints will be manufactured in compliance with EN 253 standards. The heat losses and size of trenches for the spine network have been based on a series three insulation thickness of polyurethane foam with diffusion barrier.

Pipework will include a pipe surveillance system in full compliance with BC EN 14419, suitable for both raising alarm of a fault and detecting the location of a fault within all routes of the network. The alarm system will allow provision of outputs to the energy centre control system.

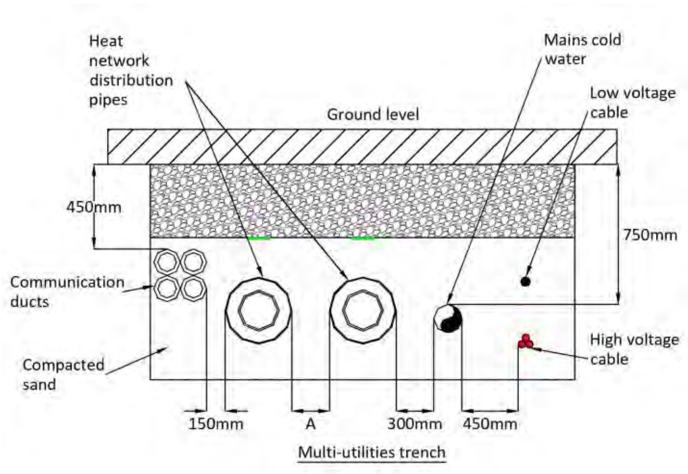


Figure 67: Multi-utilities trench

In addition to the district heating pipework the network trenches can also be used for the distribution of utilities such as water, electricity and communications infrastructure. When multiple utilities are present in a trench it is important to ensure that they are positioned a safe/workable distance from each other. The NJUG Guidance for Buried Utilities outlines how this can be achieved. Figure 67 shows an example of a multi-utility trench.

APPENDIX 4: THERMAL NETWORK TECHNOLOGY SIZING

Energy generation technologies are assessed using in house software that has been developed to allow detailed sizing of plant and thermal storage, modelling of operating parameters and conditions, financial assessment, and sensitivity analysis. The software utilises hourly network demands for each day of the year and considers hourly energy outputs from low carbon technologies, thermal storage and peak and reserve plant considering modulation limits, efficiencies and plant down time for maintenance. A range of plant and thermal store sizes and number of units are assessed and optimised to ensure key operating and financial/investment criteria are met.

The tools consider:

- Heat and electricity demand that can be served by the plant (including private wire options)
- Thermal storage - used to supply heat loads below modulation limits or peaks above plant capacity and minimise plant firing e.g. for heat pump, store size will be modelled, optimised and cost/benefit analysis conducted to consider the optimum operating strategy for heat generation
- Supply strategy - consideration of issues such as varying seasonal or diurnal operation, continuous operation, modulated or full output, primary energy source or base load only and peak and reserve plant requirement
- Peak and reserve boiler sizing - according to the diversified peak demand of the various network phases, predicted operating requirements and redundancy
- Peak supply and minimum load - this will consider plant modulation limits and the number of units
- Carbon savings - these will be calculated against the 'business as usual' case and include annual and lifetime savings based on the most up to date BEIS carbon emissions projections

Where heat pumps have been included, these have been sized based on network heat demand and have been maximised to provide the greatest economic and CO_2e savings for the network option and to provide the optimum balance between heat generation capacity, capital cost, maintenance costs and physical size.

The heat pumps and thermal stores have been sized with consideration of the hourly annual network heat demand. Peak and reserve boilers will meet any remaining demand. Technology sizing is based on an iterative process within the technical model to identify the optimal balance of the priorities.

Figure 68 shows an example output from our technology sizing tool for an example network served by the 6,826 kW heat pump. The load duration curve shows the heat demand for every hour of a year, ordered from highest to lowest. The black line shows the total low carbon and renewable capacity installed in the energy centre. The heat demand above the black line is met by thermal storage and peak and reserve boilers.

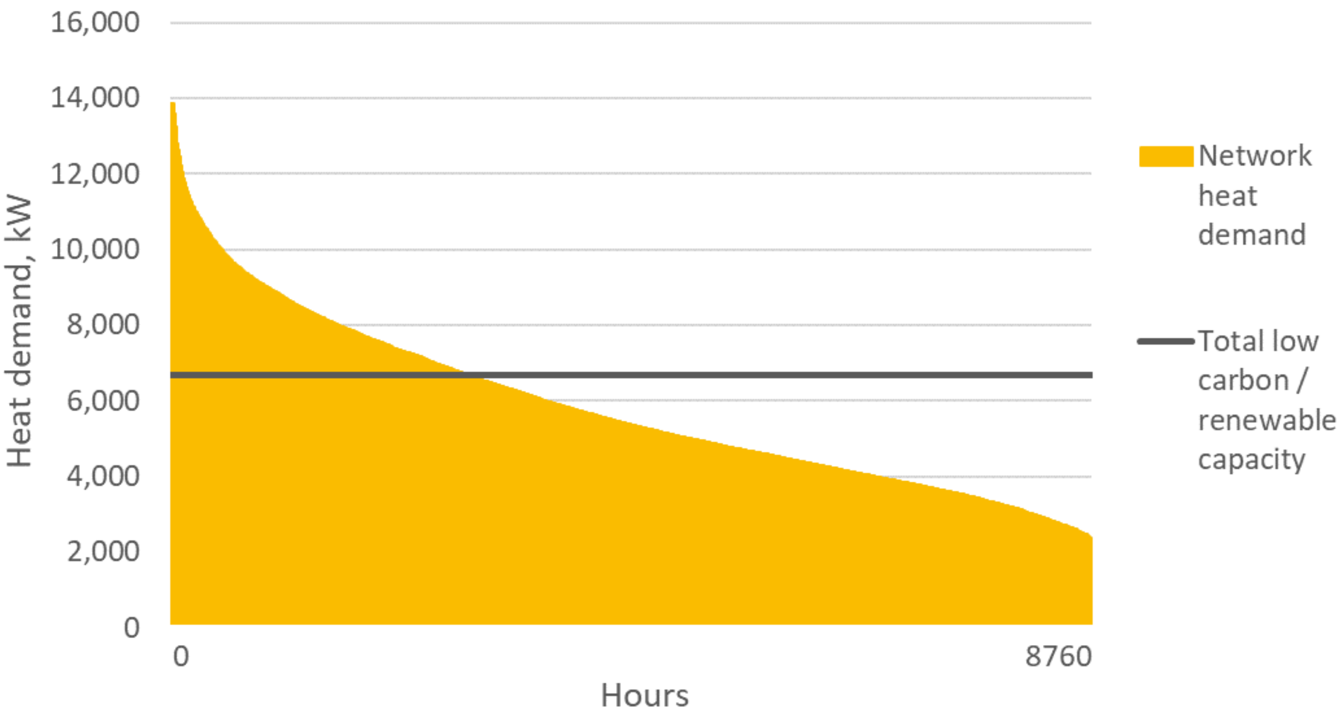


Figure 68: Load duration curve for example network

Figure 69 and Figure 70 show the proportion of the heat demand supplied by the heat pump, charge and depletion of the thermal store and heat demand supplied by peak and reserve boilers for fully built network for 1st and 2nd January and 1st and 2nd August respectively. The heat pump and thermal stores meet the majority of the baseload heat demand with a small proportion of the demand met by peak and reserve boilers. Where the thermal store charge and depletion is greater than the total heat demand shown in Figure 69 and Figure 70, the thermal store is being charged. Where the thermal store charge & depletion is below the total heat demand, the thermal stores are being depleted.

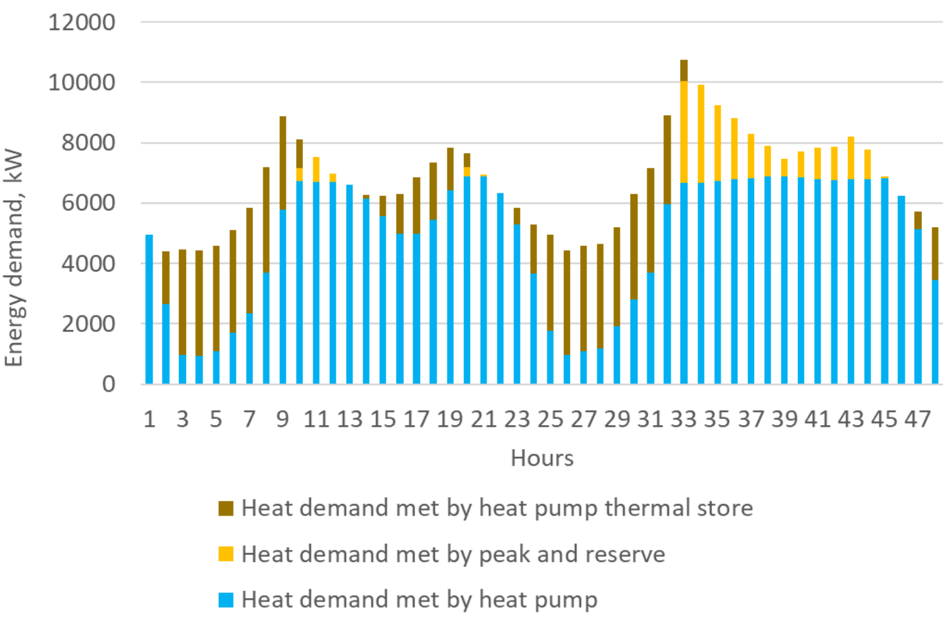


Figure 69: Heat generation 1st and 2nd January

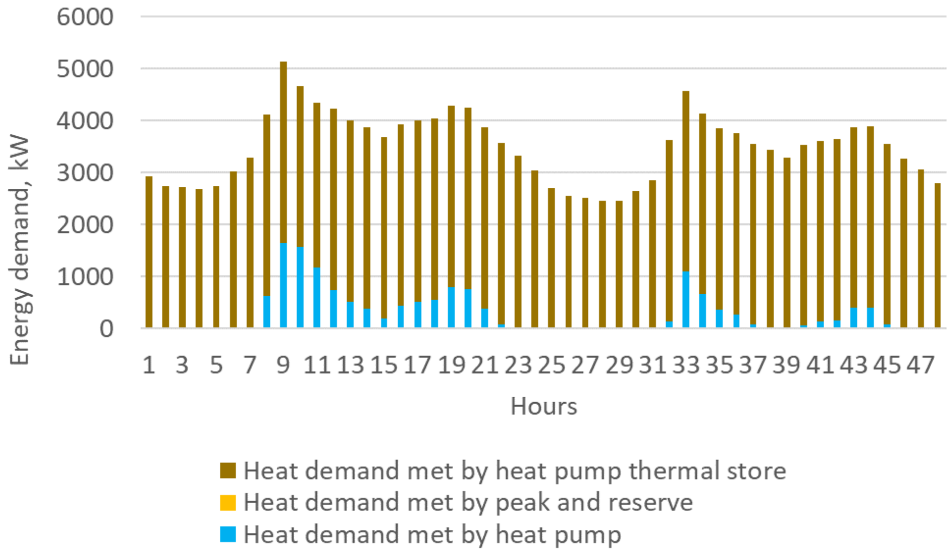


Figure 70: Heat generation 1st and 2nd August

Thermal stores have been sized based on hourly network heat demand, heat pump capacities, modulation limits and capital costs. Figure 71 shows the hourly operation of the heat pump for the example network with and without a thermal store. The thermal store provides significant benefits at times of peak network demand and when heat generation is restricted by modulation limits.

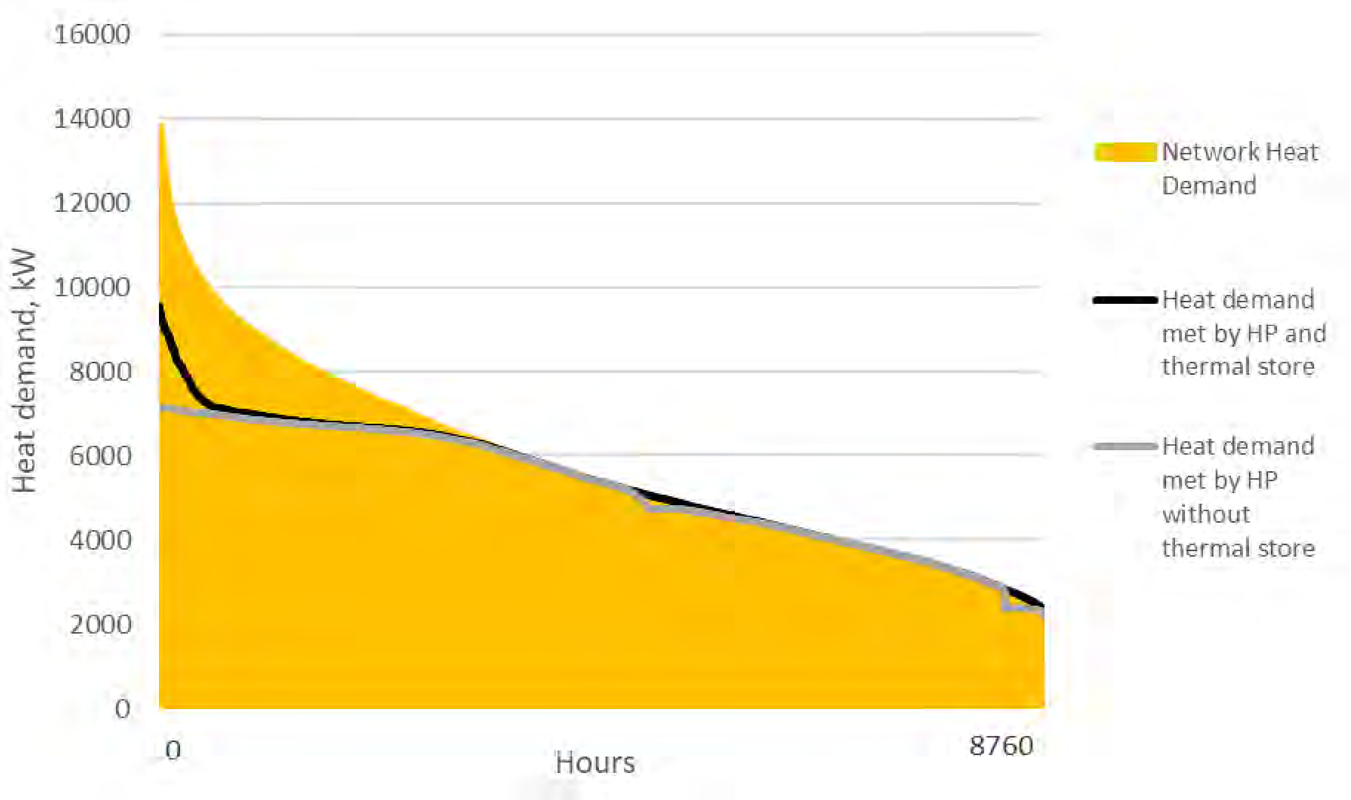


Figure 71: Load duration curve and thermal store usage

APPENDIX 5: HEAT PUMP REFRIGERANT

There are advantages and disadvantages associated with different refrigerants and the choice of refrigerant in heat pumps can depend on a number of criteria including efficiency, required water temperatures and scale.

Most domestic scale heat pumps use synthetic refrigerants (HFCs) that have a high Global Warming Potential (GWP) meaning they have a considerable environmental impact when they leak. This impact can be two to three thousand times higher than CO_2. For this reason, the UK has committed to the Kigali amendment of the Montreal Protocol in January 2019 where we commit to cutting the production and consumption of HFCs by more than 80% over the next 30 years and replacing them with less damaging, ideally natural, alternatives.

The European Commission F-gas phase down states that by 2021-2023 the average GWP of refrigerants should be less than 900, and by 2030 the average GWP should be 400. The lifetime of chilling or heating plant is approximately 15-20 years. Therefore, plant installed now will require a GWP of less than 400, as otherwise by 2030, it will exceed the Kilgali Amendment phase down targets. Net zero CO_2e targets will also be affected by plant and equipment installed in buildings that contain powerful greenhouse gases. All new buildings should consider the lifetime impacts of the refrigerant as well as efficiency to reduce overall emissions of greenhouse gases.

The main refrigerants used in commercially available heat pumps are summarised in Table 57 below:

Table 57: Refrigerants used in heat pump systems

Refrigerant	GWP	Refrigerant type	Application	Considerations
R134a	1,430	HFC	Medium and large heat pump systems	• Higher efficiency than R410a but lower than ammonia • Low pressure and high volume requirements which result in higher CAPEX • Mainly used in split heating and cooling units
R410a	2,088	HFC	Domestic heat pumps and heat and cooling installations	• Can be used in low temperature systems • Lower volume requirements and resultant CAPEX than R134a • Lower efficiency than R134a
R32	675	HFC	Domestic heat pumps	• Relatively new refrigerant often used as a substitute for R410a • Mildly flammable and non-toxic • More efficient than R410a
R454c	146	Hydro -fluoro-olefin (HFO)	Commercial and industrial refrigeration systems and domestic heat pumps	• Suitable for low and medium temperature refrigeration systems • Mildly flammable
R600 / R600a (butane / isobutane)	3	Natural refrigerant	Large heat pump and refrigerant installations	• Can provide temperatures higher than 80°C • Subject to strict safety requirements due to fire and explosion hazard
R290 (propane)	3	Natural refrigerant	Large heat pump systems and more recently a limited choice of domestic heat pumps	• Due to its low environmental impact and thermodynamic properties has started to be used in domestic heat pumps • Domestic heat pump systems higher cost than those utilising HFCs • Lower efficiency than R32 at higher temperatures in domestic models
R717 (ammonia)	0	Natural refrigerant	Large heat pump and refrigerant installations	• High efficiency • Can provide temperatures of up to 80°C

Refrigerant	GWP	Refrigerant type	Application	Considerations
			in industrial environments	• Although non-flammable, it is subject to strict safety requirements as it is toxic and carries a strong odour
R744 (CO_2)	1	Natural refrigerant	Large heat pump and refrigerant installations	• Requires a maximum return temperature of 30°C, which limits its suitability in domestic heat pumps

APPENDIX 6: TECHNO ECONOMIC MODELLING - KEY PARAMETERS AND ASSUMPTIONS

Energy Sales Tariffs

Energy sales tariffs used in economic assessments have been based on heat network energy tariffs used by clients from previous projects for commercial connections and average domestic tariffs for the area for residential connections. These have been calculated based on the current cost of heat. Tariffs are made up of a variable tariff, daily standing charge and capacity charge. Energy sales tariffs have been set for each individual network connection based on the required connection capacity and annual heat demand and BEIS price projections have been used. These can be varied in the TEM.

An example calculation for the heat sales tariffs used in assessments for commercial sites is shown in Table 58 and residential tariffs are shown in Table 59 and Table 60.

Table 58: Example commercial heat sales tariffs calculation with ASHP counterfactual

	Calculation	Value
Annual demand, kWh		1,000,000
Peak heat demand, kW		600
Assumed ASHP capacity (assumed as 2 units at 60% capacity), kW	600 x 60% x 2	720
Estimated annual replacement costs		£23,400
Estimated annual maintenance costs		£15,000
Total annual fixed costs	£23,400 + £15,000	£38,400
Current fixed cost, £/day	**£38,400 / 365**	**£105.21**
Electricity tariff, p/kWh		13
ASHP CoP		2.5
Current variable cost of heat, p/kWh	**13 / 2.5**	**5.2**

Table 59: Current residential tariffs – uSwitch (accessed 21st September 2021)

Supplier	Gas unit rate, p/kWh	Gas standing charge, p/day	Electricity tariff, p/kWh
SO Energy	6.05	26.11	25.12
EBS Energy	6.06	26.11	25.18
Zebra Power	3.44	26.6	19.83
Nabuh Energy	3.44	26.59	18.84
E.On Next	3.96	19.27	19.82
Sainsbury's Energy	3.96	19.27	19.82
SSE Southern Electric	4.17	26.11	20.67
Co-op Energy	3.95	23.85	20.12
Octopus Energy	3.95	23.85	20.11
Average	**4.315**	**24.39**	**20.92**

Table 60: Residential heat sales tariffs

Business as usual	Individual gas boilers	Individual ASHPs	Direct electric heating
Average efficiency / CoP	80%	2.50	1
Annual maintenance costs	£140	£140	-
Cost to replace technology	£2,425	£8,000	£2,000
Expected lifetime of technology	20	20	10
Unit cost of gas / electricity, p/kWh	4.32	20.92	20.92
Annual replacement costs	£121	£400	£200
Current fixed heat sales tariff, £/annum	£334	£513	£190
Current variable heat sales tariff, p/kWh	5.39	8.37	20.92
Variable only heat sales tariff, p/kWh	11.43	19.24	24.05

Energy Centre Tariffs

Gas and electricity purchase tariffs for the energy centre have been based on current energy tariffs for existing energy centres, identified in previous projects. CCL has been included for all gas (if selected) required for the peak and reserve boilers and all electricity imported from the national grid. The gas rate for CCL is due to increase to match the rate for electricity by 2025. These proposed rates have been used (0.667 p/kWh for both natural gas and electricity).

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 and fractional repairs are shown in the section "Key Technology Parameters"

Capital costs for the scheme are based on a combination of previous project experience, quotations for recent similar works and soft market testing. Soft market testing has been conducted with potential suppliers of plant and equipment.

To develop an accurate estimate of the heat network costs, the proposed network has been broken down into constituent parts (i.e. straight pipe lengths, pipe bends, valves, valve chambers, welds, weld inspections, etc.) for each pipe section. These quantities have then been multiplied by the average rates taken from numerous quotations obtained for similar work. A complexity factor has been added to this to account for the areas of lower implementation or construction complexity and areas of higher complexity such as main roads, key intersections and areas of congested utilities.

Estimated capital costs for key plant items (such as heat pumps, thermal storage tanks, etc.) have been obtained from the respective suppliers.

By using the above methodology, CAPEX estimates are within the tolerance stated in the project requirements and ITT and contingency has been applied to each element of capital expenditure as appropriate.

BEIS Energy Price Projections

To assess the impact of expected future price changes on the financial outputs, the BEIS central scenario price projections for natural gas and electricity have been used (last updated October 2020). The projected changes in prices for electricity and natural gas for residential, services and industrial is illustrated in Figure 72. The projected price variations have been applied to the energy tariffs calculated as discussed in section "*Energy Sales Tariffs*" above.

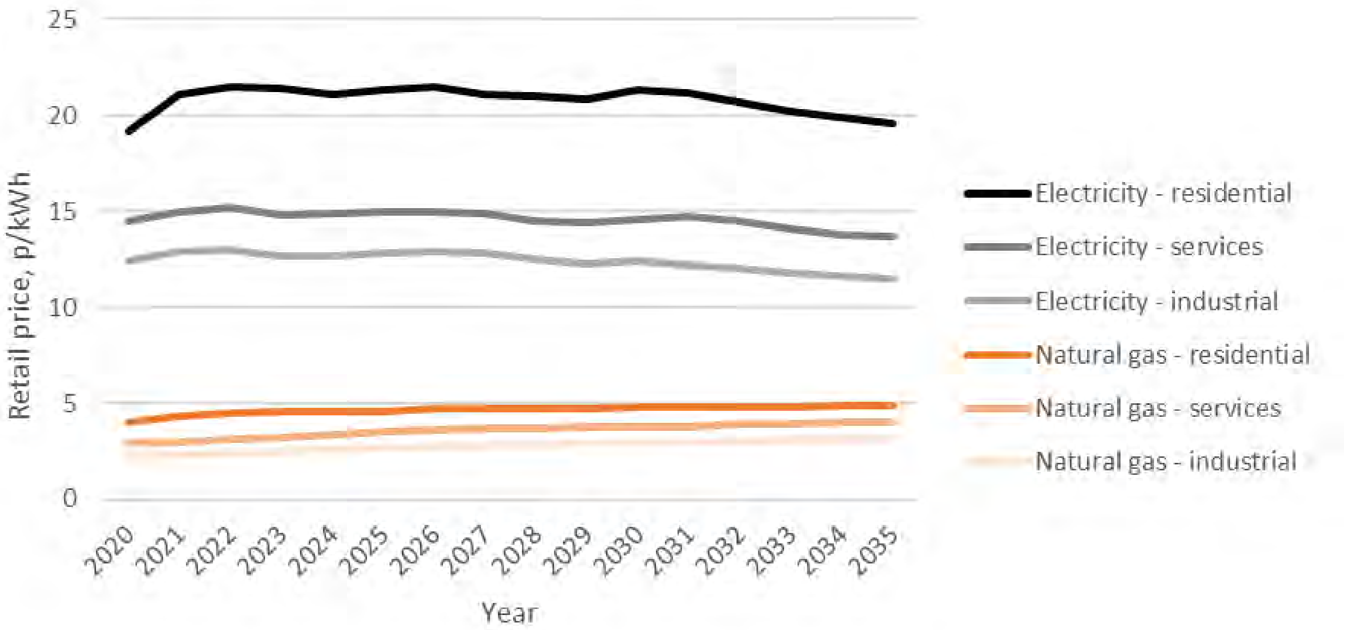


Figure 72: BEIS price projections, updated October 2020

The above projections indicate that while both gas and electricity prices are predicted to increase in the short and medium term, in the long term, electricity prices are expected to show a decreasing trend, while gas prices continue to increase. This will result in improved viability of heat from heat pumps. The BEIS low and high scenarios, as well as a fixed indexation rate has also been assessed for the network option.

The BEIS fossil fuel price projections (central scenario) are shown in Table 61.

Table 61: BEIS fossil fuel price projections

	Sector	Units	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Electricity	Industrial	p/kWh	12.4	12.9	13.0	12.7	12.7	12.8	12.9	12.8	12.5	12.3	12.4	12.2	12.0	11.8	11.6	11.5
	Residential	p/kWh	19.2	21.1	21.5	21.4	21.1	21.3	21.5	21.1	21.0	20.9	21.3	21.2	20.7	20.2	19.9	19.6
	Services	p/kWh	14.5	15.0	15.2	14.8	14.9	15.0	15.0	14.9	14.5	14.4	14.6	14.7	14.5	14.1	13.8	13.7
Natural gas	Industrial	p/kWh	2.2	2.3	2.4	2.5	2.6	2.7	2.7	2.8	2.8	2.9	2.9	3.0	3.0	3.1	3.1	3.1
	Residential	p/kWh	4.0	4.3	4.5	4.6	4.6	4.6	4.7	4.7	4.7	4.7	4.8	4.8	4.8	4.8	4.9	4.9
	Services	p/kWh	2.9	3.0	3.1	3.2	3.4	3.5	3.6	3.7	3.7	3.8	3.8	3.8	3.9	3.9	4.0	4.0

CO_2e Emissions Factors

The electricity grid CO_2e emissions figures used in assessments are shown in Table 62.

Table 62: Electricity grid CO_2e emissions

Electricity grid CO_2e emissions, gCO_2e/kWh				Electricity grid CO_2e emissions, gCO_2e/kWh			
Year	LCP marginal figures, gCO2e/kWh	Long run marginal figures (commercial), gCO2e/kWh	Long run marginal figures (domestic), gCO2e/kWh	Year	LCP marginal figures, gCO2e/kWh	Long run marginal figures (commercial), gCO2e/kWh	Long run marginal figures (domestic), gCO2e/kWh
2021	395.4	277.7	282.8	2036	263.8	35.7	36.4
2022	401.9	264.4	269.3	2037	250.0	28.9	29.4
2023	382.8	250.4	255.0	2038	248.9	23.4	23.8
2024	381.1	235.6	240.0	2039	249.5	18.9	19.3
2025	381.2	219.9	224.0	2040	243.4	15.3	15.6
2026	382.0	203.4	207.2	2041	239.3	12.7	12.9
2027	367.9	185.9	189.4	2042	249.0	12.1	12.3
2028	359.2	167.4	170.6	2043	246.9	11.8	12.0
2029	333.8	147.9	150.7	2044	228.7	11.1	11.3
2030	311.9	127.3	129.7	2045	228.7	9.4	9.6
2031	316.1	103.0	104.9	2046	228.7	8.6	8.7
2032	293.0	83.3	84.9	2047	228.7	7.9	8.0
2033	279.5	67.4	68.7	2048	228.7	7.5	7.6
2034	260.0	54.6	55.6	2049	228.7	7.0	7.1
2035	248.3	44.1	45.0	2050	228.7	6.9	7.0

Table 63: Natural gas CO_2e emissions

Parameter	Value
Natural gas CO_2e emissions factor, gCO_2e/kWh	183.87
Average efficiency for BAU gas boilers	85%

Connection Costs and Connection Charges

It has been assumed the network operator covers costs of all connections with connection charges from developers of planned developments. Connection charges for all residential planned developments have been included in the base case assessment at £6000/dwelling. Connection charges at £450/kW have been included in the base case assessment for all commercial planned developments.

Key Technology Parameters

Key technology parameters for the network are shown in Table 64.

Table 64: Technical inputs

Parameter	Value	Source of data / assumption
SPF_{H1} for heat pump	Various	Varies for each network and phase, derived from manufacturers performance curves based on the selected heat pump, potential water conditions for the site and required network temperatures.
Availability of heat from heat pump	52 weeks	The base case assessed assumes that there are n+1 modular heat pumps installed to ensure that at any one time the heat demand will be met. This will allow maintenance to take place on each heat pump without negatively impacting the percentage of low carbon heat.
Peak and reserve boiler efficiency	99%	Expected efficiency of new electric boilers. Electric boilers have been selected to increase the low carbon heat generated.

Technology replacement costs have been calculated on an annualised basis and take into account the expected lifetime of the technology, fractional repairs and the length of the business term. Plant / equipment lifetimes are shown in Table 65.

Table 65: Plant and equipment lifetime

Plant / equipment	Lifetime
Heat pumps	20 years
Peak and reserve boilers	30 years
Customer building connections	20 years

Table 66: Energy centre building costs

Energy centre	Cost, £/m²
Welborne Energy Centre	£2,500