Milton Keynes Council

City-Wide District Heating Feasibility – WP2

Report prepared by: Z. Moss

Report Approved by: B. Lynch

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Disclaimer

District Heating Feasibility Study

Milton Keynes

Prepared for:

Neil Allen
Milton Keynes Council
1 Saxon Gate East
Milton Keynes
MK9 3EJ

Prepared by:

Zack Moss
Anthesis
Royal London Buildings,
42-46 Baldwin Street,
Bristol
BS1 1PN

Report written by:

Zack Moss
0117 403 2656
huw.blackwell@anthesisgroup.com

Email:

Website: www.anthesisgroup.com
Tel: 01865 250818
Company Registration: 08425819

Analysts:

Zack Moss

Quality Assurance

Ben Lynch

Report checked by:

Ben Lynch, 30/08/22

Report approved by:

Ben Lynch, 30/08/22
0770 382 1918
Ben.lynch@anthesisgroup.com

Signature ………………………………………………………………

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Executive Summary

This feasibility study has evaluated the opportunity for district heating systems within the city of Milton Keynes as a component of a strategy to decarbonise local heat supply. The objectives are to inform the evidence base for local planning policy and to identify potential projects that might have viability independently or with the support of UK Government funding. The comparison within this study is for a limited set of buildings, but the outcomes can be extrapolated for the wider context of decarbonising heat across the City.

Based on previous energy masterplanning, current electrical distribution infrastructure was highlighted as being under stress across Milton Keynes. This is ahead of planned additional load anticipated from increased transportation demand (i.e. vehicle charging), electrification of heating systems and further deployment of Low Zero Carbon electrical systems as part of built assets (e.g. PV). Heating infrastructure that does not have grid dependency will free capacity for other low carbon infrastructure and generation in the City and reduce the potential upgrade expenditure to meet this increased demand.

During the masterplanning study, an opportunity for a city-wide heat network was identified, utilising the Waste Heat Recovery Park as a potential low-carbon heat source to deliver heat to central Milton Keynes and the University Hospital. This was the preferred energy source as energy-from-waste offers low-carbon heat at a significantly lower heat production cost than any other high capital cost alternative, such as air-source heat pumps (ASHPs), as well as having much less strain on local electrical infrastructure.

This feasibility study advances that opportunity and comprises of a detailed techno-economic modelling (TEM) analysis and an early commercial analysis for delivery options.

Two district heating scenarios were modelled, S1, a core scheme which supplies heat to Central Milton Keynes, and S2, an extended scheme providing heat to Central Milton Keynes and extending to the University Hospital, shown in Figure 1below. Both district heating scenarios utilise the Waste Heat Recovery Park as the main heat source, with a gas boiler located at ThamesWey serving as peaking and backup plant. To understand the viability of the proposed district heating schemes against an alternative strategy, two counterfactual scenarios were modelled. Counterfactual A assumes existing buildings transition to ASHPs by 2030 and new buildings are built with ASHPs, Counterfactual B is modelled with the same assumption except that new-build residential properties are built with direct electric heating systems.

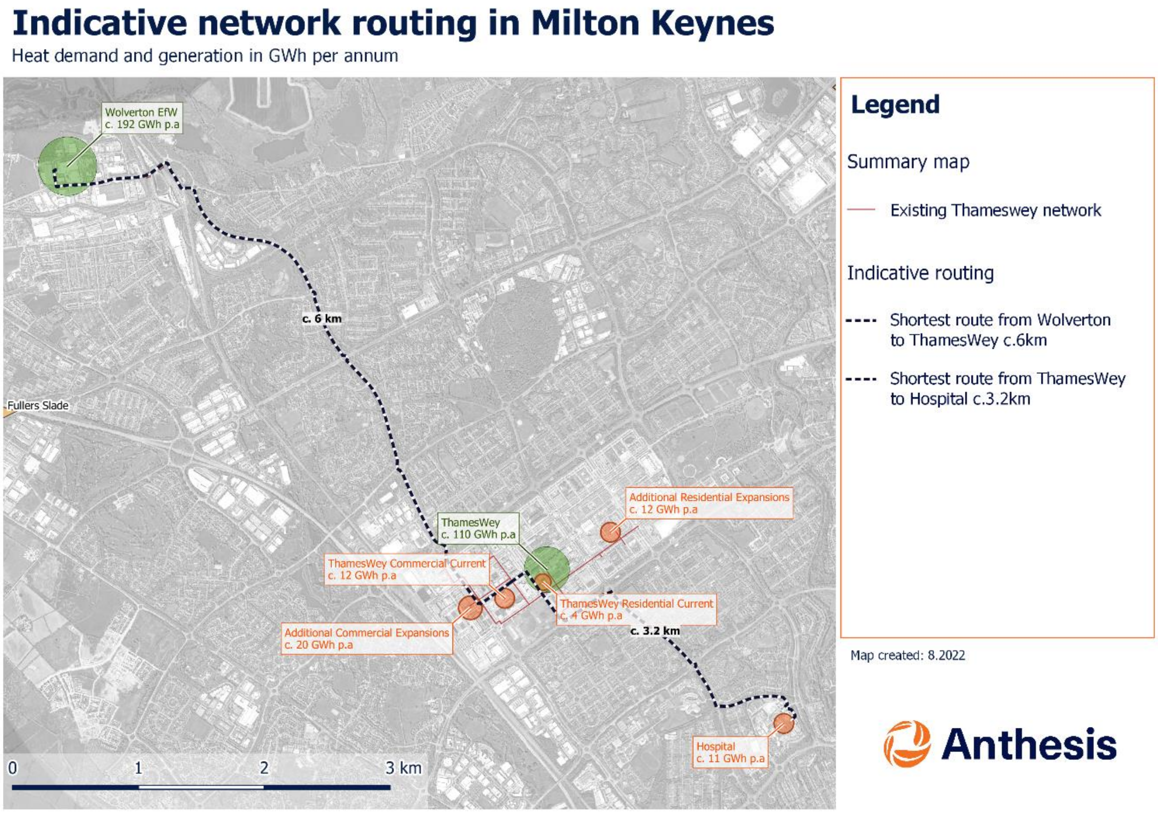


Figure 1: Indicative network routing in Milton Keynes

The discounted cash flow modelling was compared for each scenario. Both district heating scenarios are estimated to have more positive cashflows than either counterfactual, from approximately 2040 onwards, despite greater capital costs. Counterfactual B, the option with direct electric heating, performs worse than Counterfactual A despite lower capital costs, as well as providing a greater strain on local electrical infrastructure.

The results of the carbon analysis showed that the COP effect of the heat pumps result in Counterfactual A having significantly lower lifetime emissions than Counterfactual B. These results can be extrapolated to the strategy for decarbonising heat across the city and shows that the council should seriously consider whether they allow developers to build direct electric heating systems, as this will be at the detriment of residential customer energy bills, carbon emissions, and strain on local grid infrastructure.

Counterfactual A, S1 and S2 have very similar lifetime carbon emissions. However, the low carbon intensity of the district heating solutions do not rely as heavily on the decarbonisation of the grid, as it is mainly utilising the increased efficiency of the Waste Heat Recovery Park. This reduces the dependency of carbon outcomes on external factors, and therefore reduces the risk between technical solutions of providing and achieving low-carbon heat supply to the city of Milton Keynes.

High-level commercial analysis has been undertaken and the results are shown in Table 1 below, demonstrating both S1 and S2 as commercially attractive opportunities, with comparable IRRs of 7.7% and 6.6% and 40-year project revenues of £135.8m and £164.9m respectively, which could be further secured with Government grant and/or loan funding (https://www.gov.uk/government/publications/green-heat-network-fund-ghnf).

Table 1: Comparison of district heating solutions

	S1	**S2**
40-year Project Revenue	£135.8m	£164.9m
IRR	7.70%	6.60%
Saving against Counterfactual A	35%	34%
40-year Carbon Emissions (ktCO2e)	60.9	72.9

This study provides strong evidence of the technical and commercial viability of a district heating solution in Milton Keynes. There is revenue funding available from the HNDU under the DPD stage that will allow the Council to better understand it's role in the network construction and ownership, as well as refining the technical solution. Advancing this detail and clarity on the scheme will prepare the Council for a potential application to the Green Heat Network Fund which can provide capital support to enhance viability or provide stability on returns for investors. The Council need to move promptly to benefit from these funding opportunities, otherwise the counterfactual options assessed may become default options for the City.

In summary, extending the network to connect the University Hospital results in a greater quantity of low-carbon heat distributed across the City, but it does not have a material impact on the long-term finances or carbon-intensity of a district heating, and results in increased risk due to higher capital costs. Both district heating solutions demonstrate significantly beneficial performance when compared against the alternative options to deliver low-carbon heat to the city. The business case may be further improved for both solutions by identifying future connections either on route or nearby key anchor loads.

Introduction

Anthesis were previously commissioned to undertake a HNDU feasibility study for the deployment of district heating across Milton Keynes, comprising of two pieces of analysis. This document should be considered supplementary to the original study “Milton Keynes District Heating Feasibility (December 2021)”.

The first was for a planned district heating system proposed by Milton Keynes Council at the Lakes Estate. It was demonstrated that the proposed system has linear heating density <2 MWh/m/year, lower than the 2-4 MWh/m/year minimum anticipated for commercially viable district heating, highlighting how certain areas of Milton Keynes may not be suited to district heating deployment due to the general low build density of the city.

The second analysis sought to determine a maximally heat dense alternative heat network making use of waste heat supplies available at Milton Keynes and linking areas of current high and future heat load. The Waste Heat Recovery Park in Wolverton was identified as the most viable potential low-carbon heat source for a district heating network in Milton Keynes.

Anthesis received this commission, to undertake a detailed feasibility study for the development of a heat network utilising the Waste Heat Recovery Park as a potential low-carbon heat source, to carry out further analysis required for this solution to progress to detailed project development. The comparison within this study is for a limited set of buildings, but the outcomes can be extrapolated for the wider context of decarbonising heat across the city.

Supporting analysis and information is provided within Appendices at the rear of the document, for the readers reference.

Climate science, renewable technology and the policy developments and actions surrounding this remain a very dynamic environment, with constant new understandings and rapidly changing positioning. Within the last three years the UK climate change act has been amended to reflect a Net Zero Carbon Target by 2050, with most local authorities, including municipal and regional government in and around Milton Keynes, declaring climate emergencies and setting out local policy climate objectives within similar or shorter timelines. This report has been written to reflect a current understanding of commercially and technologically deployable solutions to address these, however the authors remain open to constructive debate regarding alternative solutions and recognise that future change in science or policy have the potential to change the recommended outcomes made at this point of time.

Review of past works and conclusions

For full details on the energy masterplanning of Milton Keynes, please refer to the previously issued report "Milton Keynes District Heating Feasibility (December 2021)". Summary findings that bring context to this piece are detailed below. As part of the previous works, to determine a possible city-wide district heating scheme, the areas of highest heat demand and supply were identified, and an indicative network was drawn between them.

Cooling Demands

Figure 2 details cooling loads assessed across the wider area of Milton Keynes. Based on our analysis of publicly available energy usage data there is very limited cooling consumption estimated across Milton Keynes.

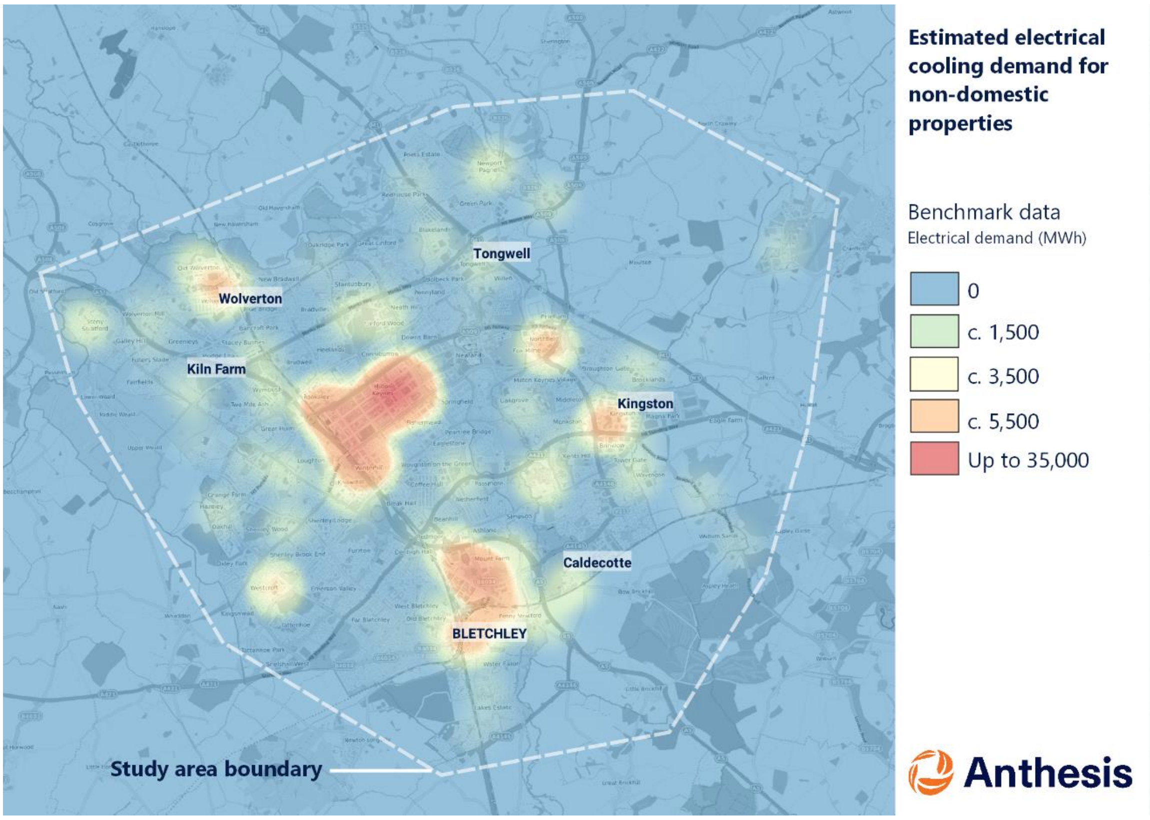


Figure 2: Cooling demand heat map for Milton Keynes from CIBSE Benchmark data

Many of the zones within the city are residential in nature, and low-density domestic properties in the UK typically do not currently have cooling systems installed. Commercial buildings are also deployed at a low density, with a few multi-storey buildings in the city centre. Some commercial properties are likely to have a cooling need met by local cooling systems. The most substantial appear to be some retail areas, for example the central retail area. However, relatively few of these are estimated to be substantial, many are likely to be only seasonal (i.e. occurring in the hottest summer months only).

As the city generally has low density cooling loads, it should not be considered for a cooling-only network. There may be potential to integrate cooling loads in with an ambient loop network. However, this should be a consideration to improve any proposed networks, rather than the basis to design a network from.

Heat Demands

Heat demand mapping has been carried out in several previous studies, using various sources (such as EPC, DEC, CIBSE Benchmarks), which generally show similar hotspots of heat demand, as shown in Figure 3 and Figure 4 below.

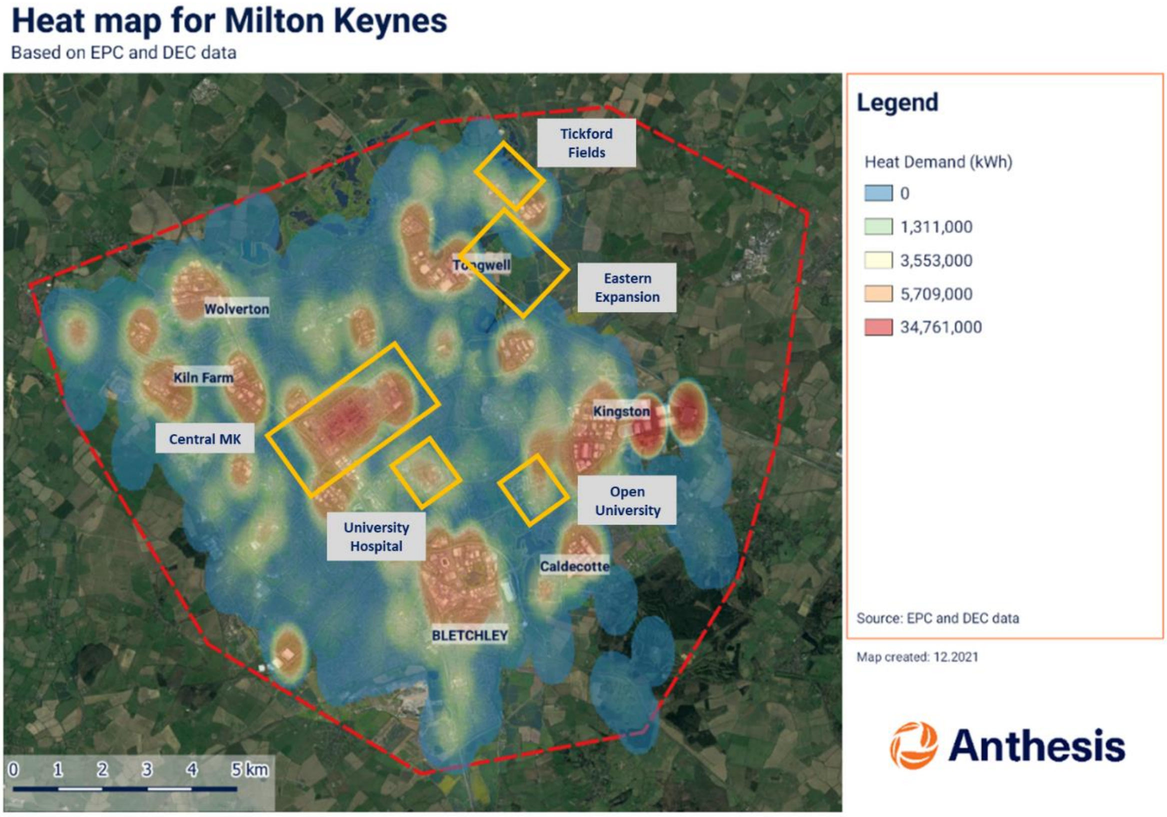


Figure 3: Heat Map for Milton Keynes based on EPC and DEC data

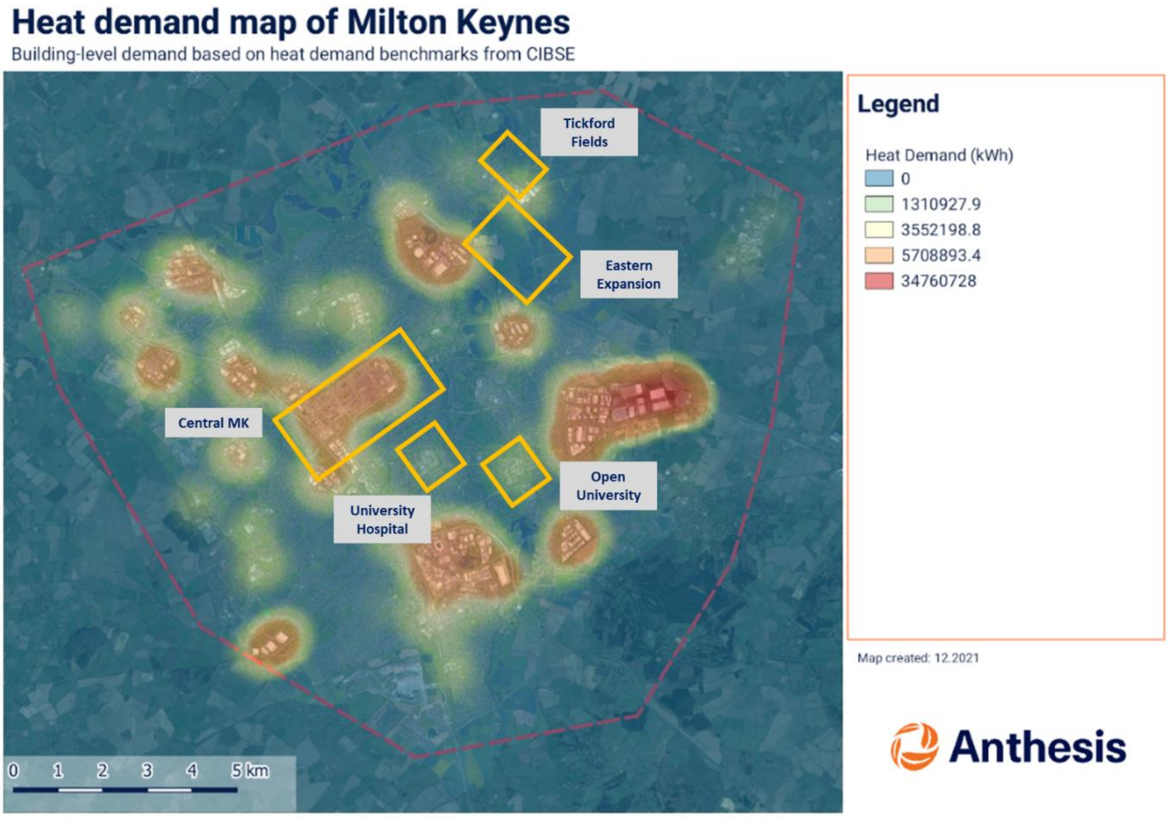


Figure 4: Heat Demand Map of Milton Keynes

The following zones were investigated further based on initial heat mapping and are discussed in more detail below.

Central Milton Keynes

This zone was identified as the area with highest density of heat demand. Furthermore, there is an existing heat network, ThamesWey, that is operating at below capacity and looking to expand its connections, whilst decarbonising the heat it delivers to its customers.

Milton Keynes University Hospital

This is a campus style hospital within the centre of the city. The hospital has identified the need to decarbonise its existing operations, including heating systems and is working towards these objectives. Milton Keynes Hospital has two large energy centres with one of these at the end of its economic life and requiring major refit.

The hospital has historically explored interconnection with the ThamesWey system, which is relatively local to the campus. This is not currently a priority owing to the higher carbon factors of heat supplied from this system.

The hospital is independently investigating the installation of large Air Source Heat Pumps at the site serving existing or networked heating systems. This would include the expansion of electrical capacity at the facility to serve these additional loads.

Open University

The open university operates a substantive campus at Walton Hall within Milton Keynes. Stakeholder engagement with the university has resulted in additional information supplied from their facilities management team pertinent to this study.

The University, like the hospital is undertaking its own net zero carbon strategic planning across its built assets. The campus has an existing district heating system serving circa 60 buildings, supplied from a gas boiler plant. Two major gas supplies feed the site, with the District Heating pipe network relatively modern and operating at approximately 80°C flow, 70°C return. No CHP is present within the energy centre and several buildings around campus use natural gas directly within local plant to provide heat and hot water services.

Milton Keynes Easter Expansion

A major residential extension to the city has been planned to the east of Milton Keynes. This comprises a total of circa 4,600 residential homes, with associated community infrastructure (retail, schools, leisure etc) and warehousing planned to be constructed through to 2040.

Limited details are currently available for the scheme owing to the early planning stages, however accommodation and energy consumption requirements have been provided by the developer, St James, as part of the masterplan planning submission, which allowed for an estimation of heat demand to be calculated.

Tickford Fields development area and the Eastern Expansion area in relation to Milton Keynes

Anthesis

Figure 5: Map of Tickford Fields development area and the Eastern Expansion area

Tickford Fields

A further large development has been highlighted through stakeholder engagement, which is the redevelopment of the Tickford fields area currently owned by the council in the Northeast of the city.

This is at an even earlier stage than the Milton Keynes East extension, therefore there is currently no appointed developer or public details of master planning for this site. Some aspirations for the site’s future have been developed, which provisionally includes an estimated 930 homes, some small retail, leisure and a primary school, as well as a redevelopment or relocation of the existing Civic waste centre.

Initial loads for this site have been developed using the estimations by St James for the nearby Milton Keynes East extension, as these are believed to be broadly consistent with design aspirations in this area and allows for direct comparison between the locations with respect to the differing scale of the development plots.

Heat Demand Summary

There are multiple zones across Milton Keynes of concentrated heat demand which would be appropriate for connecting to district heating scheme, which have been summarised in Table 2 below. Central Milton Keynes has been identified as the area with the highest existing heat demand and heat density. The University Hospital and Open University also have significant heat loads but are mostly surrounded by residential properties of low heat density. Tickford fields and Eastern Expansion Area also have considerable heat loads, however they have not been built yet so there is less certainty around the quantum and timing of these loads.

Table 2: Heat Demand Estimations

Load/Load Area	Estimated Thermal Load (GWh)	Source data
Milton Keynes Central - Gas	17.8	Metered, domestic and non-domestic MSOA, LSOA
Milton Keynes Central - Elec	0.9	Metered, domestic LSOA
University Hospital	17.6	Metered, Hospital report
Open University	12.9	Metered, University billing
Milton Keynes Extension	22.4	Estimated, developer SAP calculations
Tickford Fields	6.4	Estimated, extrapolated from MKE
Total	**78**	

Ultimately, the most appropriate zones for connecting to a heat network will depend on their proximity to the potential low-carbon heat supplies, which are detailed in the following section.

Heat Supply Opportunities

Waste Heat Recovery Park

Within Milton Keynes is the Wolverton Waste Heat Recovery Park. This contains a national leading waste treatment facility, currently the only operating example within the UK. The facility collects the black bag waste from the Milton Keynes area for processing. The waste is pre-processed with metals (ferrous and non-ferrous), plastics and organic fractions separated. The organic fraction is processed via anaerobic digestion, producing methane which is utilised on site in reciprocating gas engines to make 1.0 MW_e. The heat from these is used within the anaerobic digestion process, to warm the digestate to correct operating temperatures.

The residual fraction is processed through an advanced thermal treatment, in this case a form of gasification. The residual waste is heated in the absence of oxygen to produce Syngas, which is then burned within two 16.5 MW_{th} boilers to produce steam. The steam is utilised to produce electricity via a steam turbine. Amey has confirmed that the existing steam turbine may be fitted with a grid valve allowing heat extraction from the system, the efficiency of this processes is described by the Z-factor.

$$Z - Factor = \frac{MW\ of\ steam\ extracted}{MW\ of\ reduced\ electricity\ generation}$$

A steam extraction enthalpy profile for heat offtake and the associated impact on the steam turbine has been obtained from Amey and a Z-factor for heat extraction at 90˚C has been confirmed as 6.4.

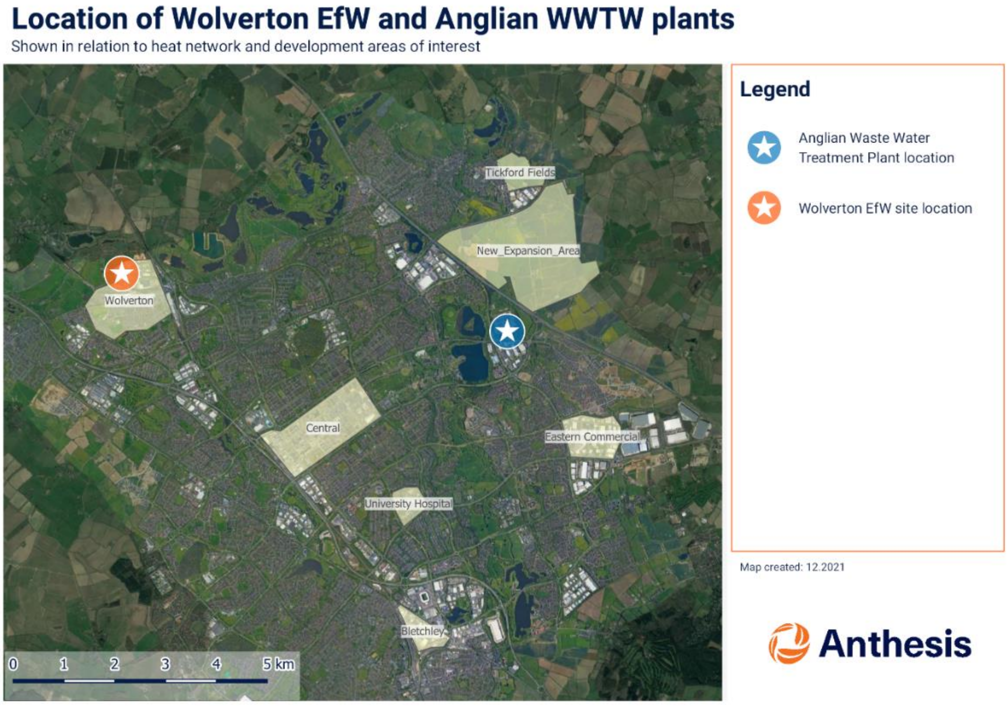


Figure 6: Map showing location of Wolverton EfW and Anglian WWTW plants

Wastewater Treatment Works

The principal wastewater treatment works within Milton Keynes are at Cotton Valley adjacent to the M1 and the A509. This is understood to serve a large part of the city and surrounding local area, processing some circa 50,000 m^3/d of wastewater. It is understood that both Thermal Hydrolysis and anaerobic digestion are used at the plant to treat the solid waste. Although no details have been provided by Anglian water, it is highly likely this results in Biogas which will be used for on-site heat and electricity production, with both outputs likely used on site.

The site is of particular interest as it is relatively adjacent to the Milton Keynes East development area, albeit with the M1 motorway situated between the facility and the development zone. This would complicate infrastructure crossing between sites, though this would remain technically feasible.

There is some potential that residual waste heat would be available from these processes for use in adjacent areas, however the other potential low grade heat source would be the sewage outfall. These usually have some residual heat levels relative to open water bodies after passing through treatment processes and accounting for hot water production and discharge into the system. For example, water temperatures of 25-30˚C may be available on the treated wastewater side, proportionally higher than the adjacent river. Abstracting heat from this water using heat pumps not only provides a higher grade of heat source (improving efficiency) in comparison with prevailing environmental air or water temperature sources, but may also assist in minimising wider environmental impacts, for example the heating of the river.

ThamesWey District Heating Scheme

An existing district heating system is in place serving Milton Keynes city centre. This is a legacy system serving 17 connections and fed from CHP and Gas boilers. It is understood 6.3 MW_{th} 6.1 MW_e of CHP is co-located with 10 MW_{th} of conventional gas boilers.

The system is likely to need a wider decarbonisation strategy to reduce future delivered heating emission, which may in turn require financial assistance (e.g., grant funding) to realise. It does appear to be located in an area of high heat use, as identified via the heat mapping exercise.

Were a wider district heating system deployed across the Central zone of Milton Keynes it would be highly unlikely to duplicate connections already made by the ThamesWey system. The more likely practical solution would be the integration of the ThamesWey scheme into a wider city network. As a result, there may be opportunity to utilise energy assets with remaining economic life, or existing energy centre spaces as resilient back-up, for thermal storage deployment or booster pumping stations as necessary in the wider strategy.

The following text commentary on the ThamesWey system has been provided by Local Partnerships, advisors to Milton Keynes on District heating Feasibility, and not an employee or associate of Anthesis. It is included here at the request of Milton Keynes Council's project management team to provide additional context on this system.

"ThamesWey Central Milton Keynes Ltd (TCMK) is a subsidiary of ThamesWey ltd, a wholly owned subsidiary of Woking Borough Council. TCMK supplies customers with heat and private wire electricity from their energy centre housing 6MW of gas fired CHP and 10MW of gas boilers. It is understood they also provide cooling via absorption chillers. Woking BC are looking to sell TCMK however TCMK is heavily indebted and therefore embarking on an 'expand and exit' strategy with a

view that an enhanced customer based will make a sale more viable. TCMK heat is gas fired and they recognise the challenge in decarbonising their supply, especially as a significant part of the revenue stream is from private wire which would not be available without the use of CHP's.

It is understood that TCMK has spare capacity within its energy centre and network to supply more heat and would be open to options from full acquisition, joint venture to use of network arrangements. Furthermore, consideration could be given to the use of the return network to provide source heat to heat pump-based network expansions.

The TCMK assets are strategically located within the city, and it could be commercially advantageous to utilise this existing network as part of any wider city heat network."

Utility Infrastructure

Gas

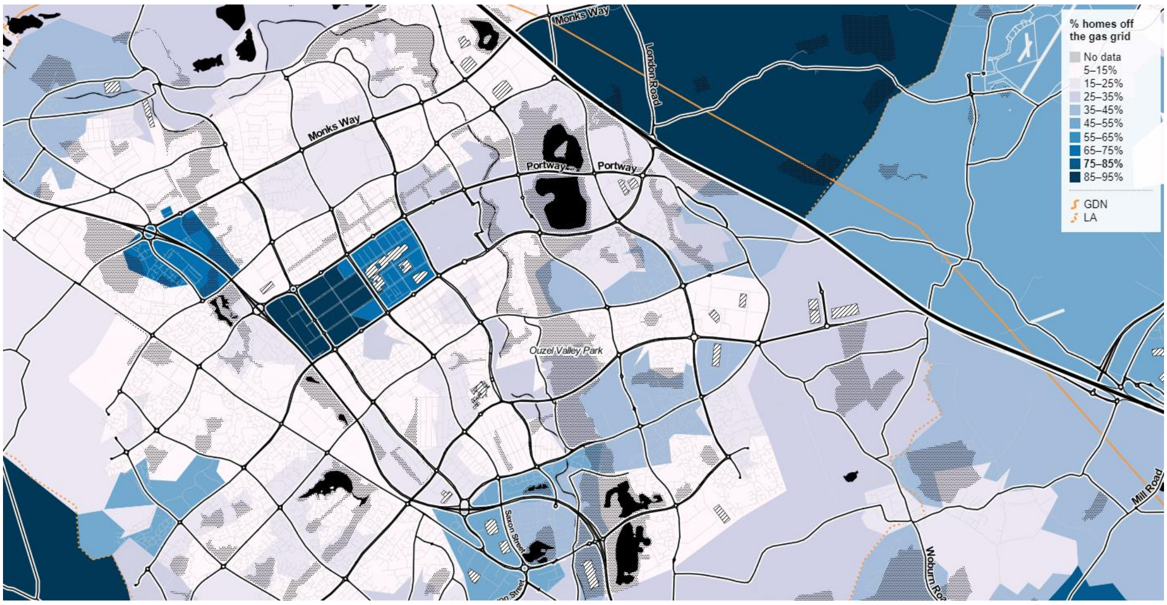


Figure 7: Map outlining residencies connected to the national gas network

Figure 7 is a selection of mapping from nongasmap.or.uk, itself based on government data detailing which residencies are connected to the national gas network. As may be observed, most residential properties across Milton Keynes appear to be served from the local gas distribution network. There are areas of note where gas appears to be less likely the heating energy used. The central area of Milton Keynes has a higher proportion of homes served by other systems. This is likely to include the existing ThamesWey District heating system, but electrical systems are also reported as widely deployed. The overarching residential type in this area is also reported as 'flat or apartment', which as an archetype is more likely to be electrically heated.

Electricity

Western Power Distribution is the District Network Operator (DNO) for Milton Keynes. They provide publicly available information on electrical supply via their mapping platform. This includes details of existing and available capacity for the local area.

From this information it appears there are three bulk electrical supplies to Milton Keynes at 33kV, likely supplied from the 132 kV substation at Bradwell Abbey, which also contains one of the 33kV substations.

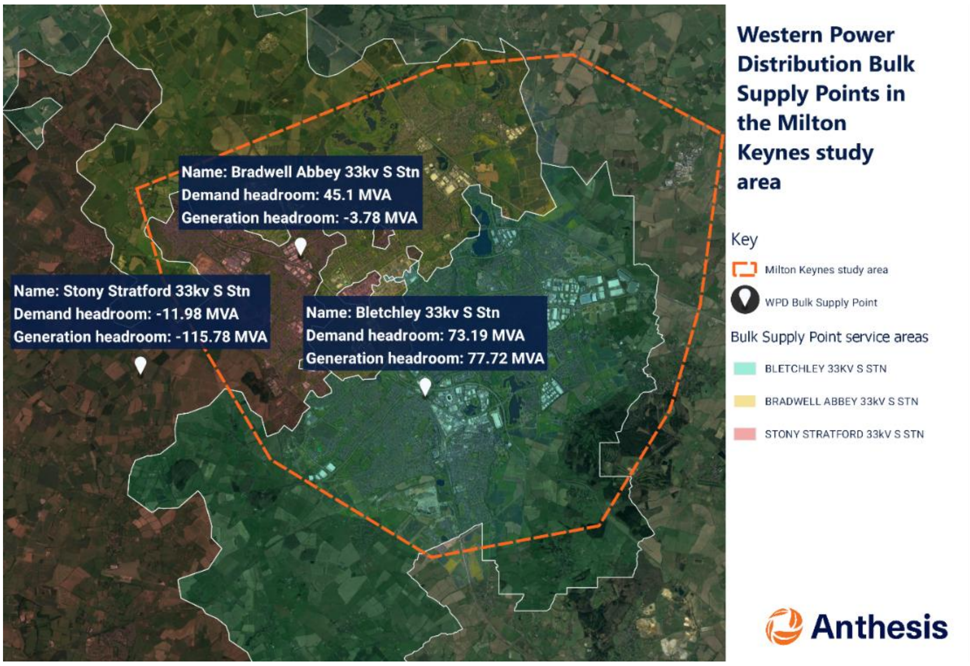


Figure 8: Map outlining the bulk electrical supplies to Milton Keynes

The Stony Stratford substation, which appears to supply parts of Milton Keynes centre is likely under substantive constraint. Peak electrical demand is currently reported as 11.98 MVA above the substation capacity. Although for short periods of time this may not be problematic for the DNO it means there is likely no spare demand for future electrical expansion with the existing equipment. This substation also appears constrained on the generation side (i.e., the allowance of connection of renewables) with negative headroom of 115.78MVA. This will likely prevent the further roll out of renewable electricity generation plant with the existing distribution equipment.

The Bradwell Abbey substation does appear to have some spare demand capacity of circa 45 MVA. Existing demand is 71.9 MVA out of a total of 117 MVA, leaving some headroom for expansion. However, this substation also appears constrained on the upstream (renewable generation) reverse power headroom. This is also now a negative number (-3.78 MVA) and is again likely to prevent the further roll out of renewable electricals with the existing equipment.

The Bletchley 33kV substation is stated as having both supply headroom and reverse power headroom. This is a 200 MVA substation with a current peak demand of 127.81 MVA, leaving 73.19 MVA remaining. There is also reported reverse power headroom of 77.72 MVA, which would allow for expansion of renewables to this location. Initially this appears a reasonable position, however as stated from the earlier Milton Keynes East Expansion stakeholder engagement, 27.46 MVA of supply has been reserved by the developer. This is not reported on the mapping tool, however assuming this does not form part of the current peak demand this reduces available supply for Milton Keynes from this location to 45.73MVA.

Considering the apparent electrical demand constraints, as well as potential generation constraints for existing equipment, it is strongly recommended the local authority engage with Western Power Distribution to understand the proposed scope of any future upgrade works, and the likely implications to local electrical infrastructure considering a widespread roll out of heat pumps, electric vehicle charging and renewable electrical generation across the city to address local and national policy objectives. A district heating solution would reduce the strain on the electrical network in comparison to individual systems.

Indicative Routing

Following the above energy masterplanning exercise, an indicative route was drawn between the areas of interest. Estimations on heat supply (Table 3) and demand (Table 4) were calculated for each of the areas described, as well as including some additional demand either along the network routing, or close to the areas of heat supply, shown in Figure 9.

Load/Load Area	Estimated Thermal Supply Potential (GWh)	Source data
Waste Heat Recovery Park	79	Estimated from heat availability assessment
ThamesWey	127	Provided by ThamesWey
Wastewater Treatment Works	79	Estimated from heat availability assessment
Total	285	

Table 3: Heat Supply Estimations

Table 4: Heat Demand Estimations

Load/Load Area	**Estimated Thermal Load (GWh)**	**Source data**
Milton Keynes Central - Gas	17.8	Metered, domestic and non-domestic MSOA, LSOA
Milton Keynes Central - Elec	0.9	Metered, domestic LSOA
University Hospital	17.6	Metered, Hospital report
Open University	12.9	Metered, University billing
Milton Keynes Extension	22.4	Estimated, developer SAP calculations
Tickford Fields	6.4	Estimated, extrapolated from MKE
Wolverton Demand Area	6.2	Estimated, CIBSE benchmark consumption data for each building
Portway Demand Area	2	Estimated, CIBSE benchmark consumption data for each building
Fox Milne Industrial area (adjacent to WWTW)	3.4	Estimated, CIBSE benchmark consumption data for each building
Demand within 20m of route	4.2	Estimated, CIBSE benchmark consumption data for each building
Total	94	

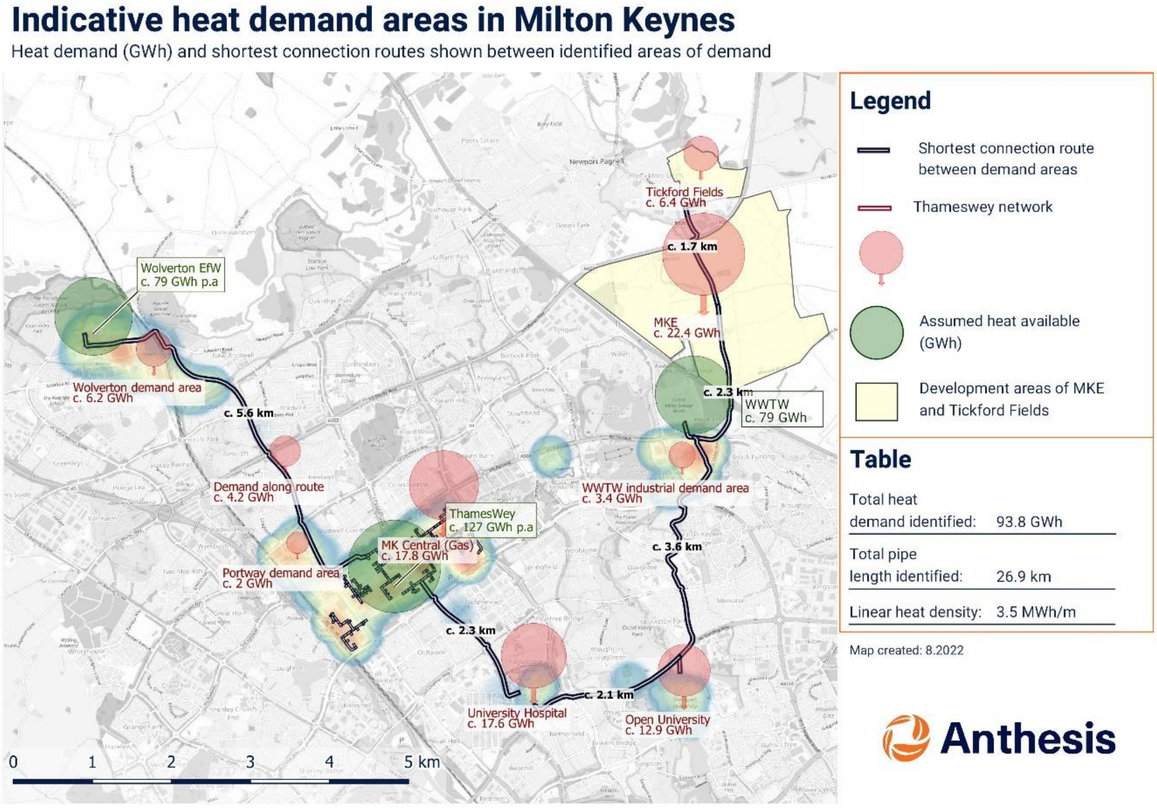


Figure 9: Indicative heat demand areas in Milton Keynes

Of the three potential heat supplies, the Waste Heat Recovery Park is considered to have the highest potential to offer a balance between low-carbon and low-cost heat supply. Of the heat demand areas, Central Milton Keynes was considered to be of the highest heat density.

Therefore, to test the initial viability of a city-wide heat network within Milton Keynes, it was decided that a detailed feasibility study should be carried out for the potential of supplying heat to Central Milton Keynes from the Waste Heat Recovery Park in Wolverton, potentially extending to the University Hospital if there is heat available for this connection.

Work package 2 – Milton Keynes District Heat Network

Anthesis have been commissioned to carry out a detailed feasibility study of the potential heat network supplied by the Waste Heat Recovery Park in Wolverton, delivering heat to Central Milton Keynes (via the existing ThamesWey network) and the University Hospital.

This study has been approached with the perspective of testing the scheme's viability against the business-as-usual (BAU) counterfactual options for delivering low-carbon heat within the city. To make all the scenarios tested truly comparable to each other, certain assumptions have been made and particular approaches taken, which are fully explained further in the report. The work assesses the economic viability at a system level, allowing comparison between scenarios, but does not necessarily reflect the commercial reality of attempting to secure the projected revenues based on a counterfactual argument.

This report will outline the preferred scenario which makes the most technical and economic sense for the city of Milton Keynes. The comparison within this study is for a limited set of buildings, but the outcomes can be extrapolated for the wider context of decarbonising heat across the city.

Stakeholder Engagement

To improve the accuracy of the techno-economic modelling, further stakeholder engagement was carried out with all parties involved in the proposed scheme to gather more detailed information.

Waste Heat Recovery Park

In the previous study, several assumptions were made to estimate the quantity of heat available from the steam turbine, resulting in an estimation of 10-15MW capacity of heat supply, totalling 79GWh across the year.

During this study, Amey were approached to help determine the possible heat extraction from the steam turbine, availability of heat, and capital costs related to modification of plant for heat extraction. An industry standard commercial arrangement is that the heat purchase price is linked to the lost revenue from electricity grid export, as useful heat is transferred from the steam turbine recirculation process and into useful heat for the district heating network. This links purchased heat price to the operation of the EfW plant and provides a stable and equivalent income stream that is led by the operation of the plant. This provides an attractive commercial arrangement for the heat provider.

Amey confirmed that the steam turbine had originally been built with a grid valve for controlled heat extraction. Due to the current operating strategy, the steam turbine was modified to remove this. Without controlled extraction it is very difficult to extract a useful amount of heat. Firstly, the maximum heat offtake is significantly limited, in this case to 1.7MW (with a Z-factor of 7.1), far below the originally assumed heat capacity. Secondly, if steam mass flow rate drops below a certain threshold (63%), then heat can no longer be extracted (shown in Table 5 below).

Condition	Elec output (MW)	Heat Output (MW)
100% rated operation with no bleed flow	7.208	0
100% rated operation with bleed flow	6.967	1.708
63% rated operation with bleed flow	4.54104	0

Table 5: Electrical and Heat Outputs for varying conditions

Monthly generation data was provided by Amey for the performance of the steam turbine (Table 6 below), as well as a view of the half hourly data across this period (Figure 10).

	Electricity Generation (MWh/Day)	Average Electrical Capacity (MW)	Average Rated Operation
Apr-21	122	5.1	71%
May-21	50.7	2.1	29%
Jun-21	22.77	0.9	13%
Jul-21	21.65	0.9	13%
Aug-21	70.16	2.9	41%
Sep-21	69.47	2.9	40%
Oct-21	85.52	3.6	49%
Nov-21	86.7	3.6	50%
Dec-21	108.35	4.5	63%
Jan-22	59.61	2.5	34%
Feb-22	50.89	2.1	29%
Mar-22	132.13	5.5	76%

Table 6: Steam Turbine Performance

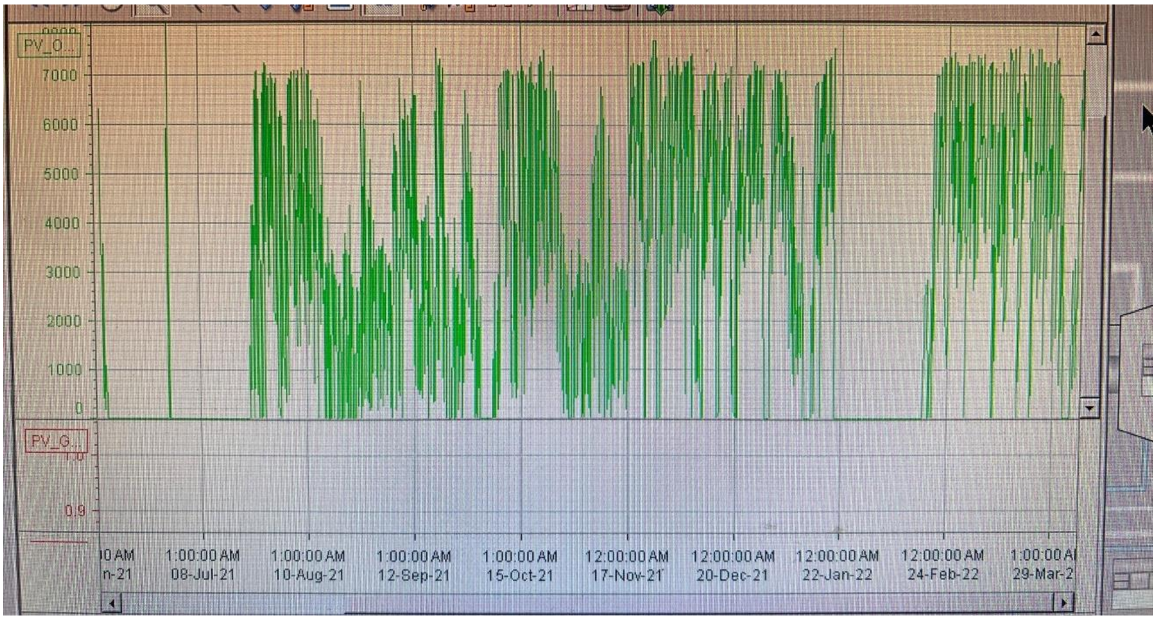


Figure 10: Half Hourly Data from April-21 to March-22

Variations in waste incineration (either volume or composition) can result in reduced heat output, which then reduces the steam flow rate entering the steam turbine, reducing the overall availability of plant. Based on the monthly data provided, it was observed that the Waste Heat Recovery Park had undergone operational issues resulting in low availability. Under uncontrolled extraction, very limited heat extraction would be able to occur (as shown in Figure 11).

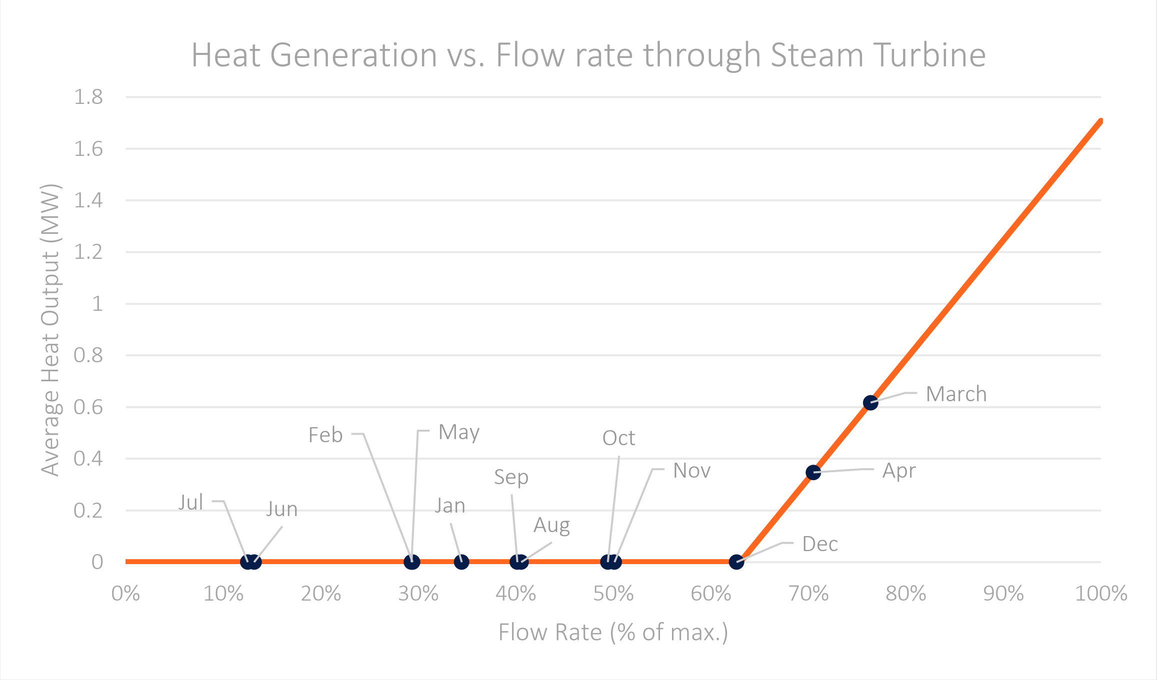


Figure 11: Heat Generation vs Flow Rate though Steam Turbine – Uncontrolled Extraction

Through discussions with Amey, it was determined that the operational issues have now been resolved and that heat availability had been restored to approximately 90%, through a continuous steam flow rate of approximately 100% but accounting for two two-week maintenance periods through the year. This would result in a maximum heat generation of 13.4GWh/annum. Based on this information, the network length feasibility exercise was carried out using the same method as in the previous study, to determine the extent of network that could be built and expect a 10% IRR under uncontrolled extraction with a 1.7MW peak heat capacity.

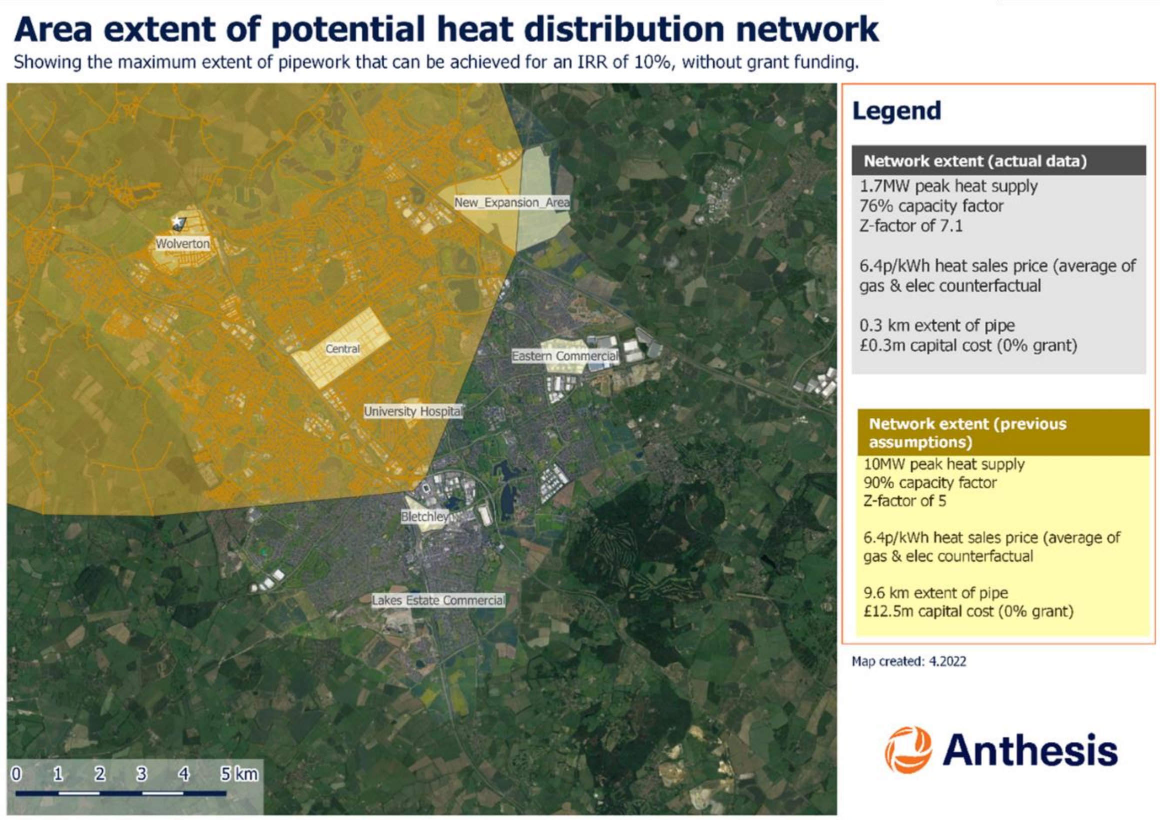


Figure 12: Area extent of potential heat distribution network

When there is less available heat supply, the potential for revenue from heat sales reduces, resulting in a smaller extent of pipework that can be installed for a 10% IRR. As shown above in Figure 12, the distance of the network was severely reduced under the reduced heat output, from a 9.6km extent of pipework (shown in yellow), to 0.3km extent of pipework (shown in grey).

Therefore, it was concluded that controlled heat extraction, via the installation of a grid valve to increase the potential heat supply, would be required if the Waste Heat Recovery Park were to be considered as a heat source.

Amey provided updated details on the heat extraction capacity of the steam turbine with a grid valve installed, shown in Table 7 below. This was indicated as the maximum heat extraction that could occur whilst allowing enough electricity generation to meet other commercial arrangements. The full performance curve of the turbine and operating conditions for heat extraction can be found in Appendix A.

Condition	Elec output (MW)	Heat Output (MW)
100% rated operation with no bleed flow	7.208	0
100% rated operation with bleed flow via controlled extraction	3.495	23.8
50% rated operation with bleed flow via controlled extraction	1.515	10.71

Table 7: Heat Extraction involving a grid valve

As the turbine was originally designed with the grid valve, this makes it much easier to re-install, reducing capital costs of modifying the steam turbine. Amey provided a schematic of the proposed configuration of plant for connection to a heat network, shown in Appendix A. Once installed, although Z-factor is slightly reduced from 7.1 to 6.4, a much higher capacity of heat can be extracted, calculated as 23.8MW. Furthermore, there is no longer a mass flow rate threshold for heat extraction, allowing heat extraction during all available periods. A controlled extraction operation allows the heat extraction to vary with heat demand, allowing Amey to increase electricity production in periods of lower heat demand, maximising the economics of the scheme.

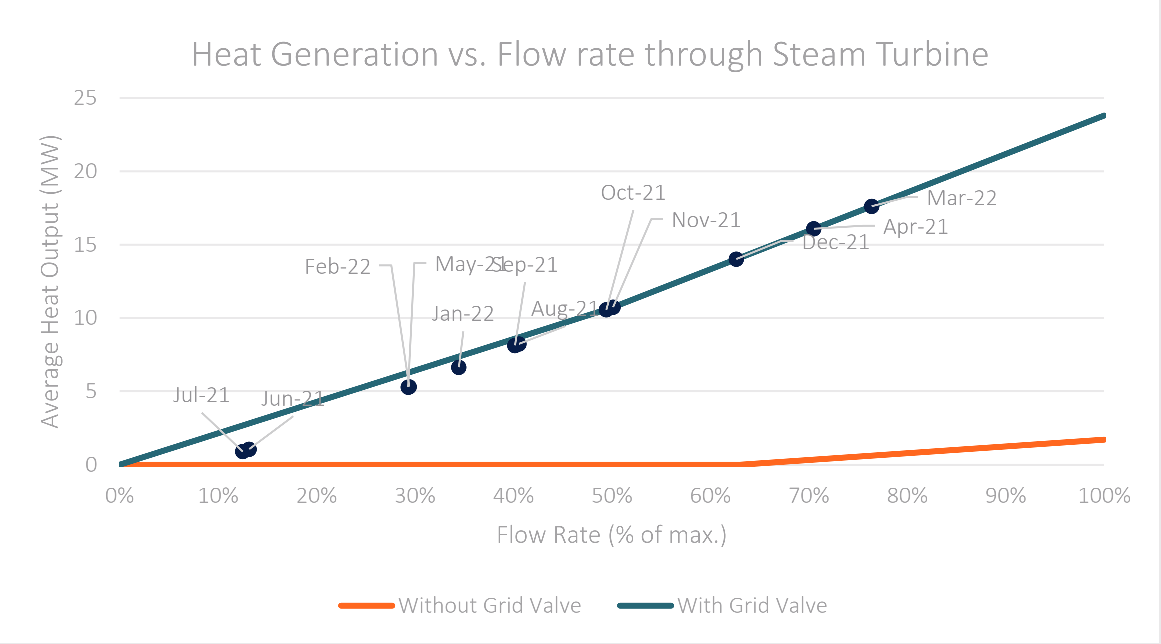


Figure 13: Heat Generation vs Flow Rate through Steam Turbine - Controlled Extraction

The updated heat supply data of controlled extraction indicates a significantly improved performance on uncontrolled extraction (Figure 13) and the initial estimate of 10-15MW from the previous study. This result supports the decision to use the Waste Heat Recovery Park as the preferred heat supply source.

The modelling assumptions listed in Table 8 below were agreed to be reasonable with the plant operator, Amey.

Item	Assumption
Maximum heat extraction at 100% flow rate	23.8 MW
Electricity generation at above condition	3.495MW
Typical steam flow rate	Modelled at 100% continuous flow
Availability	Approx. 90%, accounting for 2No. Two-week maintenance periods at the end of March and end of September
Extraction flow rate	Can vary to match heat demand
Z-factor	6.4

Table 8: Modelling Assumptions

ThamesWey

Engagement with ThamesWey was continued throughout the study and they provided significantly more data than was available in the previous study. This included half hourly generation data for their plant items, and summaries of the energy sales to each customer for existing connections.

ThamesWey have identified potential connections to their scheme through expansion of their existing network. Details on the future connections were provided. However, the majority are new-build properties. Therefore, there is no existing data on their demands and assumptions had to be made for their predicted heat demand, which are listed in Table 9 and Table 10 below. Due to a lack of verifiable completion dates, a conservative estimate was taken that all additional residential and commercial loads would connect in 2030.

Item	Value	Unit
Proposed number of flats	2882	
Annual Heat Load per flat	4	MWh
Additional Residential Demand	11,528	MWh
Assumed Space Heating Demand	50%	
Assumed Hot Water Demand	50%	

Balancing temperature	15.5	°C
Restricted space heating demand	June - September	

Table 9: First set of assumptions for heat demand predictions

Item	Value	Unit
Proposed Peak Load of Connections	6.19	MW
Demand per unit peak load for similar existing buildings on ThamesWey network	3271	MWh/MW
Additional Commercial Demand	20,247	MWh
Assumed Space Heating Demand	76%	
Assumed Hot Water Demand	24%	
Balancing temperature	15.5	°C
Restricted space heating demand	June - September	

Table 10: Second set of assumptions for heat demand predictions

In particular, there was a lack of data around the additional commercial properties. Therefore, multiple approaches were taken to estimate demand. Firstly, floor area was calculated from estimations of footprint and number of floors. It should be noted that exact floor areas of the buildings were not available, so it likely that the actual floor areas will differ from those calculated in this study. Benchmark energy consumption intensity values were applied to the floor areas, resulting in annual demand of 27-29GWh/annum (depending on the benchmark used). The second approach used the estimated peak load for the additional connections, which was provided by ThamesWey. Annual consumption was calculated by extrapolating the demand to peak load ratio (MWh/MW) of existing buildings on the network of a similar archetype (offices). Both approaches were approved by ThamesWey, but as the second method yielded a lower annual consumption, this result was used as it was considered a more conservative approach.

Demand profiles for ThamesWey's existing connections' space heating (SH) and domestic hot water (DHW) were built by using the normalised generation profile from half-hourly data provided, and this profile was applied to the annual demands for each load. For future additional connections, SH profiles were calculated based on external temperatures. DHW profiles were calculated on benchmark consumption profiles for the building archetypes.

This resulted in an overall demand profile shown in Figure 14 below. A summary of calculated annual demands is shown in Table 11.

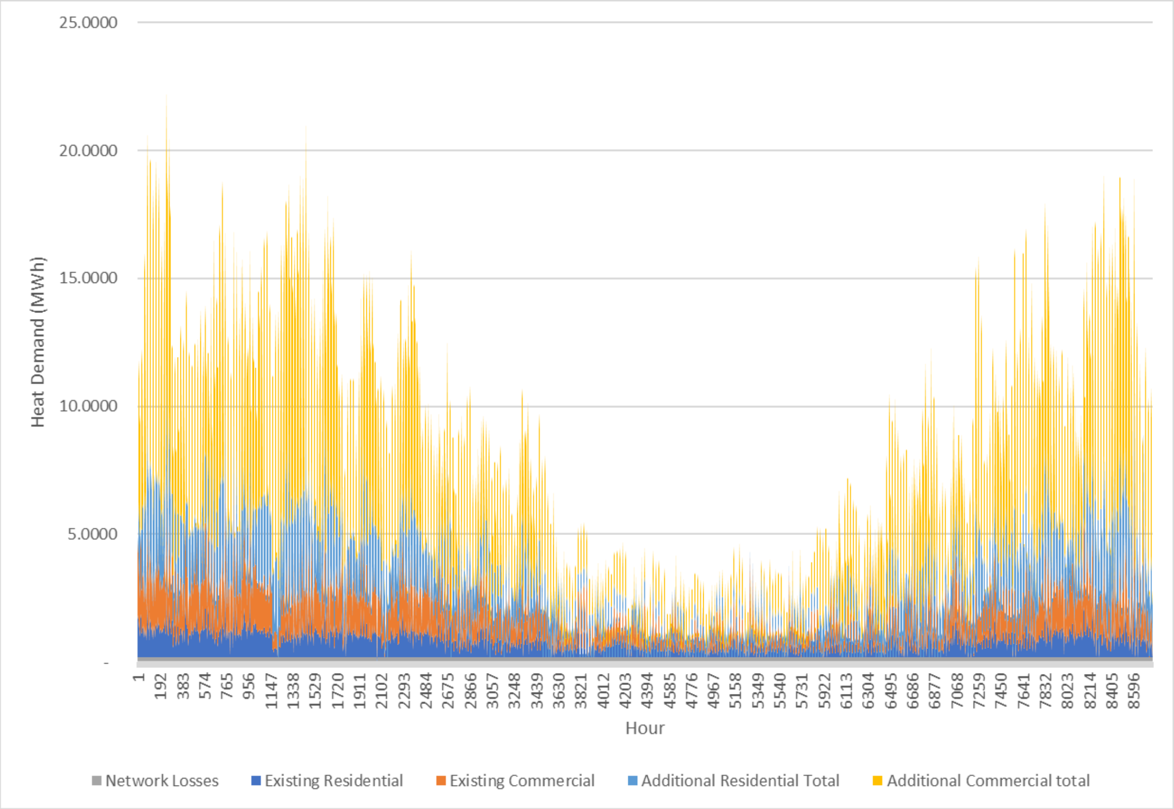


Figure 14: Overall Estimated Demand Profile

Demands	Heat On Phase	Heat Demand (MWh/annum)	Estimated Peak Demand (MW)
ThamesWey Residential Current	Initial	3,696	3.12
ThamesWey Commercial Current	Initial	12,005	5.45
Additional Residential (Estimated)	Full build-out (2030)	11,528	4.64
Additional Commercial (Estimated)	Full build-out (2030)	20,247	6.19

Table 11: Summary of Calculated Annual Demands

University Hospital

The university hospital provided annual energy consumption data during engagement for the previous study, along with confirming their intent to reduce current energy consumption through energy conservation measures and decarbonise their heat supply through air-source heat pumps.

Discussions with the hospital were continued throughout this study. They filled out a statement of intent to connect to the network, which helps to build the certainty of the connection. Unfortunately, no granular data could be obtained for their energy consumption to influence the demand profile. Therefore, assumptions had to be made to generate a proxy demand profile, which are listed in Table 12 below.

Assumption	Value	Unit
Balancing temperature	17	°C
Proportion of heat dependent on temperature	70%	%
Restricted space heating demand	June - September	

Table 12: Assumptions for a proxy demand profile

The hospital did provide the anticipated reduction in energy consumption, calculated during the first stage of their retrofits, this yielded an energy reduction of 39.95%, which the hospital informed was representative of the remaining retrofit measures to be carried out and could be extrapolated across all heat demand. There are also plans for additional buildings to be built on the site, the estimated operational energy consumption of these buildings was provided. As a conservative estimate, the reduced heat demand was modelled as the hospital's load throughout the 40-year analysis. The summary of heat demand is in Table 13 below. The heat demand profile is shown in Figure 15.

Demand	Value	Unit
Current Heat Demand	14,981,191	kWh
Retrofit Savings	39.95%	
Post-Retrofit Heat Demand	8,995,897	kWh
Additional Building Consumption	1,553,295	kWh
Predicted Heat Demand	10,549,192	kWh
Predicted Network Losses	527,460	kWh
Predicted Total Heat Consumption	11,076,652	kWh

Table 13: Heat Demand Summary

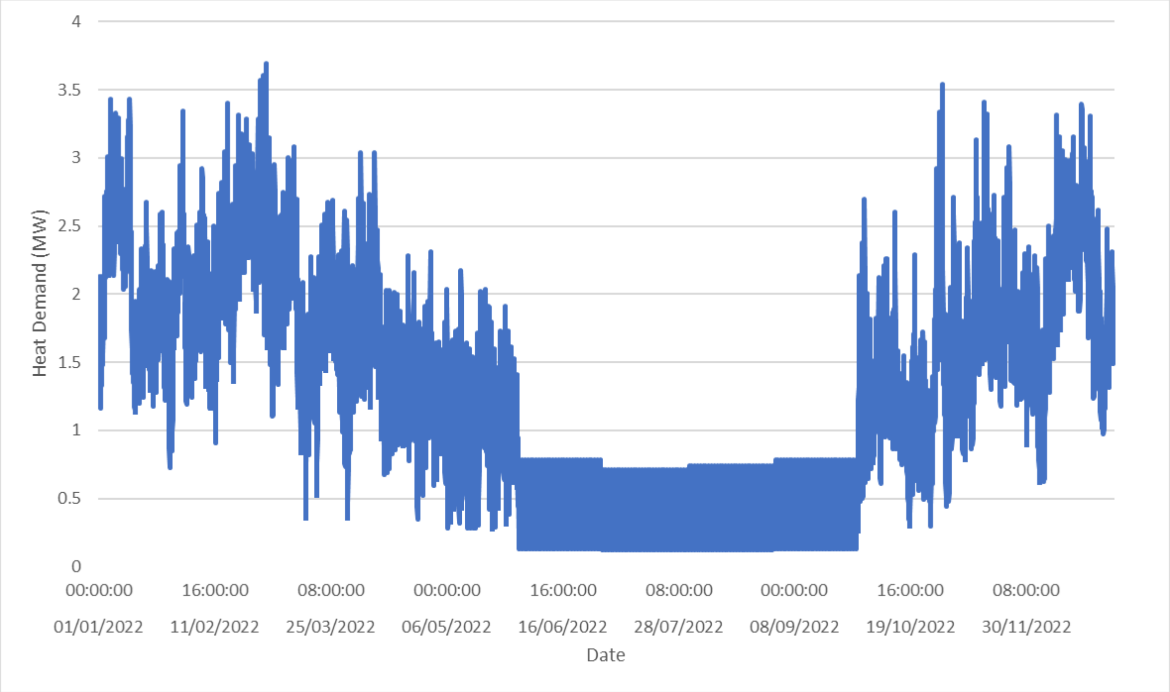


Figure 15: University Hospital estimated demand profile

Heat Demand Summary

Each scenario was modelled with the same heat loads, defined through the stakeholder engagement exercise detailed above. Other heat demands were considered within Wolverton and on route, but the buildings in these areas were either of archetypes not preferable for heat network connections or had heat demands deemed insignificant compared to those identified in Central Milton Keynes or the University Hospital. Thus, buildings on route and in Wolverton were not deemed pivotal to the viability of a heat network in the city but should be considered within future work, if a heat network solution is deemed viable, to strengthen the business case. Other heat demands have been mapped in context to the proposed heat network routing in Appendix B, including several new development areas, however they are considered a significant distance from the proposed heat network routing. The summary of modelled heat demands is detailed in Table 14 below.

Table 14: Heat Demand Phasing, values given in MWh

Phase	Initial	Full-build out (2030)
ThamesWey Residential Current	3,696	3,696
ThamesWey Commercial Current	12,005	12,005
Hospital Estimated	10,549	10,549
Additional Residential	0	11,528
Additional Commercial	0	20,247
Total	26,250	58,025

Counterfactual Scenarios

Counterfactual A

Stakeholder engagement played a key role in the development of the counterfactual scenarios. Discussions were held with ThamesWey and the University Hospital to understand their current operations and how they anticipate this to change over time. A plant summary of Counterfactual A is shown in Table 15, with further detail provided below.

Table 15: Plant Summary of Counterfactual A

Phase	ThamesWey Residential Current	ThamesWey Commercial Current	Hospital Estimated	Additional Residential	Additional Commercial
Initial	Existing Network	Existing Network	Existing Network	Heat on date 2030	Heat on date 2030
Full-build out	ASHP-led Network	ASHP-led Network	ASHP-led Network	Building ASHP	Building ASHP

ThamesWey's current heat network is CHP-led, with gas boilers providing backup and peaking load (detailed in Table 16 below). This operation was modelled for ThamesWey's existing residential and commercial loads until 2030. As part of ThamesWey's commitment to decarbonise they are planning to transition to an air-source heat pump lead network from 2030 onwards to ensure they are delivering low-carbon heat, so this was the operation strategy modelled.

Connection	Phase	Unit Type	Quantity	Specification
ThamesWey Current Connections	Initial	CHP	2	3.4MWth, 3.2MWe
ThamesWey Current Connections	Initial	Boiler	1	10MWth
ThamesWey Current Connections	Initial	Thermal Store	1	480m3
ThamesWey Current Connections	Full build-out (2030)	ASHP	2	2.18MWth heat pump
ThamesWey Current Connections	Full build-out (2030)	Boiler	1	10MWth
ThamesWey Current Connections	Full build-out (2030)	Thermal Store	1	480m3

Table 16: Summary of ThamesWey's current heat network

The additional residential and commercial buildings are located within central Milton Keynes. Planning conditions set out by the council requires them to connect to the existing ThamesWey network, unless they can demonstrate they can deliver a low-carbon heating solution more cost effectively. Therefore, the likely counterfactual system for these developments are air-source heat pumps, as agreed by the council (detailed in Table 17).

Connection	Phase	Unit Type	Quantity	Specification
Additional Residential	Full build-out (2030)	ASHP	36	0.2MW Mitsubishi heat pump (4 per residential block)
Additional Residential	Full build-out (2030)	Thermal Store	9	50m3 of thermal storage per residential block
Additional Commercial	Full build-out (2030)	ASHP	8	1MW Mitsubishi heat pump (2 per commercial building)
Additional Commercial	Full build-out (2030)	Thermal Store	4	50m3 of thermal storage per residential block

Table 17: Counterfactual System Summary

The University Hospital current operates with a CHP and gas boiler led system (detailed in Table 18). Its existing plant is coming to the end of its economic life and requires replacing in the near future. Thus, the hospital is considering transitioning to a low-carbon heat solution to align with the NHS Net Zero target of 2045. This is likely going to be an air-source heat pump led solution, which has been agreed to be modelled as coming online in 2030.

Connection	Phase	Unit Type	Quantity	Specification
Hospital	Initial	CHP	1	0.52MWth, 0.34MWe
Hospital	Initial	Boiler	1	7.5MWth
Hospital	Initial	Thermal Store	1	100m3

Hospital	Full build-out (2030)	ASHP	3	2.18MWth heat pump
Hospital	Full build-out (2030)	Thermal Store	1	100m3

Table 18: Summary of the University Hospital's current system

Counterfactual B

ThamesWey highlighted that some developers of residential blocks have been allowed to install direct electric (1:1 power to heat ratio) heating systems. Allowing this type of heating system will likely lead to much higher tenant bills and increases risk to tenants with rising fuel prices, as the efficiency of this type of system cannot compete with the COP effect of a heat pump (1:3 power to heat ratio). Furthermore, this would significantly increase the load on the electrical infrastructure of the area, which is already under considerable strain. For these given reasons, a second counterfactual has been modelled with the additional residential load being served by direct electric heating systems to demonstrate the impact this will have compared to other scenarios. All other commercial heat loads were modelled under the same conditions as Counterfactual A, as shown in Table 19. Further design assumptions are provided in Table 20.

Table 19: Plant Summary of Counterfactual B

Phase	ThamesWey Residential Current	ThamesWey Commercial Current	Hospital Estimated	Additional Residential	Additional Commercial
Initial	Existing Network	Existing Network	Existing Network	Heat on date 2030	Heat on date 2030
Full-build out	ASHP-led Network	ASHP-led Network	ASHP-led Network	Direct Electric Heating	Building ASHP

Connection	Phase	Unit Type	Quantity	Specification
Additional Residential	Full build-out (2030)	Direct Electric Heater	14,410	Direct electric radiators (5 per flat)
Additional Residential	Full build-out (2030)	Thermal Store	2882	200L Storage Cylinder

Table 20: Summary of Counterfactual B, incorporating direct electric heating systems

Heat Network Scenarios

Two heat network scenarios have been modelled. Both utilise the Waste Heat Recovery Park as the primary heat supply and a 10MW gas boiler at ThamesWey acting as a peaking and backup plant. There is an 8MW electrode boiler assumed at Wolverton to serve as backup plant during maintenance periods for the Waste Heat Recovery Park. This has been sized according to the likely electrical connection at the site to facilitate up to 8MW of electrical export. Operation of the electrode boiler and steam turbine have been modelled as mutually exclusive to avoid potential constraints on the electrical grid.

Heat would be provided to consumers within Central Milton Keynes through a sleeving arrangement with ThamesWey. Sleeving is the process whereby an energy supplier acts as an agent on behalf of the buyer to manage the offtake from a generator's asset, where the supplier charges an additional fee for this service. Within the context of this scheme, the operators of the proposed network would act as the generators, ThamesWey would be acting as the heat suppliers, distributing and selling this heat on to their existing and future customers (the buyers) through their own infrastructure.

The network is assumed to operate at 90°C with return temperatures of 65°C on the basis of a 60°C achieved return temperature at ThamesWey. This avoids the additional Health and safety considerations of higher temperature systems (i.e. Medium Temperature Hot Water (MTHW) operating above 100°C, which introduces additional risk with steam explosion on pipework and equipment. This would require appropriate design and management on an ongoing basis. This may be a feasible solution, but at this stage this risk has been designed out by this temperature selection. This does impact (increase) pipe sizing increasing capital cost and highlights the importance of minimising district heating return temperatures to improve efficiencies and economics. This is usually the ultimate responsibility of the connecting parties and terminal systems and is recommended to help improve the economics of any scheme taken forward. This is also now noted within building regulations which now set a low temperature for wet heating systems at below 55°C flow. This requirement is recommended to be respected in any new buildings connected to the proposed network where technically possible.

There may be some leeway to increase system flow temperatures to just below boiling (95°C) subject to safety valve selection for the new scheme to further increase temperature differential without operating above 100°C, however this has not been assumed at this stage to provide some design leeway at future stages.

Similarly direct hydraulic connection with existing ThamesWey pipework may be possible, eliminating a hydraulic break and assisting in reducing return temperatures, as well as mitigating risks of temperature drop at low loads and potentially reducing capital expenditure. Anthesis have not explicitly investigated the potential of this in particular the pressure ratings of existing equipment and pipework compared to the revised design requirements, however this is recommended at the next design stages to be investigated as a potential opportunity for the system installer and operator.

MTHW may offer capital cost savings if it were adopted as a distribution network design approach (increased temperature differential, smaller pipework), with the additional design risks managed accordingly, however it is recommended this is considered in more detail at later design studies, including the potential costs optimisation considering pipework operations across the pipework lifetime. The capital costs saving will be offset to some extent by higher pipework thermal losses driven by the higher temperatures., therefore the cost/benefits of this approach need consideration in the round. For clarity this aspect of design detail has not been considered at this stage.

The difference between the two modelled heat network scenarios is shown in Table 21.

Table 21: Plant Summary for S1 and S2

Scenario	Phase	ThamesWey Residential Current	ThamesWey Commercial Current	Hospital Estimated	Additional Residential	Additional Commercial
S1	Initial	Waste Heat-led Network	Waste Heat-led Network	Existing Network	Heat on date 2030	Heat on date 2030
S1	Full-build out	Waste Heat-led Network	Waste Heat-led Network	ASHP-led Network	Waste Heat-led Network	Waste Heat-led Network
S2	Initial	Waste Heat-led Network	Waste Heat-led Network	Waste Heat-led Network	Heat on date 2030	Heat on date 2030
S2	Full-build out	Waste Heat-led Network	Waste Heat-led Network	Waste Heat-led Network	Waste Heat-led Network	Waste Heat-led Network

Details of the network plant configuration can be found in Table 22 and below.

Supply	Phase	Unit Type	Quantity	Specification
Waste Heat Recovery Park	All	EfW	1	23.8MW Capacity
Waste Heat Recovery Park	All	Electrode Boiler	1	8MWe (backup only)
Waste Heat Recovery Park	All	Thermal Store	1	1000m3
ThamesWey	All	Boiler	1	10MWth
ThamesWey	All	Thermal Store		480m3

Table 22: Summary of the Network Plant Configuration

S1 – Waste Heat to MK Central Only

S1 is defined as a new heat network connecting the heat supplied by the Waste Heat Recovery Park to the existing ThamesWey network, delivering heat to the existing and additional connections. The University Hospital operates under the same conditions as the Counterfactual scenarios. The indicative network routing is shown in Figure 16.

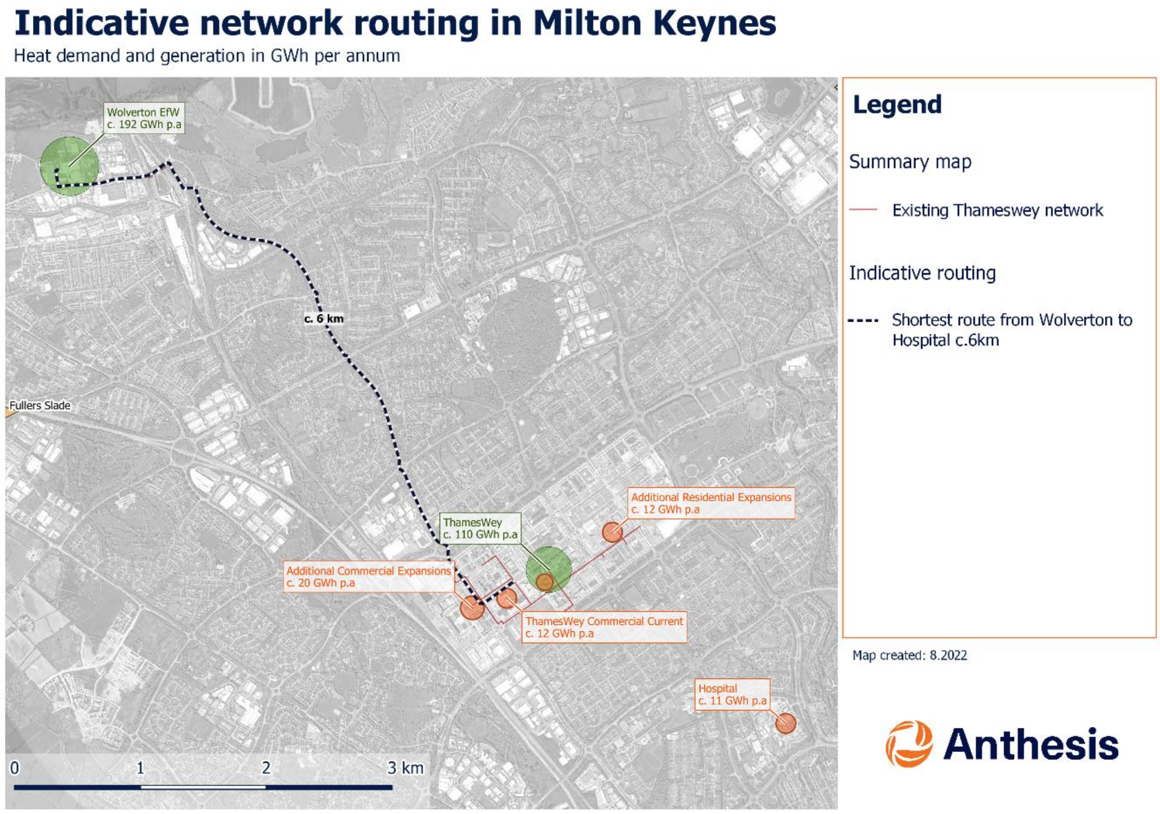


Figure 16: Indicative network routing in Milton Keynes (S1)

S2 – Waste Heat to MK Central + Hospital

S2 is defined as the new heat network connecting the heat supplied by the Waste Heat Recovery Park to the existing ThamesWey network as well as extending southward to supply heat to the University Hospital. This scenario has been modelled to investigate whether extending the network is a financially beneficial decision. The indicative network routing is shown in Figure 17.

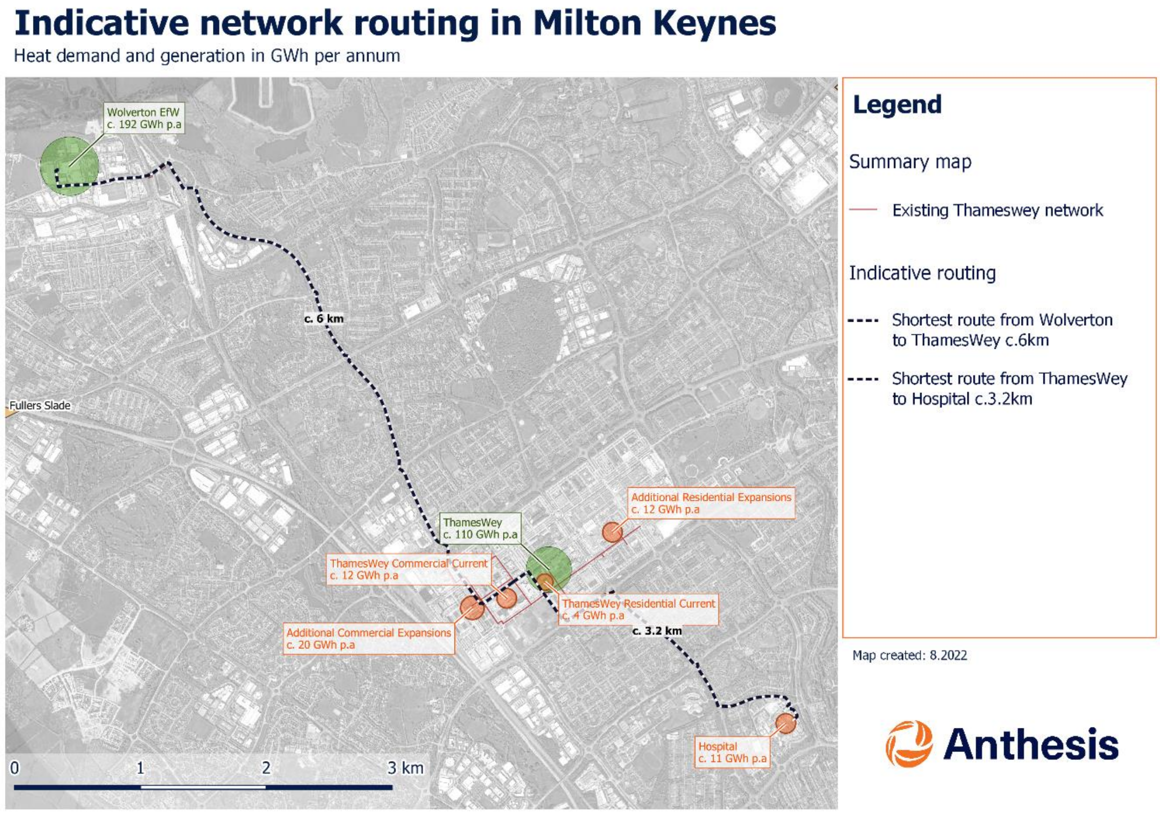


Figure 17: Indicative network routing in Milton Keynes (S2)

Linear Heat density

Linear heat density is an expression of the quantity of demand supplied by a network in a year divided by the network length. High demands on shorter networks result in higher linear heat density and are generally accepted as an indication as to whether a demand is suited to a district heating network. As below ground pipework is one of the more capital-intensive elements of network deployment, sufficient revenue (i.e., demand) needs to exist to support its deployment. Typically, District heating networks may be commercially viable with a linear heat density greater than 2 MWh/m/yr, with 4 MWh/m/yr preferable.

Linear heat densities for both heat network scenarios are presented in Table 23 below.

Scenario	Network Heat Demand (MWh/Annum)	Network Length (m)	Linear Heat Density (MWh/m/Annum)
S1	47,476	6,000	7.9
S2	58,025	9,176	6.3

Table 23: Summary of linear heat densities for both scenarios

As may be observed, the linear heat density in both scenarios is higher than the 2-4 MWh/m/yr benchmark for typical commercial viability. It should be noted that the extension to the hospital results in a reduction linear heat density from S1 to S2. However, this doesn't necessarily mean that the scenario with the lower value will perform worse financially. The linear heat density of both scenarios could possibly be increased by connecting to surrounding heat users, for example council owned properties within Central Milton Keynes.

Network Pipework

Routing & Connections

Network routing was optimised around reducing overall length of the network, whilst trying to maximise the proportion of "soft dig" to "hard dig", through visual inspection of the route on GIS, to reduce the CAPEX related to the installation of pipework. Example of "soft dig" opportunity within Milton Keynes is displayed in Figure 18 in the form of a pedestrian path surrounded by grassy terrain. It was assumed that approximately 80% of the network length could be considered "soft dig".

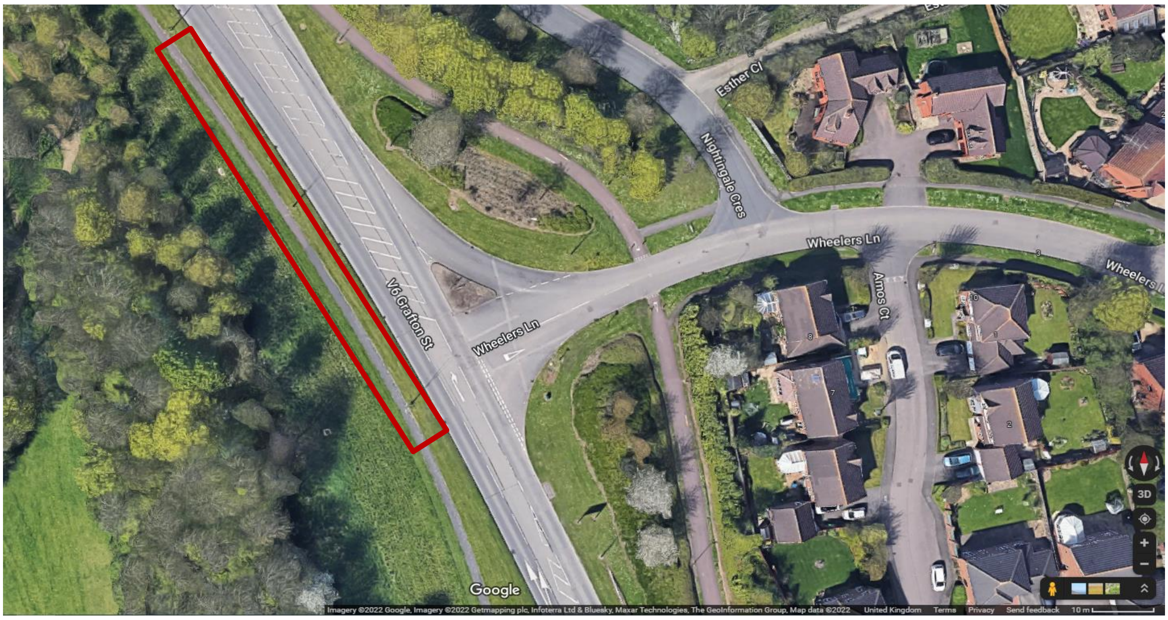


Figure 18: An example of a "soft dig" opportunity

The network pipework leaves the Waste Heat Recovery Park via the road closest to the steam turbine on-site. Some capital cost may be reduced by routing the initial length of pipework through the site before joining the road, but this should be investigated further in future work through discussions with Amey, the plant operator.

Between the Waste Heat Recovery Park and Central Milton Keynes, the network must cross two railway lines, as shown in Figure 19. Crossing this type of infrastructure often has a significant cost, thus an allowance of £1million has been allocated for this based on previous project experience. However, National Rail should be contacted to understand the potential costs for this particular location.

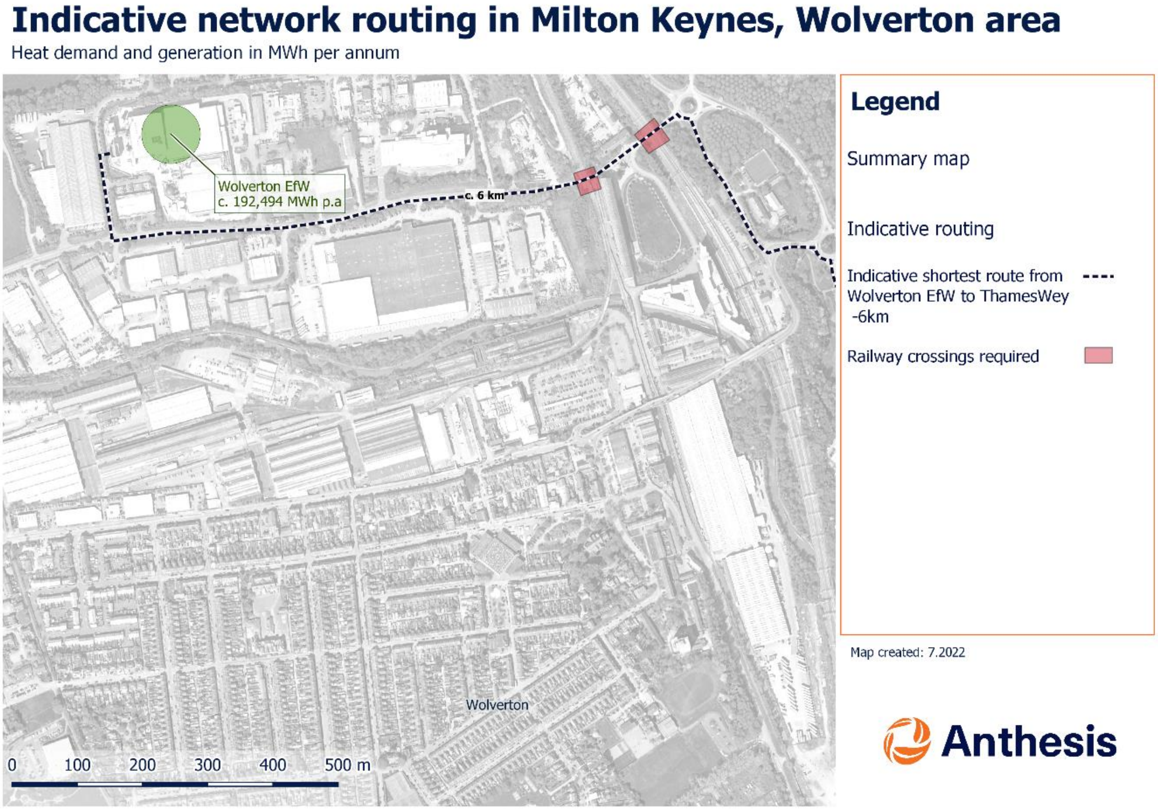


Figure 19: Indicative network routing in Milton Keynes, Wolverton area

Once the network reaches Central Milton Keynes, it will need to deliver heat to the ThamesWey network pipework. An indicative routing has been plotted that would allow for the existing or planned ThamesWey network to offtake heat at several different locations. If a heat network solution is progressed to further stages of development, ThamesWey should be engaged to discuss at which location they would need to offtake heat. Furthermore, capital costs of digging could be reduced if the proposed network and ThamesWey's planned network could be consolidated so that one set of pipework may be installed in the same sections of road where new ThamesWey demands are planned to be connected.

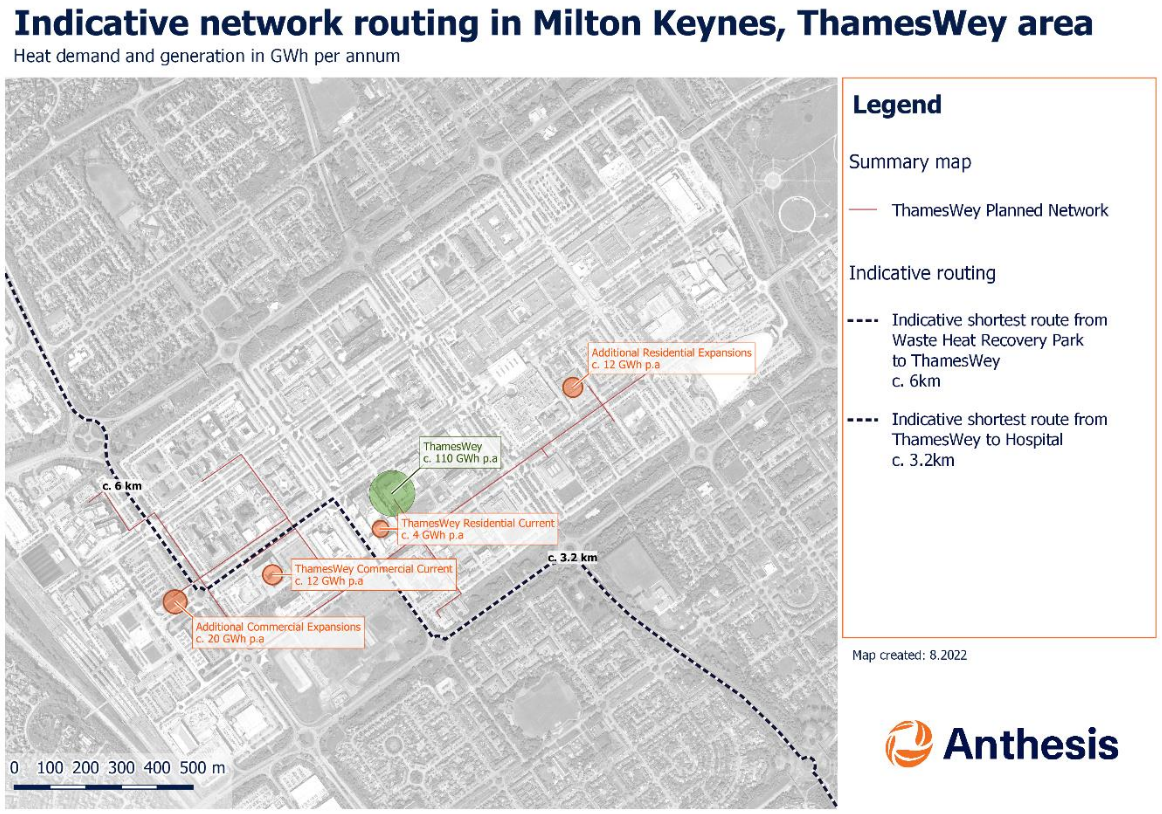


Figure 20: Indicative network routing in Milton Keynes, ThamesWey area

For S2, the network extends southward towards the University Hospital. It is understood that the hospital has an existing network connecting its buildings. If a heat network solution is progressed to further stages of development, they should be engaged to discuss the exact locations they would want to offtake heat. For the purposes of this study, the network routing connects to the existing two main energy centres for the site, utilising the “soft dig” opportunity to the north as the entrance to the site, as shown in Figure 21.

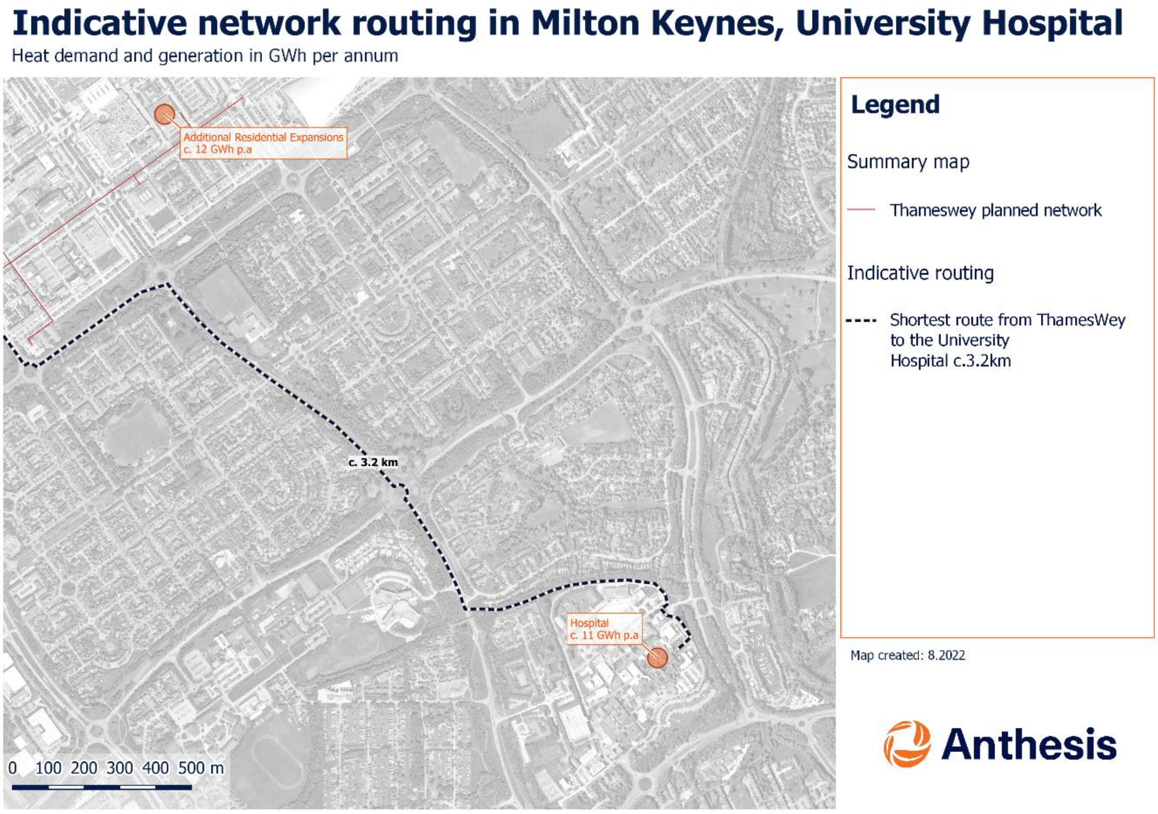


Figure 21: Indicative network routing in Milton Keynes, University Hospital area

Sizing

The proposed network will be carrying a large amount of heat, meaning it will require large diameter pipework, which has higher capital costs related to it. Due to the significant length of pipework for the proposed scheme, it is important to try and optimise the diameter of pipework to reduce associated costs. At the feasibility stage of design, CP1 guidance typical flow velocities are used for initial pipe sizing. Generally, reducing pipework diameter reduces overall costs, as shown in Figure 22, unless pipes are under-sized. During more detailed design, pipe sizes should be further optimised to ensure that under-sizing of pipes is not occurring, which can lead to increased costs.

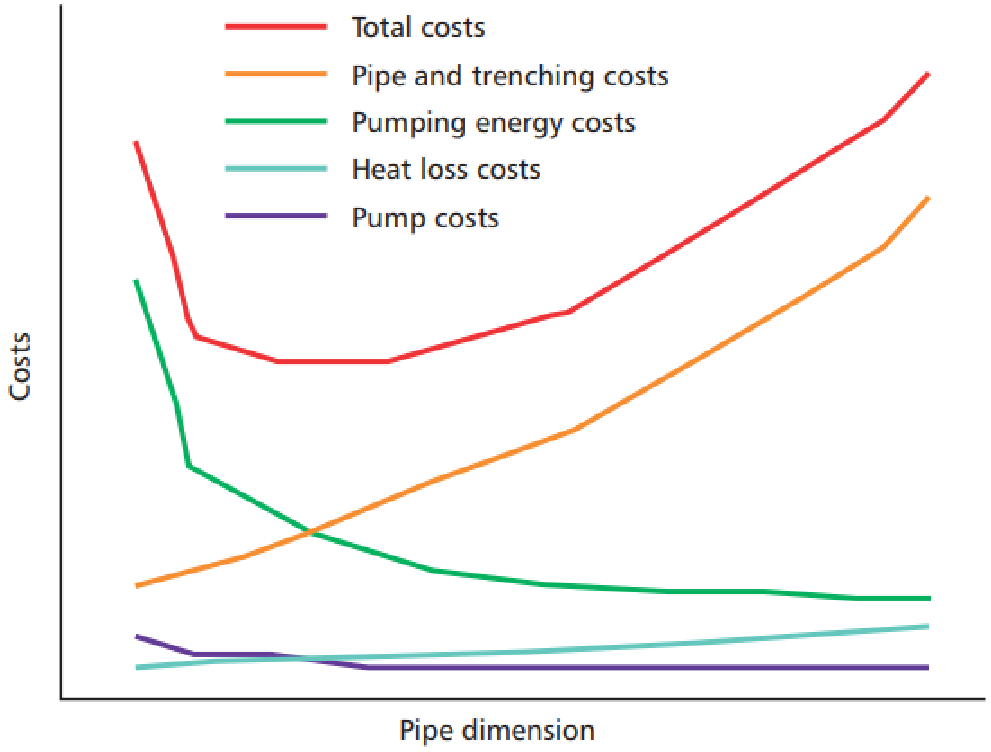


Figure 22: Typical optimisation of pipe sizes on lifecycle cost basis, source: CP1 (2020)

One approach to reducing the pipework diameter required is by maintaining a high temperature differential across the network. For modelling purposes, the flow/return temperatures have been assumed at 90/65°C, based on a 60°C return at ThamesWey. A 25°C temperature differential allows for a pipework diameter of 350mm, rather than 400mm required at a temperature differential of 20°C.

The return temperatures that are achievable in reality will depend upon the secondary network temperatures of the connected loads. Thus, if a heat network solution is progressed to further development, engagement should be carried out with heat customers to discuss current secondary network temperatures and whether they can be reduced. If there is no possibility of achieving a 65°C return temperature on the primary network, then increasing the flow temperature to 95°C could be considered to maintain a 25°C temperature differential. However, increasing flow temperatures above this will approach the boiling point of water, which will have associated health & safety risks that will require mitigation.

From assuming a flow/return of 90/65°C, the pipework sizes were calculated for each major section of the network, based on the maximum load it is required to deliver at velocity of 2.5m/s (the typical flow velocity stated in CP1). These conditions were input into LOGSTOR calculator to calculate the network losses and potential temperature drop that could be expected, assuming that series 2 insulation is used on an equal pair pipe configuration made of steel. These outputs are detailed in Table 24 below.

Section	Heat Load (MW)	Pipework Length (m)	Diameter (mm)	Network Losses (MWh/year)	Temperature drop at average annual load	Temperature drop at minimum annual load
Waste Heat Recovery Park to Central Milton Keynes	25.1	6,000	350	2,282	0.6	4.1
Central Milton Keynes to Hospital	12.8	3,177	250	1,068	1.3	3.7

Table 24: Summary of network losses and temperature drops for each section

It can be seen that network losses are low, at approximately 5% of annual heat demand, due to the use of moderate insulation and the fact that most of the pipework on this network is of a large diameter. Typically, a disproportionate amount of the network losses on a district heating system occurs in the smaller diameter pipework leading to heat customers. As the configuration of this network uses sleeving of the ThamesWey network to deliver heat to final consumers, a lower network loss is anticipated for the primary network. To keep network losses low, it is recommended that final insulation values are NOT to be limited to regulatory minimums (e.g., part L), but to the economic level of insulation (i.e., the most economic thickness given the lifetime cost of losses), which usually requires levels beyond these.

At average load, temperature drop across the network is relatively insignificant. However, at minimum load, the temperature drop across the network increases, resulting in almost an 8°C drop across the full length of the potential network. It is likely that minimum load will occur in the summer when demand is much lower, therefore a lower temperature differential is less significant. However, as large temperature drops are possible at low loads, this should continue to be considered in any further development of a heat network solution, and design intent amended to suit.

CAPEX Estimation

Capital costs have been estimated from a variety of sources, including SPONS 2022, Climate Change Committee reports, BEIS heat network research and equipment quotations. Cost have been inflated in line with ONS Construction Inflation Index.

A key difference between installing a direct electric system and an air-source heat pump system is the shell & core fit-out costs, which refer to the installation of the basic structure of the building, specifically the mechanical and electrical distribution systems in this case. These costs were included in the analysis to ensure that the wider context of how to decarbonise heat across the city of Milton Keynes was satisfied. To create consistency in the analysis, a baseline reference point is needed for a representative comparison of the costs of each scenario. Therefore, although a district heating operator is unlikely to incur shell & core costs, these costs were included across all scenarios for consistency purposes.

As some of the significant capital costs are not representative of the costs that a network operator will incur, it is likely that a network operator would incur lower CAPEX and REPEX costs than has been modelled within this study, thus shell & core costs were removed for the purposes of commercial modelling. Costs are summarised in Table 25 below and broken down into HNDU Defined Areas within Appendix C.

Scenario	Total Capital Cost	Capital Cost Apportioned to Shell & Core Costs
Counterfactual A	£59.0M	£31.2M
Counterfactual B	£54.3M	£29.0M
S1 - Waste Heat to Central MK only	£67.7M	£24.4M
S2 - Waste Heat to Central MK + Hospital	£62.8M	£24.4M

Table 25: Summary of Capital Expenditure

Both heat network scenarios have higher capital costs than the counterfactual scenarios due to the expense of the heat network pipework which accounts for between 30-45% of total costs. S1 has a higher capital cost than S2, despite a shorter network, due to the cost installing an ASHP solution instead at the hospital as a counterfactual. Counterfactual B has lower capital costs than Counterfactual A due to the lower cost related to installing direct electric systems in additional residential properties in comparison to ASHP systems. However, the direct electric systems will result in a significantly greater operational cost over their lifetime as they cannot compete with the coefficient of performance of the ASHP. Both scenarios are being modelled to see if the lower capital cost of Counterfactual B is worth the greater operational cost over its lifetime.

It should be noted that the heat network scenarios had a heat connection charge applied, at £450/kW capacity connected (excluding ThamesWey existing connections), which resulted in offsetting some of the capital costs in these scenarios.

OPEX estimation

OPEX was estimated in the following manner. For direct electric heating systems, £100/year/dwelling has been applied to allow for maintenance of pressurised DHW cylinders served from immersion heaters, equivalent to that available on the commercial market.

For communal and district heating systems the following operational costs were estimated from BEIS research and industry sources.

Charge	Rate
CHP Maintenance	£17.10/hr running time
Electrode Boiler Maintenance Fixed Rate	£8800/boiler pa
Electrode Boiler Maintenance Variable Rate	£4.04/hr running time
Heat Pump Maintenance	5% CAPEX pa
Boiler maintenance	£8000/boiler pa
Heat Network Maintenance costs	£0.67 /MWh
Heat Meter Maintenance costs	£3.8/MWh
HIU maintenance	£10.1/MWh
Staff Costs (metering, billing etc)	£19 MWh
Substation Maintenance cost	£5300/Substation

Table 26: Estimated OPEX for communal and district heating schemes

For commodity prices, stakeholders communicated that current fluctuations in market prices meant that any values they could provide were likely to be unrepresentative of future costs. Therefore, the most up to date BEIS consumer pricing was used, summarised in Table 27 below. The cost of heat from the Waste Heat Recovery Park is assumed to match the lost revenue from a reduction in exported electricity, calculated by dividing the grid export rate by the Z-factor of the steam turbine.

Tariff	Variable Charge (£/MWh)
Electricity Commodity Cost	180.6
Gas Commodity Cost	35.32
Gas CCL	1.68
Waste Heat Cost	9.9

Table 27: Summary of BEIS Consumer Pricing

Operational model results

The systems detailed in this report have had an operational model constructed in EnergyPRO and run for one standard year of operation for each phase identified.

Subsequently, a detailed FAST compliant operational Techno Economic Model has been developed for 40 years operation. This also accounts for a phased spending of capital and replacement costs to reflect likely cashflows for the deployment of real systems, in comparison to a single large capital payment on day 1.

EnergyPRO accounts for Hot water consumption on a diurnal consumption pattern (accounting for seasonal volume and temperature variations), with space heating dependant on ambient temperatures. Space heating was held off between May to September and CIBSE TRY weather data (2016) for Birmingham was utilised to profile consumption in the winter. Milton Keynes is between weather profile zones (London vs Birmingham). However, Birmingham was utilised to reflect a more conservative performance of heat pumps, as Birmingham has lower average temperatures and heat pumps perform worse under these conditions.

The private wire electricity sales tariff used in the modelling was defined by rates provided by ThamesWey. ThamesWey also provided heat sales prices for the residential and commercial connections. The values provided do not include standing charges as these were not provided by ThamesWey. This means it is likely that more revenue is achievable from the sale of heat to these customers. For the purposes of this study, values were fixed to the variable sales price of heat for all scenarios.

Currently, there is no heat sales to the additional residential, additional commercial, and hospital customers as they either aren’t yet built or produce their own heat, so a notional heat sales price related to the electricity commodity cost divided by 2.5 (typical COP of an individual ASHP) was established, as advised by the commercial consultant at Local Partnerships. This heat sales price was fixed for all scenarios.

By fixing the heat price the relative benefit of each alternative solution may be assessed against the counterfactual scenarios. I.e., If a further loss is made, that case is detrimental, if a further profit is made, that may be advantageous. The heat sales prices are summarised in Table 28 below.

The grid export rate is difficult to define owing to substantive current fluctuations in market prices. However, a typical trend of 35% of the current purchasing price was used to estimate a variable rate of £60/MWh, which was agreed as representative with Amey.

Tariff	Variable Charge (£/MWh)
Heat Variable Charge - ThamesWey Residential	27.25
Heat Variable Charge - ThamesWey Commercial	47.35
Heat Variable Charge - Additional Residential	68.88
Heat Variable Charge - Additional Commercial	68.88
Heat Variable Charge - Hospital	68.88

Private Wire Tariff	108.3
Grid Export Tariff	63.21

Table 28: Summary of Heat Sales Prices

A summary of the four scenarios modelled is detailed in Table 29 below, as previously defined within this report:

Table 29: Scenario summaries

Scenario	Summary
Counterfactual A	Additional residential and commercial customers to be served by air-source heat pumps. Existing networks at ThamesWey and the University Hospital to continue operating as usual until 2030, at which point switching to a heat pump solution.
Counterfactual B	Additional residential properties to be served by direct electric heating. All other loads to be served as described in Counterfactual A.
S1 – Waste Heat to MK Central Only	A heat network solution supplying heat from the Waste Heat Recovery Park to deliver heat to existing ThamesWey customers, as well as additional residential and commercial customers. The gas boiler at ThamesWey acts as peaking and backup plant for the network. There is an electrode boiler at the Waste Heat Recovery Park which acts as backup plant during maintenance periods. The hospital operates as defined in Counterfactual A.
S2 – Waste Heat to MK Central + Hospital –	Waste Heat to MK Central + Hospital – A heat network solution supplying heat from the Waste Heat Recovery Park to deliver heat to existing ThamesWey customers, as well as additional residential, commercial customers, and the hospital. The gas boiler at ThamesWey acts as peaking and backup plant for the network. There is an electrode boiler at the Waste Heat Recovery Park which acts as backup plant during maintenance

The initial results of the detailed Techno Economic Model are as follows.

Financial results

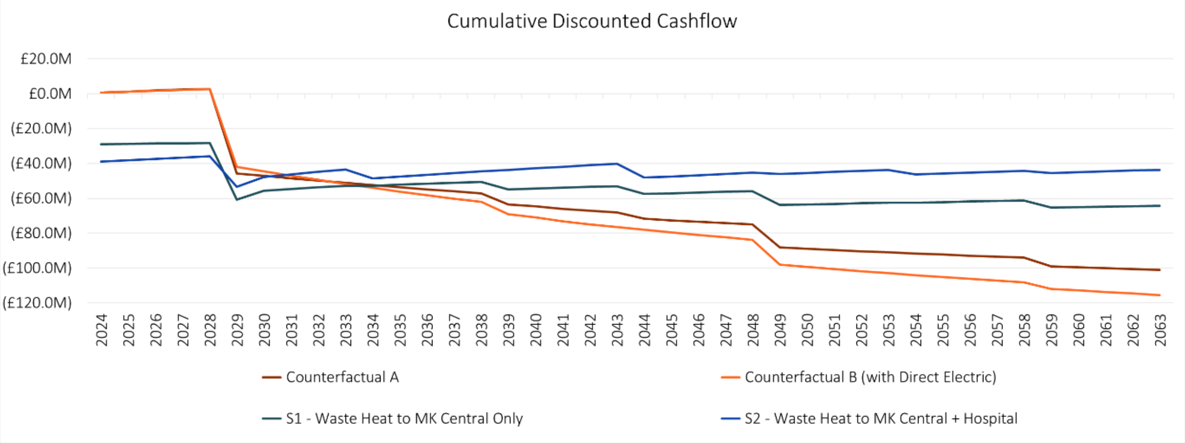


Figure 23: Cumulative Discounted Cashflow for each scenario

Figure 23 shows cumulative discounted cashflows for each of the scenarios investigated. Discounted cash flow is a valuation technique that uses expected future cash flows, in conjunction with a discount rate, to estimate the present fair value of an investment. This demonstrates the economic performance across the project lifetime, accounting for the time value of money.

This is an example reference scenario provided from the TEM. The TEM allows modifications to be made to various financial parameters which naturally impacts cashflow. This effect is discussed further in this report in the sensitivity analysis section.

Both district heating scenarios have a large capital cost from the beginning of the project, this is due to investment cost in the heat network. Both counterfactual scenarios operate with existing plant until they switch to low-carbon generation in 2030 which has an associated capital cost in 2029. All scenarios incur capital costs in 2029, associated to the additional residential and commercial loads coming online in 2030.

At the end of the economic life of capital items, they are replaced. This results in regular replacement costs incurred in all scenarios across the 40-year period, demonstrated by periodic drops in the cumulative discounted cashflows.

Although all scenarios return a negative cashflow over the 40-year period, it is important to compare relative cashflows against each other on a relative basis, due to the perspective of the modelling approach. In reality, a network operator could expect to see lower capital costs for a district heating solution (especially if grant funding is received), as well as higher operational revenue from higher heat sales charges.

The Net Present Value (NPV), as shown in Table 30, describes the cumulative sum of discounted cashflows, which shows the aggregated economic value over the course of the operation at a systems level.

Table 30: Net Present Values

Metric	40yr NPV at discount rate of 3.5% (£m)
Counterfactual A	(101.1)
Counterfactual B (with Direct Electric)	(115.4)
S1 - Waste Heat to MK Central Only	(64.2)
S2 - Waste Heat to MK Central + Hospital	(43.7)

It can be seen that both district heating scenarios have less negative NPV than either counterfactual, despite greater capital costs, from approximately 2040 onwards. This is since waste heat is considerably cheaper than the cost of electricity for running heat pumps. The difference in cost between these commodities is a safe assumption due to the nature of how their costs are derived.

The cost of heat from a heat pump relies on its coefficient of performance (COP) and the cost of electricity. Whereas the cost of heat from waste heat depends on the electricity export rate, likely to be lower than the electricity commodity rate, and the Z-factor, which is typically greater than the COP of the heat pump. Even with fluctuations in market prices, electricity export rates will be changed according to changes in commodity prices, therefore the relationship between cost of heat from waste heat and cost of heat from heat pumps should stay generally the same over time.

Another advantage of moving to a centralised system is a reduction in maintenance costs of separate systems, which outweighs the increase in heat network costs. This contributes to the observed improved operational cashflow compared to the counterfactual scenarios.

S2, the extended network option, seems to outperform S1, this is due to the district heating solution having both a lower capital cost and a lower operational cost than the counterfactual for the hospital. So, this makes sense economically, but whether it makes sense commercially is yet to be investigated.

Counterfactual B, the option with direct electric heating, performs worse than Counterfactual A despite lower capital costs. This is due to much higher operational costs where direct electric heating is present, as the efficiency of this type of system cannot compete with the COP of a heat pump. This result shows that the council should seriously consider whether they allow developers to build direct electric heating systems, as this will be at the detriment of residential customer energy bills and carbon emissions for the lifetime of the properties permitted to do so.

Carbon Emissions

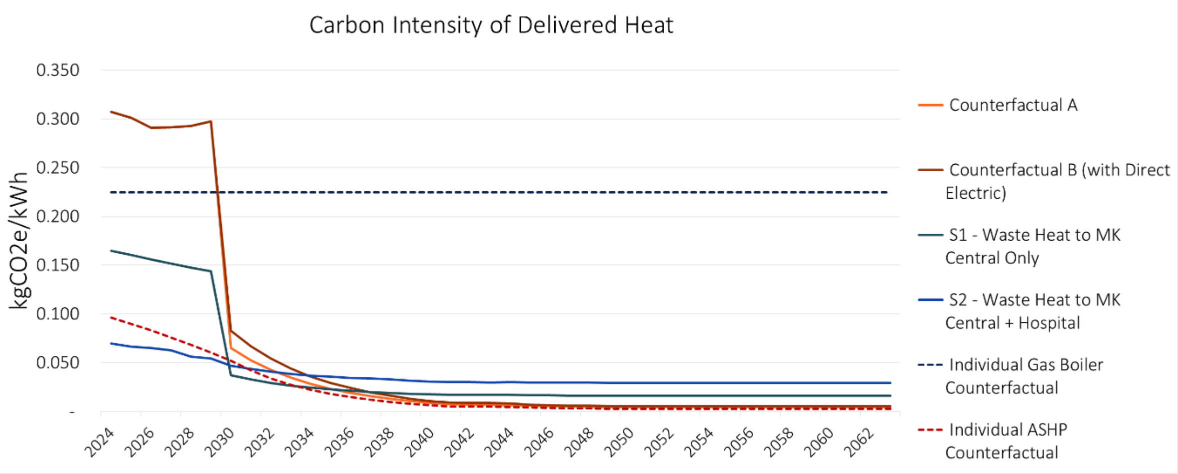


Figure 24: Carbon Trajectories for each scenario

Figure 24 highlights the differing carbon trajectories of the systems modelled. These are all lower than an individual gas boiler alternative, shown as a dotted line across the top of the graph.

Carbon emissions for waste heat have been calculated as the emissions related to the displaced electricity export. Practically, this is the electricity export marginal carbon factor, divided by the Z-factor, leading to low carbon emissions of waste heat. Emissions from the processing of waste has not been considered as the waste will continue to be processed, independent of this solution selected. Therefore, there will be no net change in system emissions.

S2 initially has the lowest carbon intensity of delivered heat due to the low carbon factor related to waste heat. All other scenarios have higher carbon intensities, owed to running gas-based systems initially and the relatively high carbon factor of electricity currently. As time progresses, the national grid is anticipated to decarbonise, reducing emissions related to electricity consumption, shown by the reducing carbon intensity of all scenarios. In 2030, both counterfactuals and S1 have a switch of systems to ASHPs which takes advantage of the grid decarbonisation, demonstrated by the significant drop in carbon intensity in this year.

As time progresses, and significant grid decarbonisation occurs, scenarios with predominantly electric-based systems (ASHPs and direct electric) start to have the lowest carbon intensity, this is due to the fact that the waste heat scenarios does not benefit from the decarbonisation of the grid, as well as using gas boiler as peaking plant, so their carbon intensity levels off after reaching a threshold. To reduce carbon intensity of the district heating solutions, gas boiler peaking plant could be replaced with electrode boilers or ASHPs, both of which would result in higher operational costs but lower carbon emissions.

At the end of the 40-years, S2 has the highest carbon intensity of delivered heat. However, all scenarios converge towards a relatively low carbon intensity, well below the gated carbon intensity of 0.1kgCO2e/kWh required by the Green Heat Network Fund (GHNF).

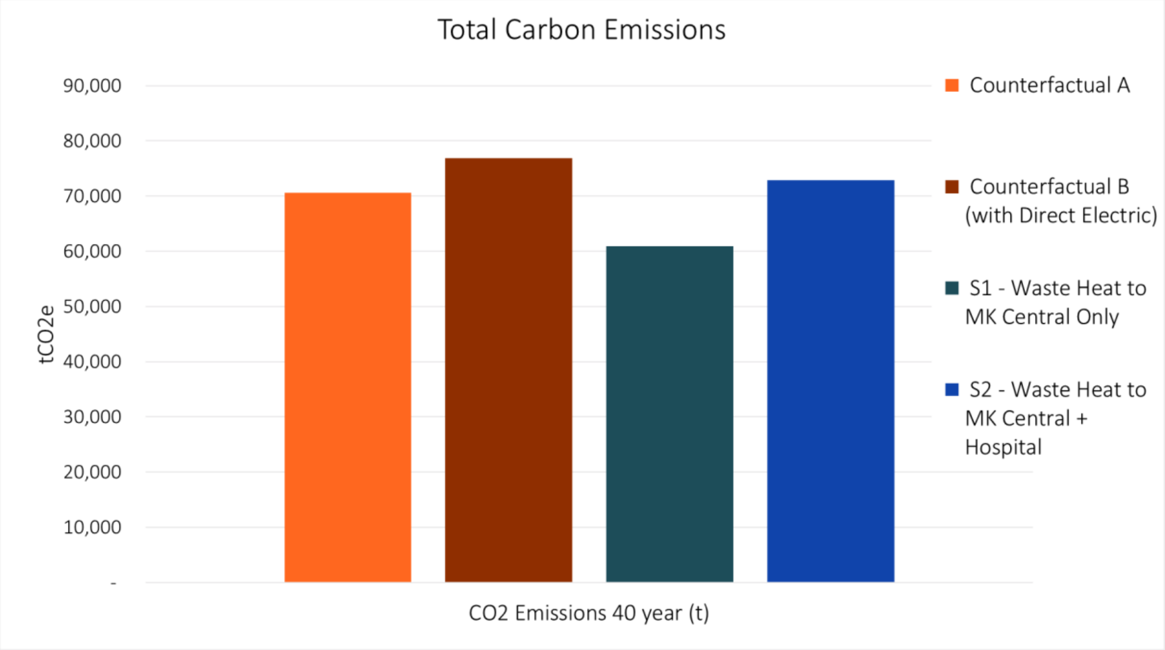


Figure 25: Total carbon emissions for each scenario over a 40-year period

Figure 25 shows the cumulative carbon emissions for each scenario across the 40-year period. Despite the electric-based systems having a lower carbon intensity over the majority of the 40-year period, the carbon impact of the initial running period results in higher lifetime carbon emissions for Counterfactual B. The COP of the heat pumps result in Counterfactual A having significantly lower lifetime emissions than Counterfactual Both district heating scenarios have low lifetime carbon emissions, which could be reduced further by switching from gas boiler peaking plant to an electric-based peaking plant.

Overall, counterfactual and district heating scenarios have very similar lifetime carbon emissions. However, the low carbon intensity and overall low carbon emissions of the district heating solutions do not rely as heavily on the decarbonisation of the grid, as it is mainly utilising the increased efficiency of the Waste Heat Recovery Park. This reduces the dependency on external factors, and therefore reduces the risk, for providing low-carbon heat to the city of Milton Keynes.

Sensitivity Analysis

Overview

A multi-parametric sensitivity analysis was carried out to quantify the impact of model parameters on the target KPIs of the techno-economic model. For this, we used global sensitivity analysis techniques which are known to outperform local sensitivity analysis. Given a range of lower and upper bounds for the different parameters of interest, sample data was generated using the Sobol low-discrepancy sequence uniformly sampling the parametric space for 10,000 variations. Using this method varies parameter simultaneously, which presents a more realistic representation of parameter variation.

The lower and upper bounds follow HNDU sensitivity analysis requirements, namely +/-10% for all variables apart from CAPEX, which uses +/- 30%. For this analysis, to represent recent market fluctuations in energy prices, electricity and gas commodity rates were varied +/-30% and grid export price was varied +/- 50%.

The techno-economic model was then run on this sample data to generate output data. Using this input-output data, we used screening methods to eliminate non-influential parameters and calculated Global sensitivity indices (a method based on partial variances) to rank the remaining parameters. The sensitivity indices include first order indices which correspond to individual parameter contributions to the total variance of the output and higher order indices which correspond to interactions between parameters. It is usually sufficient to truncate the interactions to the second order.

Monte Carlo Analysis

The Monte Carlo Sensitivity Analysis enables the calculation of the Value at Risk (VaR). VaR is taken at the lower 95th percentile outcome, reflecting the worst 5% of outputs. It is considered representative of the worst-case scenario that could actually happen in reality, considering the assumptions made in the model, i.e., 95% of all outcomes are better than this result.

The Mean NPV and VAR for each scenario is summarised in table form, as follows in Table 31. As previously mentioned in the report, it is important to NPV values on a relative basis, as this work assesses the economic viability at a system level, allowing comparison between scenarios, but does not necessarily reflect the commercial reality of attempting to secure the projected revenues based on a counterfactual argument.

Scenario	Mean NPV	Value at Risk (VaR)
Counterfactual A	(101,131,545)	(126,279,450)
Counterfactual B (with Direct Electric)	(114,941,221)	(142,414,051)
S1 - Waste Heat to MK Central Only	(64,252,857)	(87,864,734)
S2 - Waste Heat to MK Central + Hospital	(43,728,762)	(66,544,610)

Table 31: Summary of Mean NPV and VaR values

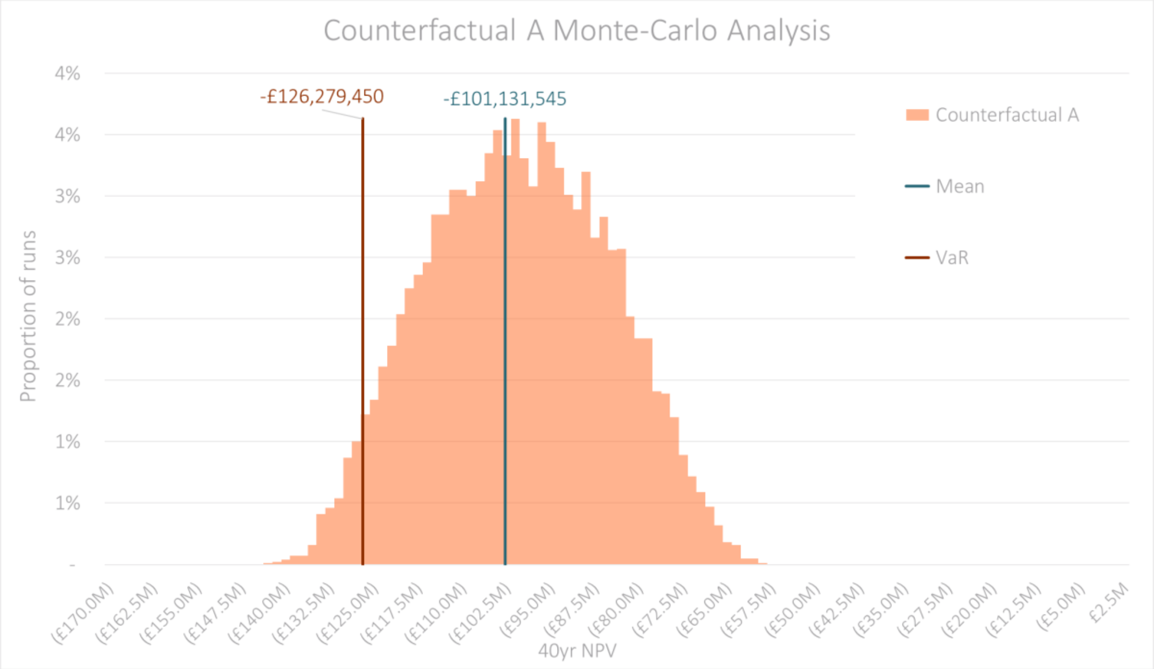


Figure 26: Counterfactual A Monte-Carlo Analysis

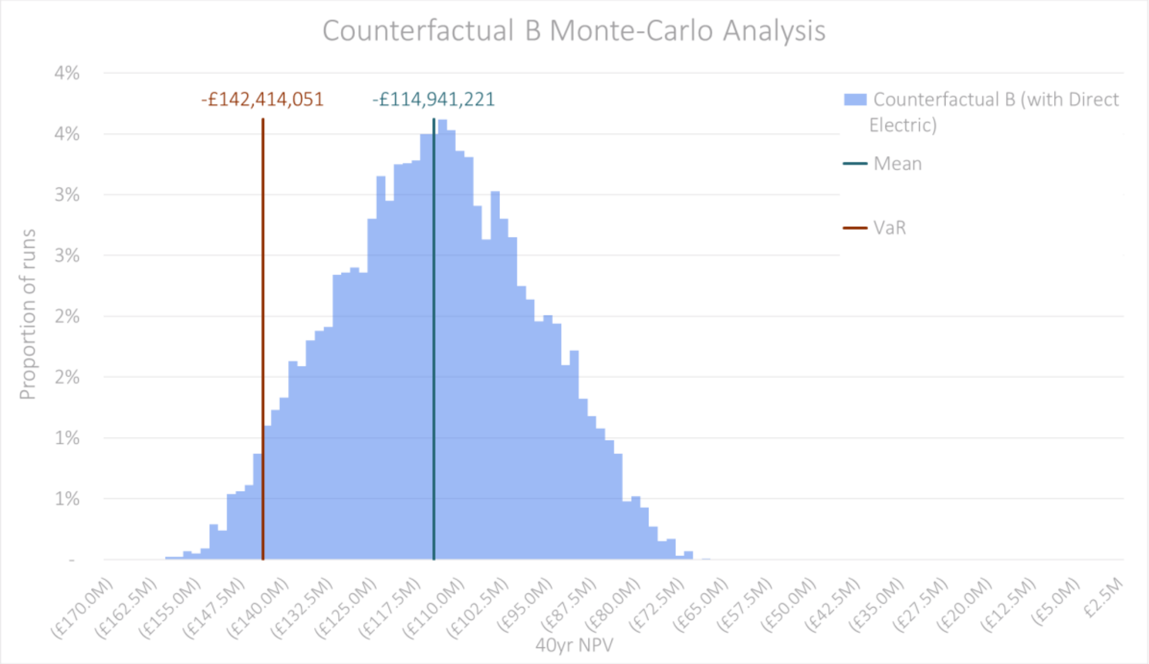


Figure 27: Counterfactual B Monte-Carlo Analysis

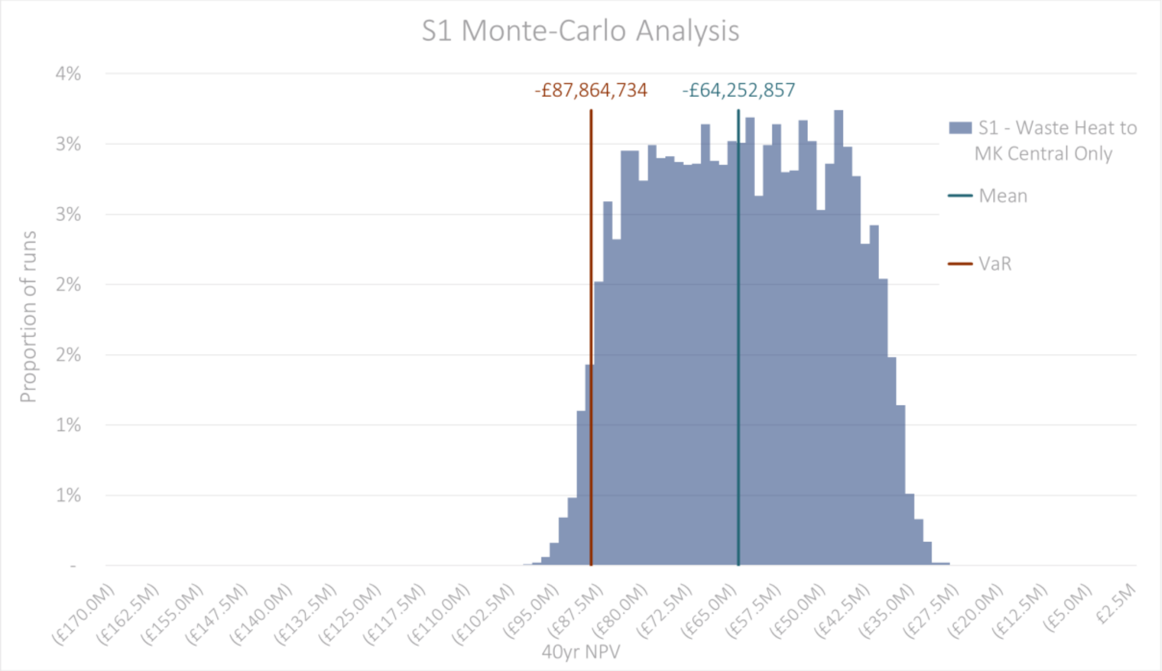


Figure 28: S1 Monte-Carlo Analysis

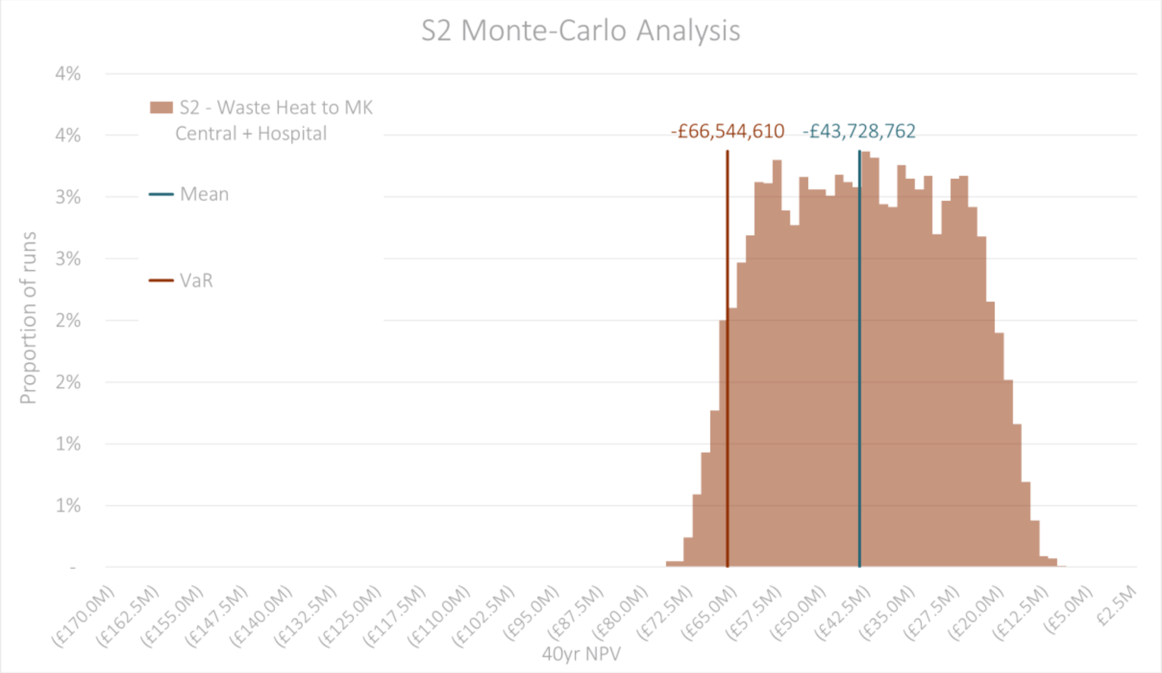


Figure 29: S2 Monte-Carlo Analysis

Reviewing the above figures, there are no significant skews in the results which would indicate a trend in one direction or other. The difference between the current modelling conditions and the mean values revealed in the sensitivity analysis, for all scenarios, is small, so the current modelling conditions can be considered representative of the range of modelling conditions tested for all scenarios.

Although all scenarios return a negative NPV for all modelled conditions, they can still be analysed on a comparative basis. When comparing the outputs against each other the results remain in-line with those outlined in the Operation Model Financial Results.

The following table and figures are the outputs of the Sobol analysis and indicate the key parameters influencing each scenario according to these assumptions.

Parameter	Counterfactual A	Counterfactual B	S1 - Waste Heat to MK Central Only	S2 - Waste Heat to MK Central + Hospital
CAPEX	58.7%	41.8%	84.7%	83.3%
Electricity Rate	20.5%	40.8%	-	-
Air Source Heat Pump Maintenance Rate	6.4%	4.3%	-	-
Grid Export Tariff	-	-	-	1.1%
Heat Variable Charge - Additional Commercial	4.0%	3.5%	5.0%	5.0%
Heat Variable Charge - Additional Residential	-	-	1.5%	1.5%
Heat Variable Charge - Hospital	1.7%	1.6%	2.4%	2.7%
Waste Heat z-factor	-	-	-	1.1%
Other factors	8.7%	7.9%	6.3%	5.3%

Table 32: Summary of the Sobol Analysis Outputs

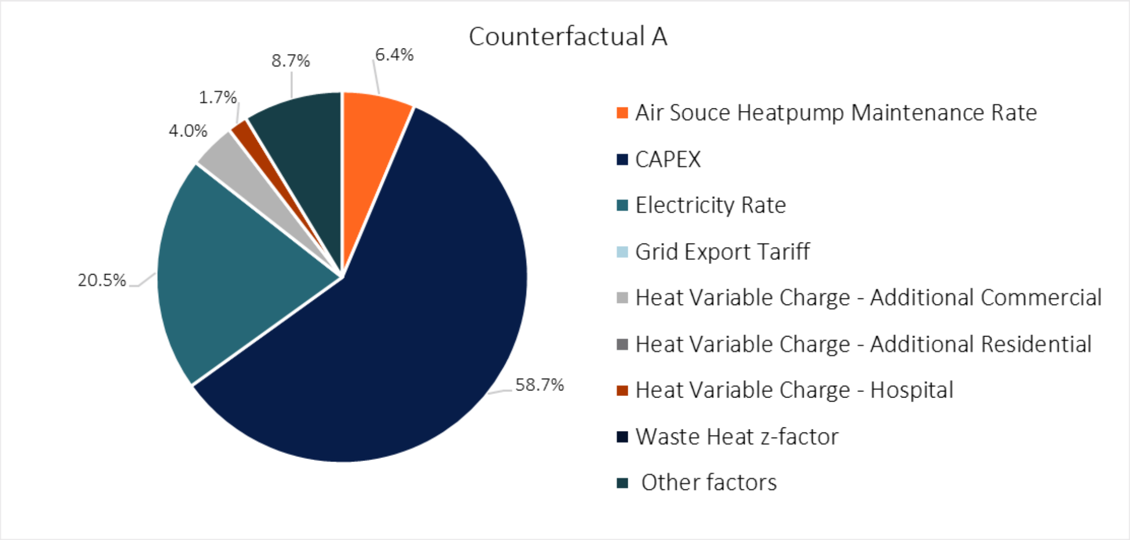


Figure 30: Sobol Analysis - Counterfactual A

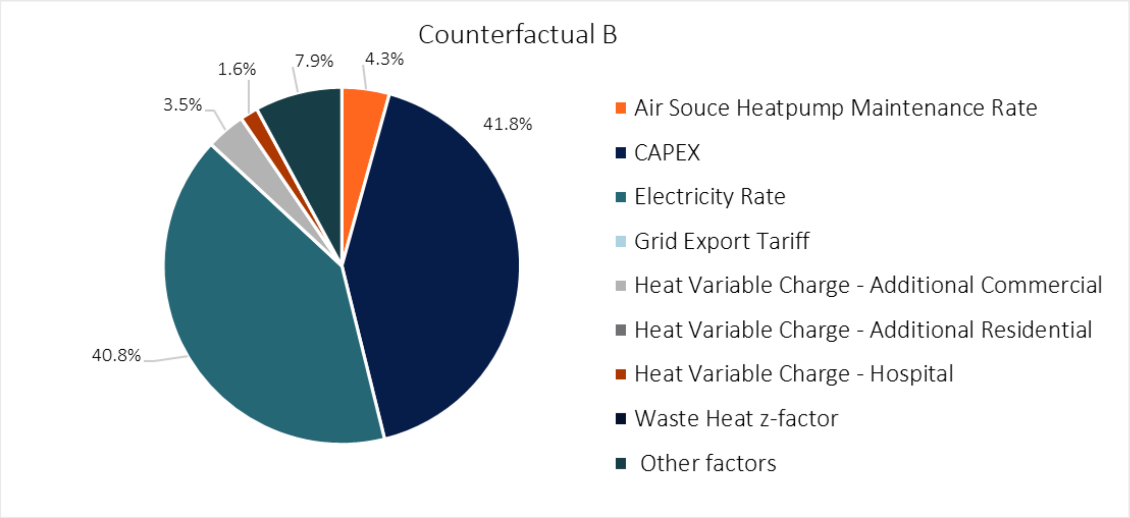


Figure 31: Sobol Analysis - Counterfactual B

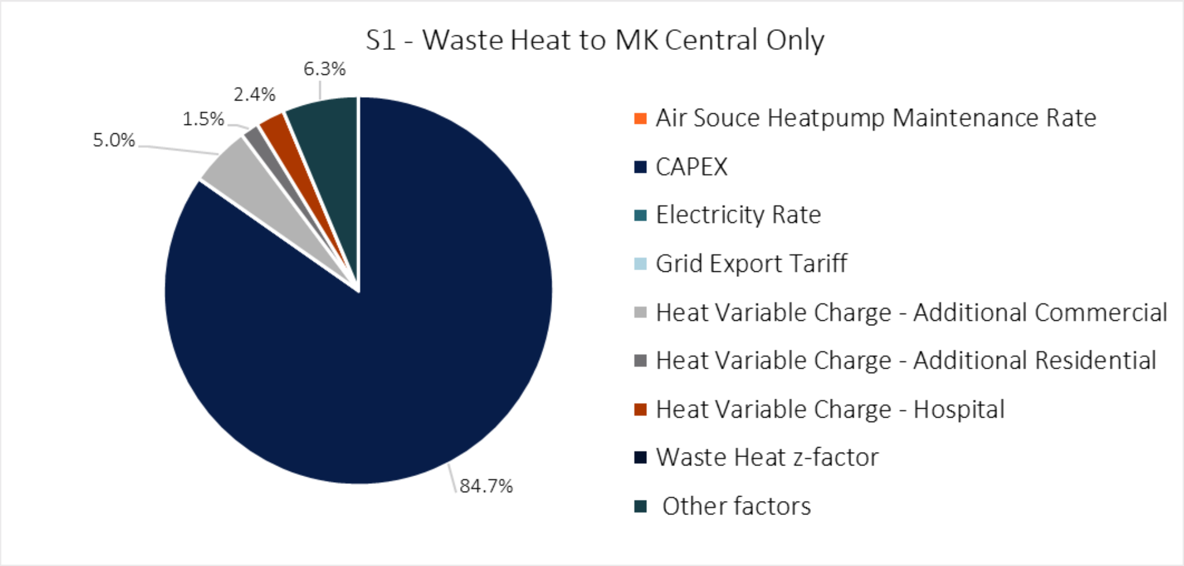


Figure 32: Sobol Analysis - S1

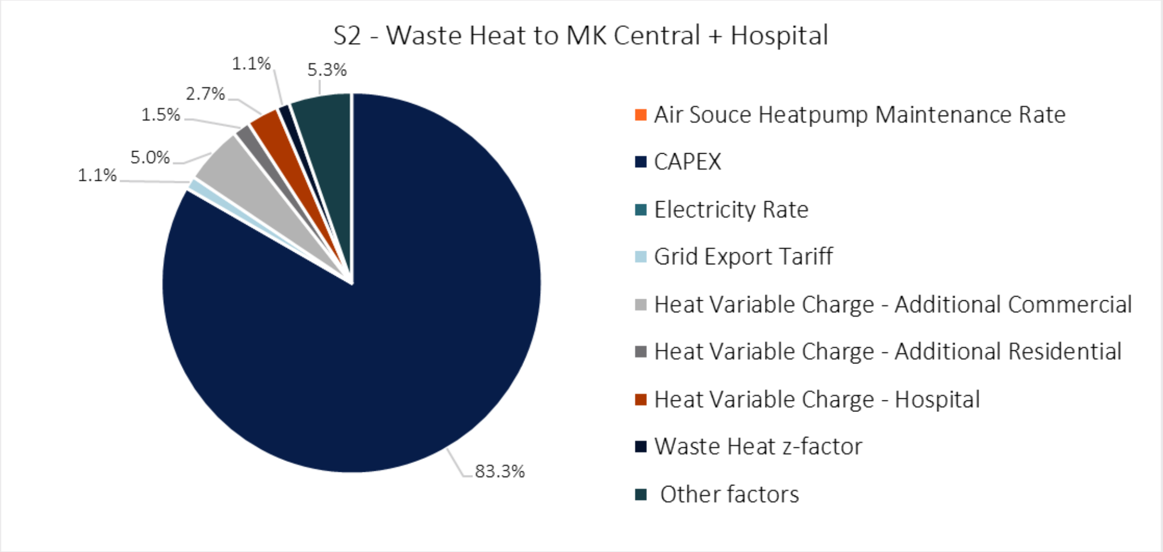


Figure 33: Sobol Analysis - S2

All scenarios have a very strong dependence on CAPEX in the sensitivity analysis. This is due to the modelling approach taken. To make scenarios comparable to each other, capital items were included that would not be incurred by a network operator, resulting in increased capital costs. Therefore, as the starting CAPEX value is greater, proportional variation of this value will have a greater impact on outcomes.

The scenario with lowest dependency on CAPEX is Counterfactual B. However, this is due to the significant dependence on the Electricity Rate (41%), which is twice as high as the next closest scenario, due to the effect it has on the operational cost of properties with direct electric heating in particular, as well as for ASHP-led systems. Counterfactual A also has a high dependence on the

Electricity Rate (21%) due to ASHP-led systems. The impact of variation in electricity prices is reduced by using a heat pump, as the high efficiency (COP) reduces the constant of proportionality between electricity prices and running costs. Therefore, the higher the COP that can be achieved, the lower the risk of variation in commodity prices.

Both district heating led systems have little dependence on commodities. Given recent market fluctuations in commodity prices, solutions that are resilient to these fluctuations are more commercially attractive.

Heat variable charges are significant variables in all scenarios, which is to be expected as they are the only revenue sources. These variables are preferably indexed against variable expenditures, which will assist in reducing any significant variation from the modelled cashflows.

Commercial Analysis

The following section has been carried out by Local Partnerships.

Intro & assumptions

The Techno Economic Model (TEM) outputs have been further assessed to determine the commercial viability of developing, delivering and operating a Milton Keynes heat network. To determine the commercial viability, heat demand, energy balances and capital cost data has been extracted from the TEM and combined with market-based assumptions on customer pricing and operational costs.

The customer pricing structure includes three charges

- Connection charges based on a £/kW charge for connected capacity
- Variable charges based on a £/kWh charge for heat used.
- Fixed charges/standing charges based on a £/kW charge for the connected capacity

This approach is consistent with the market standard approach.

To be commercially viable the project should return a positive return on investment whilst supplying customers at a price point below the counterfactual. To be investable by the private sector it is assumed that a 10% pre-tax, real rate of return is required, which consistent with market analysis carried out by BEIS.

The counterfactual is an alternative low-carbon /zero carbon heat source that customers could install. For the purposes of this analysis this alternative solution has been assumed to be an Air Source Heat Pump (ASHP).

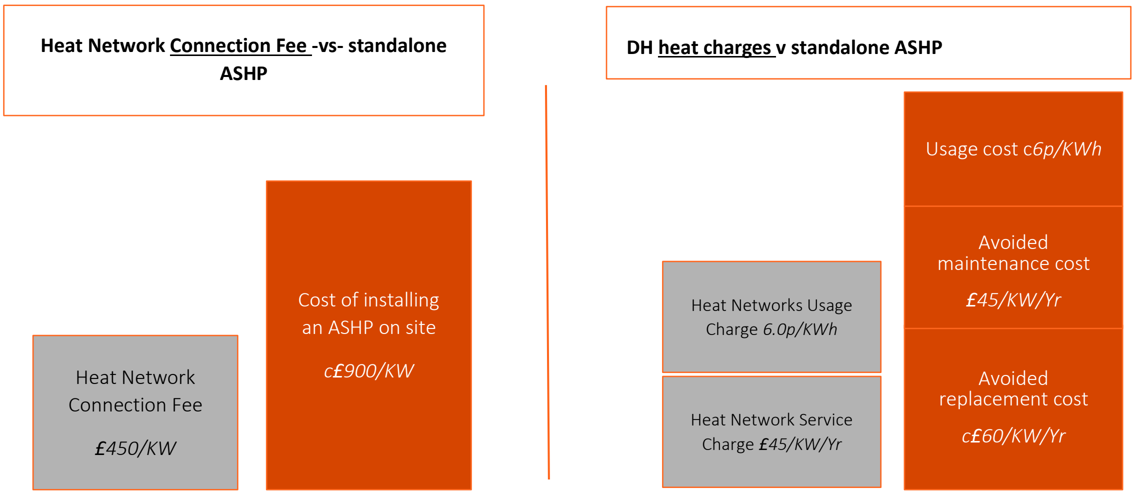
In addition to the assumptions above the heat price payable for the EFW offtake has been calculated based on the following formula.

*(PPA rate/ Z factor) * (1+ margin%)*

The PPA rate has been assumed as 6p/kWh based on the BEIS forward curve and the Z factor is assumed to be 6.4. These assumptions are subject to further verification.

Counterfactual Comparison

The diagram below shows the comparison of the assumed district heating charges compared to the ASHP counterfactual.



Scenario S1 Commercial Analysis Results

The table and chart below summarises the commercial analysis results for Scenario 1 (without the hospital connection).

This analysis is prior to any grant funding.

Table 33: S1 analysis summary

Annual Customer Demand		47,476,000	KWh
Connected Capacity		19,400	KW
Heat Price	£	0.060	£/KWh
Capacity Charge	£	45	£/KW
Connection Fee	£	450	£/KW
Capex (excl Comercialisation)	£	27,005,895	
Repex	£	18,054,530	
Connection Fee Income	£	8,730,000	
40 Year Pre tax Real IRR		7.7%	
40 Year Pre tax Real Cash	£	44,966,877	
Counterfactual saving		35%	
40 Yr Project Revenue	£	135,836,940	

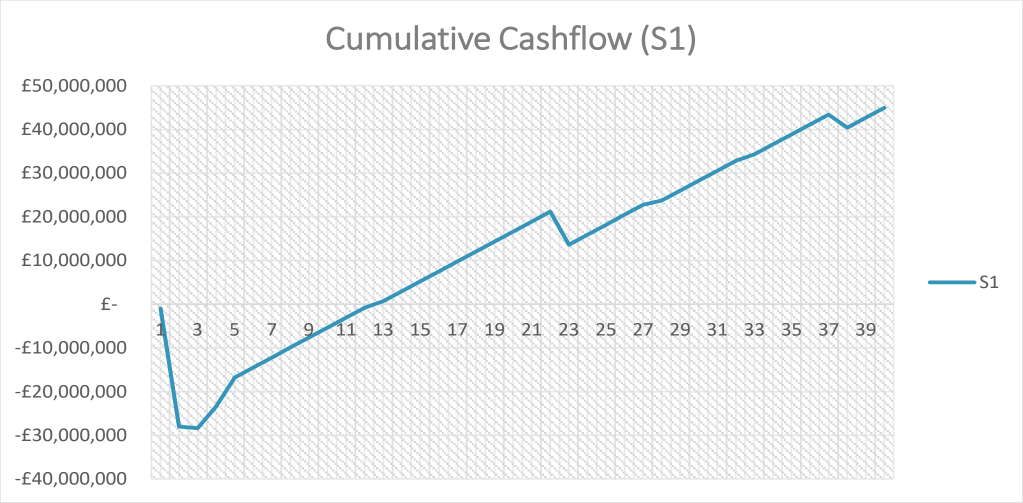


Figure 34: S1 Cashflow

A 10% IRR can be achieved if a 17% capital grant is awarded.

The Green Heat Network Fund (GHNF) awards capital grants of up to 50%. If a 50% grant was awarded the headline variable charge (Heat Price) could be reduced to 3.7p/kWh achieving a 53% (annualised) saving against the counterfactual.

Scenario S2 Commercial Analysis Results

The table and chart below summarises the commercial analysis results for Scenario 2, including the hospital connection.

Table 34: S2 commercial analysis summary

Annual Customer Demand		58,025,000	KWh
Connected Capacity		23,000	KW
Heat Price	£	0.060	£/KWh
Capacity Charge	£	45	£/KW
Connection Fee	£	450	£/KW
Capex (excl Comercialisation)	£	38,429,232	
Repex	£	17,375,845	
Connection Fee Income	£	10,350,000	
Capex per KWh	£	0.66	

40 Year Pre tax Real IRR		6.6%
40 Year Pre tax Real Cash	£	58,165,591
Counterfactual saving		34%
40 Yr Project Revenue	£	164,852,250

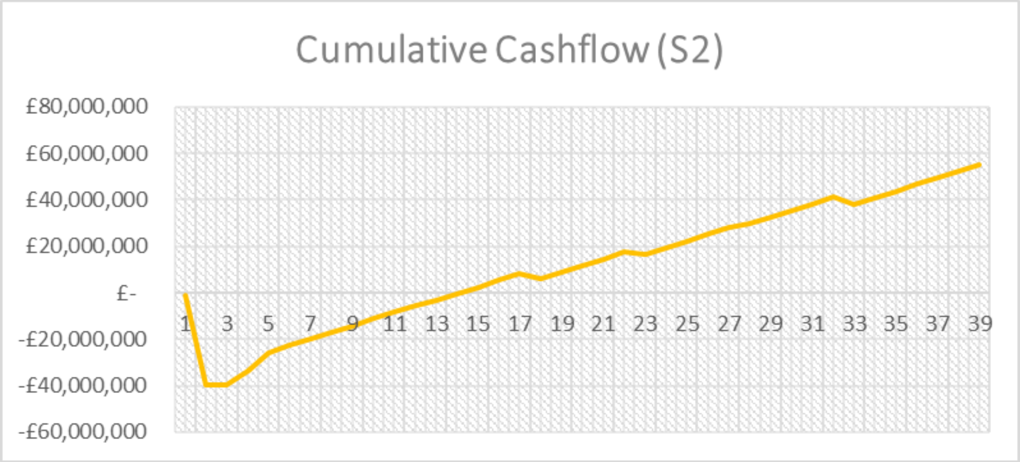


Figure 35: S2 cashflow

A 10% IRR can be achieved if a 26% capital grant is awarded.

If a 50% grant was awarded the headline variable charge (Heat Price) could be reduced to 4.0p/KWh achieving a 50% (annualised) saving against the counterfactual.

Scenario Comparison

The difference between scenario 1 and scenario 2 is the inclusion of the hospital (in scenario 2). The additional capital expenditure to extend the network to the hospital, taken from the TEM, is £11.4m for an additional heat demand of 10.5 GWh. This equates to £1.08 of capex per kWh of demand which is significantly higher than the £0.57 for scenario 1, without the hospital. This has the effect of lowering the overall IRR of the project, but at 6.6% pre-grant this still represents a commercially attractive opportunity.

In addition, the extension of the network to the hospital may facilitate further connections and demand not included in the model and therefore reducing the capex cost per KWh.

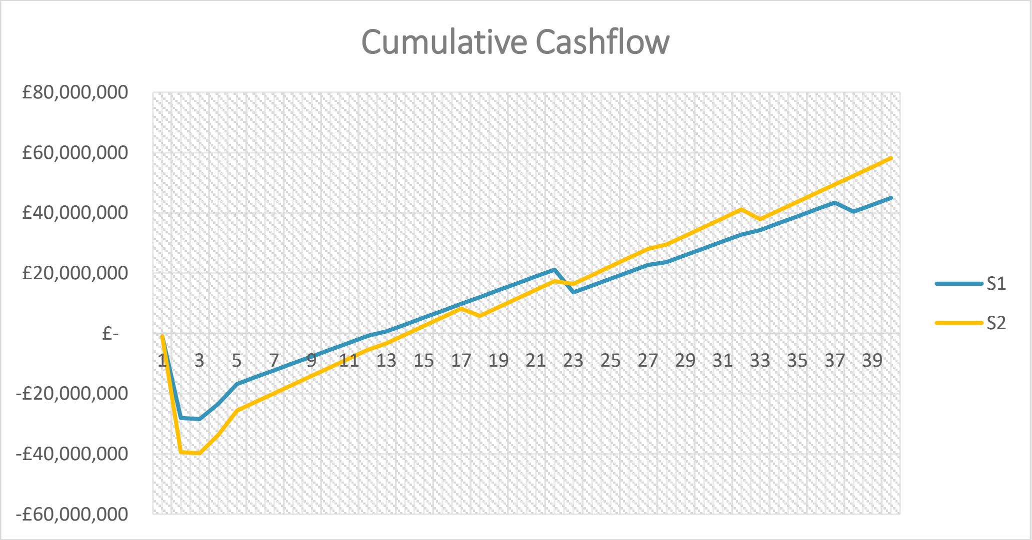


Figure 36: comparison of the cumulative cashflows of S1 and S2

This analysis is for the purposes of providing a high-level view of the commercial viability. More detailed analysis will be required to form any future business case.

Risks Identified

Risks have been identified at relevant points through this report. The risks considered to have the most impact on future development have been summarised in Table 35 below.

Table 35: Project risks

Identified Risk	**Likelihood (1-5) 1 = Low 5 = High**	**Severity (1-5) 1 = Low 5 = High**	**Risk Level (1-25)**	**Rationale and Mitigating Actions (actions in bold)**	**Post mitigation likelihood (1-5)**	**Post mitigation severity (1-5)**	**Risk Level (1-25) post mitigation**
Capital Costs	3	4	12	As demonstrated within the global sensitivity analysis, all scenarios have a significant dependence on capital costs. Therefore, in future development of any scenarios a particular focus needs to be taken on improving the accuracy of capital cost estimates by **obtaining quotes where possible and feasible, for the large capital items at a minimum**. For the counterfactual scenarios, the most significant costs are ASHPs and their related ancillaries. For the district heating solutions, the most significant cost is the network pipework. This is assumed at this stage as LTHW solutions (<100C), to assist in mitigating the design risk of adopting higher temperature alternatives. **An optimisation exercise is recommended** to assess how this may be sized or installed with lower whole life economic outcomes considering the management of any additional risks arising from adopting alternative temperature operations. This should include **considering the opportunity to reduce return temperatures on existing connecting systems at ThamesWey and the hospital** to facilitate better usage of any pipework installed.	2	3	6
Volatility in commodity prices	4	3	12	For the counterfactual scenarios, the next most dependent variable was commodity prices, particularly electricity. Thus, if a counterfactual scenario is chosen to be progressed then detailed work around the impact of changing commodity prices should be carried out. One of the advantages of district heating scenarios when **utilising waste heat sources directly (e.g. EfW systems)** are their relative resilience to variations in commodity prices. Therefore, this is not as big a risk for these scenarios but will still impact their financial outcome and should continue to be considered in any future work.	4	1	4

Identified Risk	Likelihood (1-5) 1 = Low 5 = High	Severity (1-5) 1 = Low 5 = High	Risk Level (1-25)	Rationale and Mitigating Actions (actions in bold)	Post mitigation likelihood (1-5)	Post mitigation severity (1-5)	Risk Level (1-25) post mitigation
Electrical Infrastructure	3	3	9	Evaluating upgrades to electrical infrastructure has not been included in the scope of the study. However, future work should **consider the potential impact a chosen solution will have on local infrastructure**, particularly if a counterfactual scenario is selected as they are anticipated to have potential to require significantly more electrical infrastructure upgrades.	2	2	4
Heat Supply	3	5	15	For the district heating solutions, modelling has assumed that the majority of the heat has been supplied by the Waste Heat Recovery Park. Through stakeholder engagement they have informed what they consider to be realistic modelling conditions. However, in the past they have had some operations issues, which if to happen again could cause the performance of these schemes to change significantly. Therefore, **the Waste Heat Recovery Park should be continually engaged to track the performance of the Waste Heat Recovery Park to ensure modelling conditions are representative of reality.** **Further work could be carried out to test how a reduced availability of the Waste Heat Recovery Park would affect the economics of the relevant schemes. Also, the technology selection for the backup plant used in planned maintenance periods could be varied to compare performance and optimise the scheme.**	2	3	6
Heat Demand	3	3	9	A large proportion of the modelled heat load for all scenarios is from additional residential and commercial connections, the majority of which have not been built yet. Industry standard approaches were taken to estimate the heat demands of these connections, but **stakeholder engagement with developers should be carried out to more accurately estimate the potential heat demand of these connections in the future.**	2	2	4

Identified Risk	Likelihood (1-5) 1 = Low 5 = High	Severity (1-5) 1 = Low 5 = High	Risk Level (1-25)	Rationale and Mitigating Actions (actions in bold)	Post mitigation likelihood (1-5)	Post mitigation severity (1-5)	Risk Level (1-25) post mitigation
Pipework Sizing	3	4	12	Due to the large quantity of heat that the pipework must transfer, large diameter pipework will be required for flow velocities aligned with CP1 Heat Networks Code of Practice (2020) recommendations. Some of the main issues with larger diameter pipework are higher capital costs, reduced installation flexibility (as they take up more room), increased network losses, and increased temperature drop. Therefore, if a district heating solution is progressed, **further work should be carried out to try and minimise the pipework diameter required for the network** through actions such as increasing the temperature differential of the network.	2	2	4
Network Routing	4	4	16	Currently, network routing has been optimised to reduce network length and maximise the opportunity for “soft dig” opportunity through visual inspection in GIS. Network routing represents a large proportion of capital cost and is the most significant dependency in global sensitivity analysis for the district heating scenarios. Therefore, if either of these scenarios are progressed then **a more detailed network routing exercise should be carried out, ensuring that the proposed network can feasibly be installed, through engagement with utilities, network rail (for the required railway crossings), and other stakeholders to clarify connection locations and requirements**.	2	2	4

Conclusion

The Techno-economic model results demonstrate that both proposed district heating solutions are projected to offer beneficial operational costs in comparison to the counterfactual business-as-usual options, whilst offering comparable lifetime carbon emissions with reduced dependency on external factors. The district heating solutions also offer the opportunity to catalyse broader rollout of the infrastructure in the City providing long-term economic benefits.

It is believed that both district heating solutions performed better economically due to the potential low-cost of the waste heat supply compared to electricity required to power heat pump solutions, and low losses occurring on the network due to the predominantly large diameter pipework with sufficient insulation modelled. The district heating solutions have slightly higher capital Expenditure, but also can benefit from Green Heat Network Capital Funding.

The district heating solutions provide annual carbon benefits until 2034 based on current grid decarbonisation projections. At this point the network would have the potential to move to an alternative primary heat source should the owner wish to follow or out-perform the grid decarbonisation trajectory. Furthermore, both S1 and S2 could reduce their carbon intensity and lifetime emissions by switching from gas boiler peaking plant to an electric-powered peaking plant, which would take advantage of grid decarbonisation, but at the cost of increased operational expenditure.

When comparing both counterfactual options, the scenario with direct electric heating for additional residential properties, Counterfactual B, has lower capital costs. However, the cashflow over 40 years, carbon intensity, lifetime carbon, and cost to tenants are all outperformed by Counterfactual A. Also, Counterfactual B has more dependence on electricity rates, and given recent market fluctuations, this increases the risk associated with this option. Furthermore, direct electric heating systems will increase strain on the local electrical network, which appears to have limited connection capacity without substantial upgrade.

The extended district heating solution (S2) demonstrated better financial performance than the shorter network solution (S1) for both capital costs and operational costs, due to the high costs related to implementing an ASHP-led system in S1. S2 performs slightly worse for carbon intensity and lifetime carbon performance, due to a slightly increased use of gas boiler peaking plant, whereas S1 uses ASHPs to deliver heat to the hospital, which capitalises on grid decarbonisation.

Through sophisticated sensitivity analysis, we have been able to demonstrate that both district heating solutions have lower dependency on commodity prices compared to the counterfactual options, which increases resilience to market fluctuations and reduces this risk to connected parties. This could become an important consideration in the context of current geo-political events and associated energy market volatility. Furthermore, by providing a significant proportion of heat from waste heat, demand on the local electrical infrastructure required is much smaller, reducing the strain on an electrical network which appears to have some sections already overloaded.

High-level commercial analysis outlined both S1 and S2 as commercially attractive opportunities, with comparable IRRs of 7.7% and 6.6% and 40-year project revenues of £135.8m and £164.9m respectively, which could be further improved with grant funding from the GHNF.

In summary, S1 demonstrates a slightly higher IRR and beneficial long-term carbon performance, whereas S2 has a higher project revenue and delivers a greater quantity of low-carbon heat to the city but has slightly more risk related to the higher capital investment required. Both district heating solutions are financially, commercially, and environmentally comparable to each other, but demonstrate significantly beneficial performance when compared against the alternative options to deliver low-carbon heat to the city. The business case may be further improved for both solutions by identifying future connections either on route or nearby key anchor loads.

If the council either delay or fail to progress the opportunity for a district heating solution, then the counterfactual options assessed may become default options for future City energy infrastructure. As the study has concluded these options are more expensive, may have higher carbon intensities than the DHN, and will cause more strain on local grid infrastructure.

We would encourage the Council to further progress the DH scenarios presented to move to a preferred option and build out the outline and full business cases under HNDU Detailed Project Development Funding (https://www.gov.uk/government/publications/heat-network-detailed-project-development).

Next Steps

This study provides strong evidence of the technical and commercial viability of a district heating solution in Milton Keynes. There are options available to bring in grant funding and/or private sector investment. The next step for the Council is to make a clear decision on how this project can move to delivery and their role of in support of this. To access this funding MKC need to make decisions in a timely manner to avoid being timed out of grant funding opportunities.

Both district heating solutions should be progressed to the Detailed Project Development (DPD) stage, with a view to obtain grant funding for the scheme through the Green Heat Network Fund. During the DPD stage, both solutions should be developed further and compared against MKC's critical success factors to prioritise and refine a preferred solution.

HNDU offer support of up to 67% for DPD funding. The deadline for Round 12 of funding is midday 30th December 2022. Anthesis has supported several councils in successfully accessing this funding. We would be pleased to advise on the evidence needed to support a successful application to BEIS.

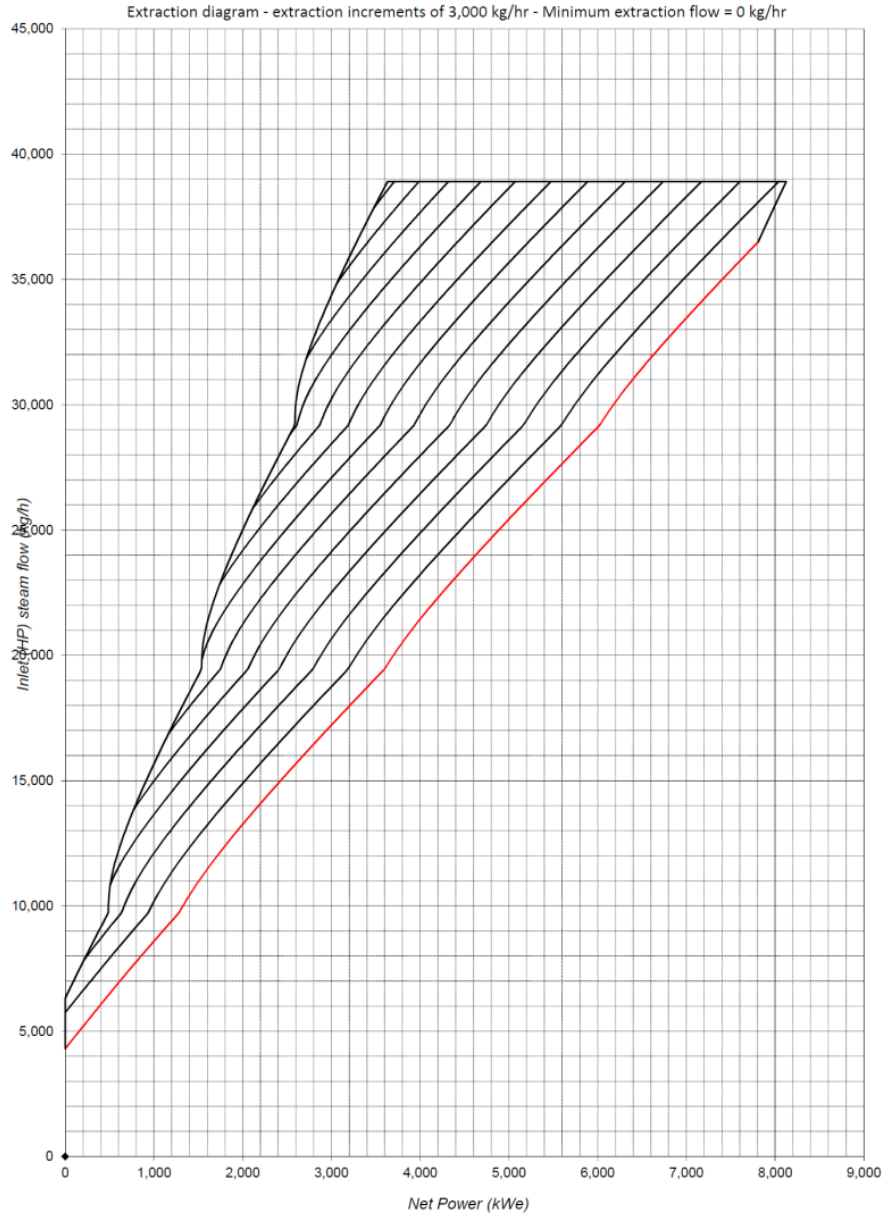
To ensure that MKC meets the necessary timelines for GHNF, the proposed solution should continue to be developed, prior to and during the DPD phase, through further stakeholder engagement and analysis to mitigate the risks identified within this study.

Appendix A – Waste Heat Recovery Park Technical Details

NG

PERFORMANCE CURVE
TURBINE HC-800E

N°: DE-415557-003.00
SHEET: 2 de 8



Inlet pressure = 22.00 bar abs.
Inlet tempreature = 380.00° C.

Extraction pressure = 3.00 bar abs.

Nominal exhaust pressure = 0.100 bar abs.

Figure 37: Steam Turbine Performance Curve

Table 36: Steam turbine operating conditions with controlled extraction

Operating Point	**100% Max Extraction**	**50% Max Extraction**	**Units**
Inlet Steam Flow	35,200	17,750	kg/hr
Inlet Steam Pressure	22.0	22.0	Bar (a)
Inlet Steam Temp	380.0	380.0	^{0}C
Inlet Steam Enthalpy	3,200.5	3,200.5	kj/kg
Extraction Steam Flow	31,310	13,860	kg/hr
Extraction Steam Pressure	3.0	3.0	Bar (a)
Extraction Steam Temp	178.0	219.0	^{0}C
Extraction Steam Enthalpy	2,820.8	2,905.0	kj/kg
Heat Transferred to District Heating	23.80	10.71	MWth
LP Exh Steam Flow	3,890	3,890	kg/hr
LP Exh Steam Pressure	0.1	0.1	Bar (a)
LP Exh Steam Temp	203.0	205.5	^{0}C
LP Exh Steam Enthalpy	2.885.5	2,890.1	kj/kg
External Heat Input	0.114	0.114	MWth
Condensate Return Temp	70.0	70.0	^{0}C
Boiler Feed Water Temp	105.0	105.0	^{0}C
Generator Terminal Power	3.495	1,515	MWe

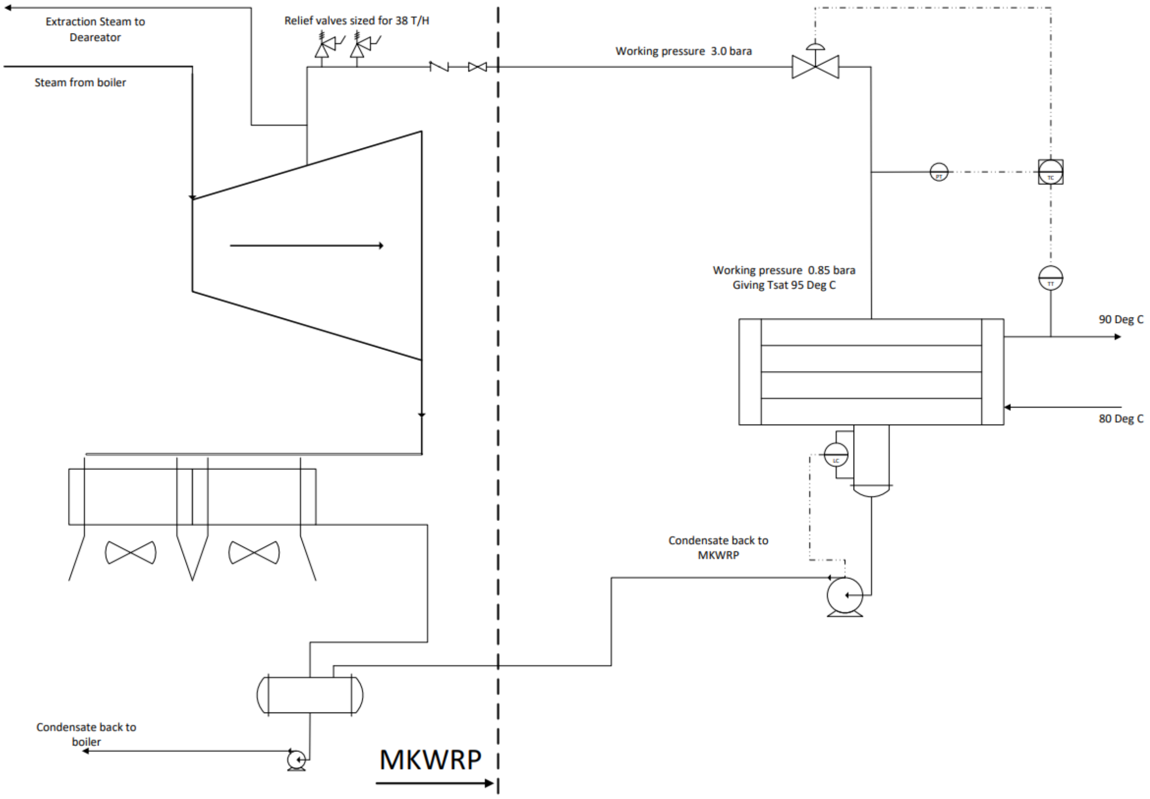


Figure 38: Schematic of heat extraction from the Waste Heat Recovery Park for district heating

Appendix B – City-wide heat demand areas

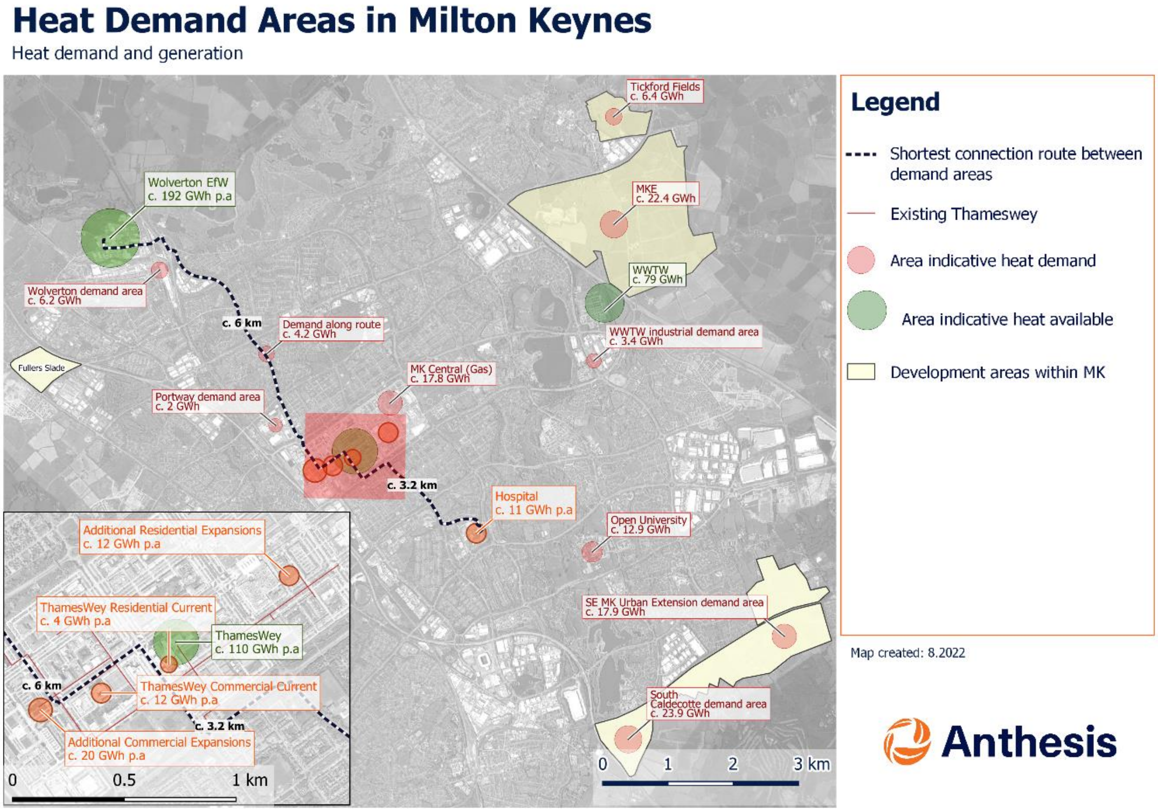


Figure 39: Heat demand areas in Milton Keynes

Appendix C – Capital Assumptions

Table 37: Total model capital costs

HNDU Defined Area	Counterfactual A	Counterfactual B	S1 - Waste Heat to Central MK only	S2 - Waste Heat to Central MK + Hospital
A) Gas fuelled combined heat and power (CHP) Units	£-	£-	£-	£-
B) Biomass heat only system	£-	£-	£-	£-
C) Heat pumps (HP)	£15,396,148	£13,635,458	£6,948,750	£-
D) Other heat supply technologies not covered above	£-	£-	£-	£-
E&F) Back-up boilers	£-	£-	£700,557	£700,557
G) Energy Centre items, or refurbishment of existing plant areas, as applicable	£2,421,058	£1,615,593	£3,344,826	£2,282,583
H) Thermal storage	£2,106,180	£5,473,078	£2,015,731	£1,033,708
I) Utility connections	£1,573,715	£7,517,451	£238,036	£48,841
J) Electrical export by Private Wire or export to grid	£-	£-	£-	£-
K) Heating Network	£22,087,513	£15,208,840	£37,631,011	£41,846,615
L) Cost of connections at heat user locations	£15,447,919	£10,860,956	£16,569,277	£16,601,630
M) Engineering, Procurement and Project Management (excluding hardware, civils and direct construction labour).	£-	£-	£-	£-
N) Any other Design & Build or Engineering, Procurement and	£-	£-	£269,548	£269,548

HNDU Defined Area	Counterfactual A	Counterfactual B	S1 - Waste Heat to Central MK only	S2 - Waste Heat to Central MK + Hospital
Construction Costs (other costs to be given in section O below).				
O) Other non-Design/Build or Engineer/Procure/Construct Project Costs	£-	£-	£-	£-
Total Cost	£ 59,032,533	£ 54,311,376	£ 67,717,736	£ 62,783,483

Table 38: Model capital costs excluding shell & core items

HNDU Defined Area	Counterfactual A	Counterfactual B	S1 - Waste Heat to Central MK only	S2 - Waste Heat to Central MK + Hospital
A) Gas fuelled combined heat and power (CHP) Units	£-	£-	£-	£ -
B) Biomass heat only system	£-	£-	£-	£ -
C) Heat pumps (HP)	£15,396,148	£13,635,458	£6,948,750	£ -
D) Other heat supply technologies not covered above	£-	£-	£-	£ -
E&F) Back-up boilers	£-	£-	£700,557	£ 700,577
G) Energy Centre items, or refurbishment of existing plant areas, as applicable	£2,421,058	£1,615,593	£3,344,826	£ 2,282,582

HNDU Defined Area	**Counterfactual A**	**Counterfactual B**	**S1 - Waste Heat to Central MK only**	**S2 - Waste Heat to Central MK + Hospital**
H) Thermal storage	£2,106,180	£1,524,719	£2,015,731	£ 1,033,708
I) Utility connections	£1,573,715	£7,517,451	£238,036	£ 48,841
J) Electrical export by Private Wire or export to grid	£-	£-	£-	£ -
K) Heating Network	£1,001,536	£1,001,536	£23,423,707	£ 32,940,285
L) Cost of connections at heat user locations	£5,300,973	£-	£6,422,332	£ 1,153,711
M) Engineering, Procurement and Project Management (excluding hardware, civils and direct construction labour).	£-	£-	£-	£ -
N) Any other Design & Build or Engineering, Procurement and Construction Costs (other costs to be given in section O below).	£-	£-	£269,548	£ 269,548
O) Other non-Design/Build or Engineer/Procure/Construct Project Costs	£-	£-	£-	£ -
Total Cost	**£ 27,799,611**	**£ 25,294,758**	**£ 43,363,487**	**£ 38,429,234**

Appendix D – Technical Assumptions

Item	GEA RedAstrum RM	Mitsubishi AW-HT 0604	Mitsubishi i-FX-N-G05 1006	Unit
COP	4.10	3.48	3.42	-
Design Air Temperature	12	7	7	˚C
Design Water Temperature	80	45	45	˚C
Air Source Heat Pump Delta T	6	5	5	˚C
Air Source Heat Pump Thermal Capacity	2175	205	1006	kW

Table 39: Heat Pump Specifications

Item	Value	Unit	Source
Electricity Commodity Cost	180.6	£/MWh	BEIS Medium Consumer 2021 Q4 price incl. CCL
Gas Commodity Cost	35.32	£/MWh	BEIS Large Consumer 2021 Q4 price not inc. CCL
Gas CCL	1.68	£/MWh	BEIS Standard Rate
Waste Heat Cost	9.9	£/MWh	Calculated using the grid export rate and provided Z-factor

Table 40: Commodities

Item	Value	Unit	Source
CHP Maintenance Rate	2.2	£/hr	Estimated from Anthesis previous project experience

Item	Value	Unit	Source
CHP W3 Maintenance Rate	11.2	£/hr	Estimated from Anthesis previous project experience
CHP W4 Maintenance Rate	3.8	£/hr	Estimated from Anthesis previous project experience
Gas Boiler Maintenance Rate	8,000.0	£/yr	Estimate per boiler
Electrode Boiler Maintenance Rate	8,800.0	£/yr	Berenschot, Energy Matters, CE Delft, Industrial Energy Experts, 2017, Adjusted for inflation
Electrode Boiler Maintenance Rate	4.04	£/hr	Berenschot, Energy Matters, CE Delft, Industrial Energy Experts, 2017, Adjusted for inflation
Air Source Heat Pump Maintenance Rate	5.00%	%	GEA Rule of Thumb
Immersion Heater Maintenance Rate	100.0	£/yr/flat	Safety check allowance
Heat Network Maintenance Cost	0.67	£/MWh	Average Typical Benchmarks Inflated according to the SPPI
HIUs Maintenance Cost	10.1	£/MWh	Average Typical Benchmarks Inflated according to the SPPI
Heat Meter Maintenance Cost	3.8	£/MWh	Average Typical Benchmarks Inflated according to the SPPI
Staff cost for metering, billing and revenue collection	18.99	£/MWh	Average Typical Benchmarks Inflated according to ONS Wage Increase

Table 41: Maintenance & Other

Item	Value	Unit	Source
Heat Variable Charge - ThamesWey Residential	27.3	£/MWh	Current price charged by ThamesWey
Heat Variable Charge - ThamesWey Commercial	47.35	£/MWh	Current price charged by ThamesWey
Heat Variable Charge - Additional Residential	68.88	£/MWh	Electrical commodity price divided by benchmark COP (2.5)
Heat Variable Charge - Additional Commercial	68.88	£/MWh	Electrical commodity price divided by benchmark COP (2.5)
Heat Variable Charge - Hospital	68.88	£/MWh	Electrical commodity price divided by benchmark COP (2.5)
Private Wire Tariff	108.30	£/MWh	Blended cost of electricity sales from ThamesWey
Grid Export Tariff	63.21	£/MWh	Assuming approximately 35% of purchase price

Table 42: Sales Tariffs

Item	Value	Unit	Source
Primary Network Flow Temperature	90	C	Anthesis
Primary Network Return Temperature	65	C	Anthesis

Table 43: Network Temperatures

Full Build-Out Data

Scenario	**Counterfactual A**	**Counterfactual B (with Direct Electric)**	**S1 - Waste Heat to MK Central Only**	**S2 - Waste Heat to MK Central + Hospital**	**Unit**
Year	**2031**	**2031**	**2031**	**2031**	
CHP Maintenance Total	-	-	-	-	£
Gas Boiler Maintenance Total	8,000	8,000	16,000	8,000	£
Electrode Boiler Maintenance Total	-	288,200	8,861	8,954	£
Biomass Maintenance Total	-	-	-	-	£
Heat Pump Maintenance Total	1,539,615	1,363,546	347,438	-	£
Store Maintenance Total	-	-	-	-	£
Waste Heat Maintenance Total	-	-	-	-	£
Chiller Maintenance Total	-	-	-	-	£
Heat Network Maintenance	31,717	23,946	40,415	39,184	£
HIUs Maintenance	172,822	56,254	172,838	172,838	£
Heat Meter Maintenance	65,288	135,693	65,294	65,294	£
Substation Maintenance	-	-	68,842	74,138	£

Scenario	**Counterfactual A**	**Counterfactual B (with Direct Electric)**	**S1 - Waste Heat to MK Central Only**	**S2 - Waste Heat to MK Central + Hospital**	**Unit**
Year	**2031**	**2031**	**2031**	**2031**	
Staff cost for metering, billing and revenue collection	324,522	324,522	324,551	324,551	£
Business Rates	£	-	-	-	£
Electricity Total Indexed	3,073,214	4,465,573	519,591	29,588	£
Gas Total Indexed	12,542	12,542	196,033	231,788	£
Biomass Total Indexed	-	-	-	-	£
Waste Heat Total Indexed	-	-	435,402	543,507	£
Electricity Standing Charge	-	-	-	-	£
Electricity Capacity Charge	-	-	-	-	£
Gas Standing Charge	-	-	-	-	£
Total Expenditure	5,227,720	6,678,275	2,195,264	1,497,842	£

Table 44: Operational Expenditure

Scenario	Counterfactual A	Counterfactual B (with Direct Electric)	S1 - Waste Heat to MK Central Only	S2 - Waste Heat to MK Central + Hospital	Unit
Year	2030	2030	2030	2030	
Indexed Heat Sales - ThamesWey Residential	148,969	148,969	148,969	148,969	£
Indexed Heat Sales - ThamesWey Commercial	451,921	451,921	451,921	451,921	£
Indexed Heat Sales - Additional Residential	780,272	780,272	780,376	780,376	£
Indexed Heat Sales - Additional Commercial	1,370,338	1,370,338	1,370,344	1,370,344	£
Indexed Heat Sales - Hospital	713,988	713,988	713,988	749,639	£
Total Revenues	3,465,486	3,465,486	3,465,597	3,501,248	£

Table 45: Operational Revenue