National Heat Study

District Heating and Cooling

Spatial Analysis of Infrastructure Costs and Potential in Ireland

SUSTAINABLE ENERGY AUTHORITY OF IRELAND

District Heating and Cooling: Spatial Analysis of Infrastructure Costs and Potential in Ireland

Report 2 of the National Heat Study

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Report 2 of the National Heat Study

February 2022

V1.1

The National Heat Study and associated reports were commissioned by a project team across the SEAI Research and Policy Insights Directorate and developed with the assistance of Element Energy and Ricardo Energy and Environment.

Disclaimer

Sustainable Energy Authority of Ireland

SEAI is Ireland's national energy authority investing in, and delivering, appropriate, effective and sustainable solutions to help Ireland's transition to a clean energy future. We work with the public, businesses, communities and the Government to achieve this, through expertise, funding, educational programmes, policy advice, research and the development of new technologies.

SEAI is funded by the Government of Ireland through the Department of the Environment, Climate and Communication.

Key insights

- Ireland ranks in the bottom five in the EU for the shares of district heating and renewable heat. The top-ranked EU countries for renewable heat shares also have high shares of district heating. By contrast, Ireland has only a few small scale district heating networks contributing less than 1% of the total heat used in Ireland.
- The Irish Government is seeking to scale the deployment of district heating. Two larger-scale projects are at an advanced stage of planning in Dublin, and the Government's Climate Action Fund is supporting both.
- The research presented in this report highlights the significant further potential for district heating. It indicates that district heating networks could supply over 50% of building heat demand in Ireland.
- We base this estimate of potential on high-resolution spatial analysis of heat demand in Ireland. We developed a model to evaluate the costs of constructing and maintaining district heat networks (including pipe costs, installation, thermal storage and connection) in 18,641 distinct areas covering the entire country.
- The research also highlights heat supply options for district heating networks, including: waste heat recovery from power stations and industrial sites, biomass boilers, biomass combined heat and power (CHP), air source heat pumps (ASHP), geothermal via ground source heat pumps (GSHP), and low-carbon gas CHP.
- There are currently six power stations, two energy-from-waste facilities, and 17 industrial sites with the potential for waste heat extraction for use in district heating networks. These sites could provide a combined heat capacity of 1,800 MWth, mostly from power station retrofit.
- Data centres are a large and growing source of energy demand in Ireland. It may be possible to supply heat networks using upgraded waste heat that is generated by the IT equipment at these sites. Mapping the potential for heat recovery from 20 datacentres across Ireland shows a cluster of potential around Dublin. Whilst data centres show promising potential for waste heat recovery in Ireland, we require more public information on how they operate to understand the potential fully.
- Geothermal energy, sourced from underground heat reservoirs, can supply heat to district heating networks. The analysis used temperature, resource and suitability data available in Ireland to depths of 400 m. The results show that most areas suitable for district heating also have high suitability for geothermal resources. In combination with deep boreholes, heat pumps can access the geothermal heat and supply it to heat networks at the necessary temperatures. Significantly, ongoing studies are quantifying potential geothermal energy lying at depths below 400 m.
- The data and analysis presented in this technical report underpin the analysis of net-zero pathways as part of the broader National Heat Study.

Acknowledgements

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- Codema
- Dublin City Council
- Geological Survey Ireland
- Irish District Heating Association
- Kerry County Council
- South Dublin County Council
- University College Dublin
- Veolia

To avoid doubt, this acknowledgement does not imply endorsement by the stakeholders listed, and this report is solely the work of Ricardo Energy and Environment and the Sustainable Energy Authority of Ireland.

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Executive summary

Introduction

Ireland's 2021 Climate Action and Low Carbon Development (Amendment) Act [1] commits Ireland to reducing greenhouse gas emissions by 51% by 2030 and to achieving economy-wide carbon neutrality by 2050. This requires immediate emissions reductions in every sector. Energy used for heating and cooling accounts for 20% of Ireland's greenhouse gas emissions, but the current pace of decarbonisation falls short of the cuts required. Almost every sector of Ireland's economy uses heat energy. Decarbonisation efforts will need to be implemented by industry, businesses and households. This requires a comprehensive, robust and actionable evidence base that policymakers and other stakeholders can use to make decisions.

The Sustainable Energy Authority of Ireland (SEAI) commissioned Element Energy and Ricardo Energy and Environment to work with SEAI on the National Heat Study to provide this evidence base. The study evaluates the costs and benefits of various pathways that reach net zero by 2050. We based the evaluation on a comprehensive understanding of heating and cooling demand in Ireland and the deployment costs, potential and suitability of technologies, infrastructure and fuels to reduce emissions.

We have separated the insights and analysis from the study into eight reports (outlined in *Figure 1*)[1]. These reports provide a rigorous and comprehensive analysis of options for decarbonisation of heating and cooling in Ireland up to 2050. The findings support Ireland's second submission to the EU of a 'National Comprehensive Assessment (NCA) of the potential for efficient heating and cooling' [2], as required by Article 14 of the Energy Efficiency Directive [3]. There are seven major technical reports, each focusing on topics that form the overall analysis. The concluding report is *Net Zero by 2050*[2], which outlines the study's key insights across scenarios that achieve net-zero emissions from heating and cooling.

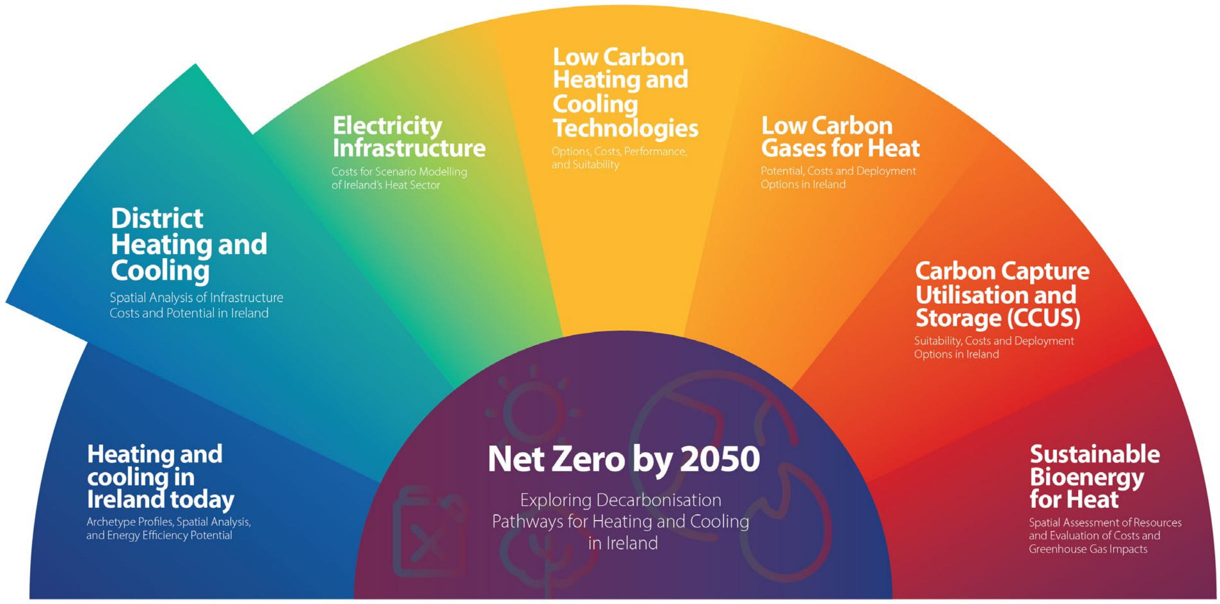

Figure 1: Framework of reports

Purpose and objectives

The purpose of this work was to develop a computational model for estimating capital and operating costs (capex and opex), and assessing the economic viability of district heating (DH) throughout Ireland. This

[1] All reports and supporting materials published as part of the National Heat Study are available from www.seai.ie/NationalHeatStudy/
[2] SEAI, 'Net-Zero by 2050: Exploring Decarbonisation Pathways for Heating and Cooling in Ireland'. 2022 [Online]. Available: www.seai.ie/publications/Net-Zero-by-2050.pdf

model calculates the capex and opex associated with the construction and operation of DH networks in 18,641 distinct land areas covering the entire country. The model also compares different technologies that can generate heat for DH. The fundamental aim of this work is to define, at a national level, which areas in Ireland show the most favourable capital investment for DH, and which generating technologies we should use.

Current status of district heating in Ireland

In order to understand the current state and future potential of DH in Ireland, we gathered existing literature on DH in Ireland and combined it with consultation and interviews with key stakeholders. This exercise confirmed limited deployment of the heat network infrastructure in Ireland, and those in operation tend to be small scale. However, previous work has suggested that DH has the potential to play a more prominent role. More recently, larger municipal scale projects such as the Dublin DH scheme and Tallaght DH scheme have made progress towards construction.

The district heating model

The model analyses the cost of constructing a DH network and operating the heat generation plant in every small geographic area in Ireland. Small areas (SA) are a useful unit, as they contain typically between 80 and 120 dwellings.

To calculate costs in the model, we assumed one centralised heat generation plant provides the domestic, commercial and public heat demand for each small area. Each SA then provides this heat to every domestic, commercial, and public property in each small area. In reality, it is not best practise to connect every property to a DH network. However, this model aims to provide a high-level analysis of which SAs in Ireland show the greatest economic viability for DH. Further detailed modelling for this National Heat Study is described in the report *Net Zero by 2050*[3].

The profile and characteristics of heat demand at SA resolution in Ireland are key inputs to this model. The *Heating and Cooling in Ireland Today* report describes the analysis carried out to create these profiles.[4] We paired the domestic, commercial and public heat demand for all 18,641 SAs in Ireland with our DH model. Pairing in this way allows us to model the capital and operating costs of implementing a DH network for each SA.

The *Heating and Cooling Demand in Ireland Today* report also describes spatial mapping of the cooling demand in Ireland. In addition, as part of the National Heat Study and as input to scenario modelling, we developed hourly cooling profiles. This data shows very low cooling demand across Ireland, and so the focus of this analysis is on DH. Separate cooling datasets should be developed for Ireland to allow district cooling to be considered for the next NCA review.

We include four key costs within the model: the generating technologies, thermal storage, the pipe network (trenching costs differ for city and rural areas) and the connection of consumers to the network. The model includes the following technology options for providing heat to the networks:

- Option 1 – Heat extraction from power stations and industrial waste heat recovery (including data centres)
- Option 2 – Biomass boiler
- Option 3 – Biomass CHP with biomass boiler back-up
- Option 4 – Air source heat pump (ASHP)
- Option 5 – Ground source heat pump (GSHP)
- Option 6 – Low-carbon gas CHP

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[3] SEAI, 'Net-Zero by 2050: Exploring Decarbonisation Pathways for Heating and Cooling in Ireland'. 2022 [Online]. Available: www.seai.ie/publications/Net-Zero-by-2050.pdf
[4] SEAI, 'Heating and Cooling in Ireland Today: Archetype Proles, Spatial Analysis, and Energy Efficiency Potential'. 2022 [Online]. Available: www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

- Option 7 – Geothermal at depth up to 400 m

In order to understand the potential that heat extraction/recovery (Option 1) and geothermal (Option 7) had within Ireland, these two options received a detailed analysis.

Heat extraction from power stations and industrial waste heat recovery potential

Power generation stations produce large amounts of low-temperature heat as a by-product of generating electricity. This low-temperature heat energy is often unsuitable for DH networks, which typically need higher temperature heat inputs. Adding additional equipment allows these power stations to provide heat at a temperature suitable for heat networks. Potential exists in Ireland for converting some existing power stations to extract heat and for building new stations as 'combined heat and power' ready plant. We evaluated the potential for heat extraction from these sources, and excluded power stations operating at peak load ‑ open cycle gas turbines (OCGT) ‑ and others closing in the next couple of years.

We estimate that the total heat extraction and waste heat recovery potential is 10.9 TWh_{th}/year (1.8 GW_{th}), which equates to 38% of national heat demand for the domestic, commercial and public sectors:

- Heat extraction from six power stations ‑ 9 TWh_{th}/year.
- Heat extraction from two energy from waste (EfW) sites ‑ 0.4 TWh_{th}/year.
- Heat recovery from 17 industrial sites ‑ 1.5 TWh_{th}/year.

Data centres show promising potential, but we need more public information regarding the operation of Irish data centres to fully assess this option.

Geothermal potential

Other countries use geothermal energy to power DH networks. These systems access heat energy available under the ground. Where suitable, it has the potential to provide abundant, low-cost heat. The Geological Survey Ireland (GSI) has carried out several detailed evaluations of geothermal energy potential [4] and data from GSI show that geothermal energy has significant potential in Ireland.

Research is ongoing, but, at the time of writing, there is no robust framework for geological suitability at depths below 400 m; hence, the focus of this report is on geothermal potential up to 400 m. It should be noted that using geothermal energy for heat at depths up to 400 m requires heat pump technology, so it is considered under GSHP (Option 5) rather than in a separate category for geothermal energy.

The district heating model – key results

An important variable when assessing the potential for DH in an SA is heat density. We can calculate heat densities in several ways; but first we considered the linear heat density, which is total heat demand divided by the road length in each SA [MWh/km].

Our analysis of DH potential in Ireland indicates that 311 SAs out of 18,641 have a heat density greater than 10,000 MWh/km; it is these locations that show the greatest potential for DH. Whilst the 2015 SEAI DH study [5], carried out by AECOM, proposed that SAs with a heat density less than 10,000 MWh/km are not viable for DH, the results from this work suggest that the crucial cut-off is in fact lower, with construction costs (€/MWh) plateauing at 1,000 MWh/km. Hence, the cost (€/MWh) of constructing a network with a heat density of 1,000 MWh/km is very similar to a heat density of >10,000 MWh/km. This is important because 51% of all SAs in Ireland have a heat density between 1,000 and 10,000 MWh/km. To put this into perspective, our analysis shows that around 2.5% of the total heat demand from the residential, commercial and public sectors has a high economic viability for DH (>10,000 MWh/km). However, DH could potentially serve up to 54% of heat demand (>1,000 MWh/km).

Results suggest that, in terms of capital costs, biomass boilers and ASHPs are the cheapest options for DH, although CHP and GSHPs are not substantially more expensive. It is also worth noting that CHP provides the ability to generate and sell electricity, which provides additional revenue. We found extraction of heat from power stations and waste heat recovery from industrial sites to be notably more expensive than the other generation options considered. However, it should be noted that we only considered existing power stations in the analysis, and the costs of retrofitting power stations to extract heat are substantial. Should new power stations be built in the coming decades that are CHP-ready, this would likely be notably cheaper.

If every property in an SA is provided with heat, the cost of connecting each property to the network is the greatest component of the total capital cost. Therefore, the number of consumers being connected to a DH scheme should be carefully optimised.

1 Introduction

Ireland's 2021 Climate Action and Low Carbon Development Bill (Amendment) Act [1] commits Ireland to reducing greenhouse gas emissions by 51% by 2030 and to achieving economy-wide carbon neutrality by 2050. This requires immediate deep emissions reductions in every sector. Energy used for heating and cooling accounts for 20% of Ireland's greenhouse gas emissions, but the current pace of decarbonisation falls short of the cuts required. Almost every sector of Ireland's economy uses heat energy. Decarbonisation efforts will need to be implemented by industry, businesses and households. This requires a comprehensive, robust and actionable evidence base upon which policy makers and other stakeholders can use to make decisions.

To provide this evidence base, the Sustainable Energy Authority of Ireland (SEAI) commissioned Element Energy and Ricardo Energy and Environment to work with SEAI on the National Heat Study. The study evaluates the costs and benefits of various pathways that reach net zero by 2050. We based the evaluation on a comprehensive understanding of heating and cooling demand in Ireland and the deployment costs, potential and suitability of technologies, infrastructure and fuels to reduce emissions.

We have separated the insights and analysis from the study into eight reports (outlined in *Figure 1*). These reports provide a rigorous and comprehensive analysis of options for decarbonisation of heating and cooling in Ireland up to 2050. The findings support Ireland's second submission to the EU of a 'National Comprehensive Assessment (NCA) [2] of the potential for efficient heating and cooling', as required by Article 14 of the Energy Efficiency Directive [3]. There are seven major technical reports, each focusing on topics that form the overall analysis. The concluding report is *Net Zero by 2050*[5], which outlines the study's key insights across scenarios that achieve net-zero emissions from heating and cooling.

1.1 What is district heating?

Domestic, commercial and public properties are typically provided with heat for space and water heating via generating equipment located in each building, usually a boiler. However, in a district heating (DH) network, heat is generated at centralised locations, and distributed (via insulated pipes) to each property connected to the network.

The main advantages of DH are:

- Centralised generation allows for the use of combined heat and power (CHP), which is more energy efficient.
- Centralised generation allows renewable biofuels to be utilised, which is often not possible when heat is generated on site.
- Extraction and distribution of heat from industrial sites and data centres which would otherwise be wasted.
- DH allows heat to be generated and supplied from a variety of sources, utilising the most cost-effective source of heat at any point in time.

Whilst DH forms a key part of some EU member states' heat sector, Ireland has one of the lowest shares of DH in Europe, providing less than 1% of Ireland's heat market [6] To date, there have been no large-scale DH schemes developed in Ireland, though work to design and construct networks throughout the country is underway. There have been some large-scale studies of the possibilities for DH in Ireland, and feasibility studies in some of Ireland's largest cities.

[5] SEAI, 'Net-Zero by 2050: Exploring Decarbonisation Pathways for Heating and Cooling in Ireland'. 2022 [Online]. Available: www.seai.ie/publications/Net-Zero-by-2050.pdf

The Energy Efficiency Directive (EED) defines 'efficient district heating' as a DH system that utilises at least 50% renewable energy, 75% cogeneration heat or 50% of a combination of such energy and heat. The DH networks modelled later in this work are designed to meet this definition [7].

For a summary of the key pieces of literature reviewed and existing DH schemes in Ireland, please see Appendix A.

1.2 The district heating model

This report describes the computational model developed to analyse DH infrastructure costs in Ireland. The outputs from this analysis are an input to SEAI's National Energy Modelling Framework (NEMF). The NEMF is a full energy systems model that is used to understand the costs and impacts of decarbonisation options and is used for scenario modelling as part of the National Heat Study. More details about the NEMF are available in the Net Zero by 2050 report published as part of the National Heat Study.

This DH model focuses on estimating capital (capex) and operating and maintenance (opex) costs and was developed to analyse the economic viability of DH across Ireland at small area (SA) level.

The *Heating and Cooling in Ireland Today*[6] report describes spatial mapping of the cooling demand in Ireland. In addition, as part of the National Heat Study and as input to scenario modelling, we developed hourly cooling profiles. These data show very low cooling demand across Ireland and so the focus of this analysis is on heating rather than cooling. The estimation of cooling demand in Ireland has proven to be difficult due to the limited availability of cooling data. It is recommended that cooling datasets are developed for Ireland to allow district cooling potential to be considered in more detail for the next NCA review

We include four key costs within the model: the generating technologies, thermal storage, the pipe network and the connection of consumers to the network. Within the model, we explore the following technology options for providing heat to the networks:

- Option 1 – Heat extraction from power stations and industrial waste heat recovery (including data centres)
- Option 2 – Biomass boiler
- Option 3 – Biomass CHP with biomass boiler back-up
- Option 4 – Air source heat pump (ASHP)
- Option 5 – Ground source heat pump (GSHP)
- Option 6 – Low-carbon gas CHP
- Option 7 – Geothermal at depths up to 400 m

1.3 Report structure

The remainder of the report is structured as follows:

- Section 2 focuses on the development of a database for pipe network costs.
- Section 3 explores the potential of technology options for providing heat to the network.
- Section 4 describes the fundamental components of the DH model.
- Section 5 presents key results from the DH model.

The information generated from this DH model is combined with data and information from the other technical reports shown in *Figure 1* and represented in SEAI's NEMF.

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[6] SEAI, 'Heating and Cooling in Ireland Today: Archetype Proles, Spatial Analysis, and Energy Efficiency Potential'. 2022 [Online]. Available: www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

2 District heating pipework cost database

The cost of pipes can be significant when constructing a DH network, and so it is important that the DH model has accurate cost input data (capex and opex). This section describes the methodology for developing the pipework cost database for DH in Ireland. We considered different cost variations as part of this exercise to obtain a comprehensive dataset. We split the cost of constructing the pipe network into three components:

- Purchasing the pipe, which depends on the pipe diameter, length and material (plastic or steel).
- Trenching, which is physically digging out the channels where the pipes will lay. This cost is greater in more built-up areas, such as cities, where the ground comprises concrete and tarmac etc.
- Installation of the pipework following trenching.

2.1 Overview of methodology

There is a lack of publicly available DH cost data for Ireland, so we sent a questionnaire to key stakeholders in the country to collect this information. We received a limited sample of responses, so to overcome the lack of Irish data, we used detailed cost data from the UK, which we verified by comparing with the small sample of stakeholder responses. We constructed the pipework database following the methodology presented in *Figure 2* [8] [9].

Source data: **Pipe cost (£/m length) vs. pipe diameter (mm)** was taken from Heating Supply Options for New Development - An Assessment Method for Designers and Developers report. These data reflect 2019 outer-city costs for 2-pipe systems for 4th generation DH and for steel pipe. They include equipment, installation and trenching costs, as well as the maximum capacity of heat a given pipe size can provide [8].

We used well-established factors to account for pipe material (steel vs. plastic, based on previous analysis by Ricardo) and geographical location (e.g. additional 25% for inner-city development based on the European Commission [9].

We estimated projection of costs for 2030, 2040 and 2050 using data from the 'European Commission, Long-term (2050) projections of techno-economic performance of large-scale heating and cooling in the EU' [9].

We sense-checked data against multiple sources including Irish stakeholder responses. Stakeholders were provided with UK data and asked to provide Irish data in a similar format.

Figure 2: Pipework database methodology

Key assumptions include:

- The analysis focused on DH due to the small demand for district cooling in Ireland and lack of cost data on district cooling (i.e. focus was on 2-pipe rather than 4-pipe systems typically used for DH and cooling systems).
- The heat network considered in the source report is a 4th generation network with pre-insulated plastic pipe. We adapted reference data from the 2009 Parsons Brinkerhoff study [8] for steel pipe for plastic pipe.

- We considered both outer- and inner-city trenching. Inner-city trenching increases the overall capital cost by 25% when compared to outer-city costs [9].

In making assumptions, we considered guidelines in the 2020 CP1 Heat Network: Code of Practice for the UK [10]. Note that specific heat network design needs to be undertaken on a case-by-case basis depending on the specific circumstances of a small area or site; however, for this work, we made assumptions to facilitate modelling and made recommendations for sensitivity analysis. The objective of this work is to understand, at a national level, the suitability for DH in Ireland, and these assumptions are the most appropriate way of doing so. The *Net Zero by 2050 report*[7] presents a detailed sensitivity analysis on heat networks.

2.2 The pipework database

Appendix B provides the complete dataset of pipe costs used in the analysis in Section 5. *Figure 3* below shows that the costs (€/m pipe length) generally double as diameters increase from <50mm to 250mm. Due to the additional trenching requirements, the cost of inner-city pipes is greater than for outer-city pipes. Also, the cost of 4-pipe systems (estimated using a typical scale-up exponent of 0.6 for pipe systems [11]) is greater than 2-pipe systems.

For illustration purposes, *Figure 4* shows the cost projection from 2020 to 2050 for 20 mm for 2-pipe systems for Ireland in an inner-city location. This demonstrates an expectation for the pipe cost to decrease marginally in the coming decades.

Although we collected the costs of 4-pipe systems, we did not use them within the model (Section 4), as there is a lack of demand for cooling in Ireland.

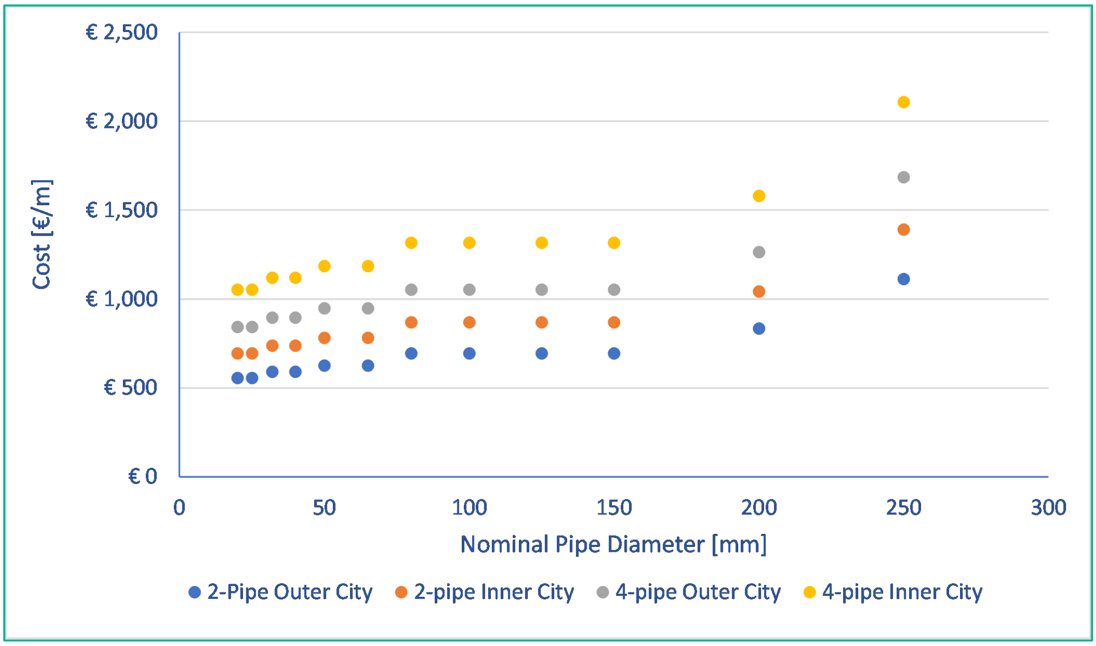

Figure 3: Cost per meter trench length for DH pipes of various sizes in Ireland (2020)

[7] SEAI, 'Net-Zero by 2050: Exploring Decarbonisation Pathways for Heating and Cooling in Ireland'. 2022 [Online]. Available: www.seai.ie/publications/Net-Zero-by-2050.pdf

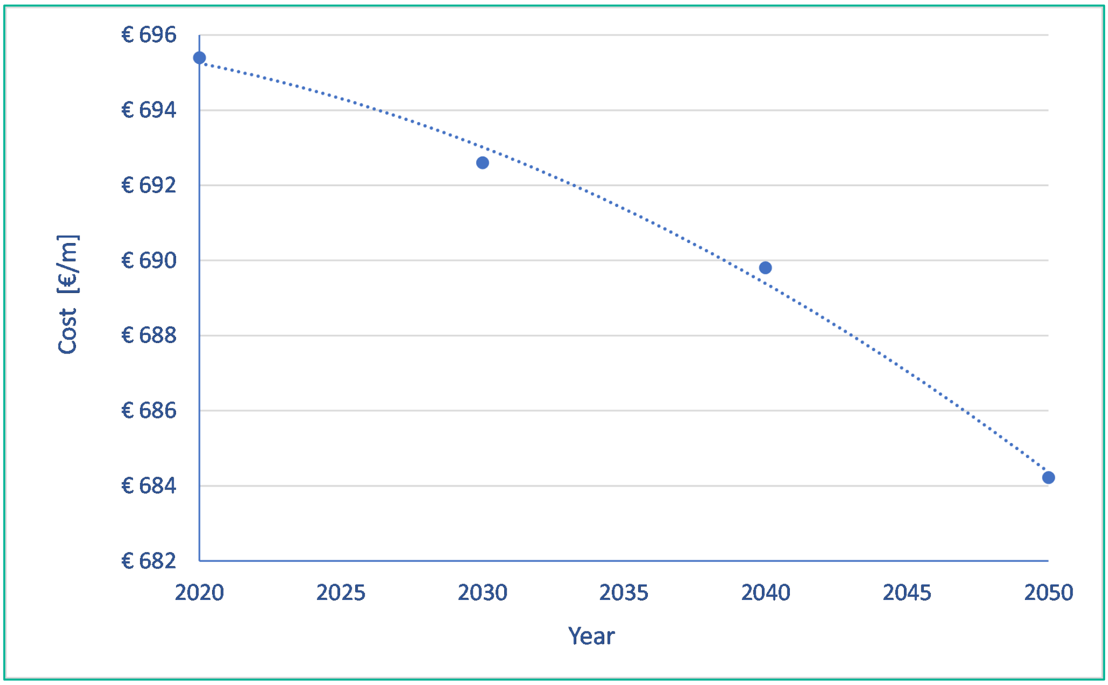

Figure 4: Cost projection for 20 mm 2-pipe DH for Ireland in an inner-city location from 2020 to 2050

2.3 Comparison with stakeholder data

We used the stakeholder data to verify the cost database. We noted that costs align well with differences of 4-13% for smaller diameters (<100mm) and up to 5% for larger diameters. This gives confidence in the data collected for modelling.

3 Heat generation technologies

In developing the DH model referred to in Section 1 and detailed in Section 4, we explored the following technology options for providing heat to the networks:

- Option 1 – Heat extraction from power stations and industrial waste heat recovery (including data centres)
- Option 2 – Biomass boiler
- Option 3 – Biomass CHP with biomass boiler back-up
- Option 4 – Air source heat pump (ASHP)
- Option 5 – Ground source heat pump (GSHP)
- Option 6 – Low-carbon gas CHP
- Option 7 – Geothermal at depths up to 400 m

Regarding Option 7, our analysis shows that there is significant uncertainty with geothermal at depths below 400 m due to a lack of a geothermal suitability framework for these depths. We discuss this issue in more detail at the end of Section 3. The focus for this report is thus on geothermal potential for depths up to 400 m. Note, however, that using geothermal for district heating at depths up to 400 m would require heat pump technology so is being considered under Option 5. Therefore, we drop Option 7 from the technologies list in Sections 4 and 5. For further analysis on the potential of geothermal energy at depth, a suitability framework below 400 m is required to assess geothermal potential at SA level.

3.1 Option 1 – Heat extraction from power stations and industrial waste heat recovery

3.1.1 Overview

This section summarises the heat extraction (from power plants) and waste heat potential (from industrial sites) for Ireland. Waste heat recovery from data centres is also analysed and discussed later in this section. The slide deck accompanying this report (Appendix C) provides a detailed description of the assumptions and methodology employed in estimating potential.

Out of an initial 67 industrial sites and power stations, those deemed suitable for waste heat extraction and recovery are in *Table 1*. The criterion for shortlisting is the site exceeds the fuel input threshold defined by the EU methodology as described below ‐ 20 MWth for industrial sites and 50 MWth for power stations [7]. Note that we only considered existing power stations and industrial sites in this analysis.

Table 1: Sites evaluated for heat extraction and recovery potential

Sector	No. sites suitable for waste heat recovery	Comment on heat extraction from power plants / waste heat from industrial sites
Power station	6*	Power plants and incinerators aim to maximise power generation with heat exiting the process at around 30 °C. In converting the power station to a CHP mode, low grade heat* (60-80 °C for 4th generation heat networks) suitable for DH can be recovered. Peaking plants and closing plants are excluded from the assessment.
Waste incineration	2	
Alumina	0**	For industrial sites, where there was a waste heat recovery opportunity, we assumed the grade of heat is based on the process itself and the grade of heat that is available. For some sites, such as food and drink, the heat available is low grade (40-250 °C), whilst for other sites, such as cement, it may be medium (250-500 °C). Due to lack of data on waste heat available from industrial sites in Ireland, waste heat was estimated based on UK data, utilising benchmarks from well-established previous work in the UK. These benchmarks were then applied to Irish data to estimate the waste heat available from various industrial sectors.
Cement	4	
Magnesia	1	
Refinery	1	
Chemicals	0	
Ceramics	0	
Food & drink	10	
Pharmaceutical	1	
Total	26	

* In total, 16 power stations met the 50 MWth threshold, but we excluded 10 e.g. due to closures - further details below.
** Whilst the one alumina site in Ireland met the threshold, we excluded it because the site already operates a CHP.

3.1.2 Heat extraction from power plants

Annex I, Paragraph 2.2 of Commission Recommendation (EU) 2019/1659 on the EU methodology for estimating waste heat [7] highlights power stations which can supply or can undergo a retrofit to supply waste heat with a total thermal input exceeding 50 MWth. We initially considered 16 power stations under this category.

We based our analysis of the potential waste heat available for DH from power plants on available Irish data. Noteworthy is that power stations and waste incineration with pass-out steam turbines extract heat at the relevant temperature for DH (60-80 °C for 4th generation heating networks). On the other hand, we assumed the grade of heat for industrial sites with waste heat opportunity is based on the process itself and the grade of heat that is available. Hence, the cost of recovering heat from a refinery differs from a cement site, which differs from a data centre, etc.

Table 2 shows our assumptions used in estimating the heat extraction potential from power plants.

Table 2: Assumptions used in estimating waste heat potential from power stations in Ireland

Parameter	Assumption	Description
Overall efficiency	80% for combined cycle gas turbines (CCGT) and pass-out / condensing steam turbine; 75% for open cycle gas turbine (OCGT)	This assumes CHP achieves high-efficiency CHP (HECHP) status. According to Annex I of the EED [7], this requires overall efficiency of 80% for CCGT and pass-out steam turbines and 75% for all other CHP technologies. The overall efficiency for power stations (electrical & heat) to convert to CHP was assumed to be 80% for CCGT and pass-out (i.e. condensing) steam turbines, whilst 75% used for OCGT power stations. The overall efficiency assumption is based on Annex I of the EED for cogeneration plants [7]. This cap on overall efficiency allows for the estimation of heat which can be extracted from a power station should it be converted to CHP mode.
Load factor	65%	We derived the load factor of 65% based on EirGrid data fromAll-Island Generation Capacity Statement 2019-2028 [12].
Z ratio	8	We chose a Z ratio of 8 assuming that sites will tend to maximise their heat extraction to feed into the DH network. This means sites will operate in a non-condensing/ maximum heat mode. For CCGT and steam turbines prime movers, we assumed the Z ratio equal to 8. This assumption means that the power stations, for which the waste heat is to be established, maximise their heat extraction. The waste heat determined in this way is the maximum waste heat potential. The previous NCA for Ireland study used a ratio of ~6.3. However, we believe that a Z ratio of 8 is more reasonable based on typical data of Z ratio vs. steam export pressure (Bar_a, for feeding into DH) for different capacities of steam turbines [13].

Figure 5 depicts the methodology for calculating waste heat potential from power plants. Economic Consulting Associates provided the fundamental dataset comprising power station name and type (CCGT, condensing steam turbine, OCGT), fuel type, maximum electrical capacity and hourly heat input (GJ/h) [14]. We assumed overall efficiency, Z ratio and load factor in order to estimate the thermal capacity and waste heat available.

We excluded power stations that are expected to cease operation by 2025, peaking plants or those with low operating hours from the analysis. Out of an initial 16 power stations, this left six suitable. Four plants had a heat extraction potential in the range 150-300 MWth and two plants were in the 300-400 MWth range. The total heat extraction potential for all six power stations is 1,570 MWth.

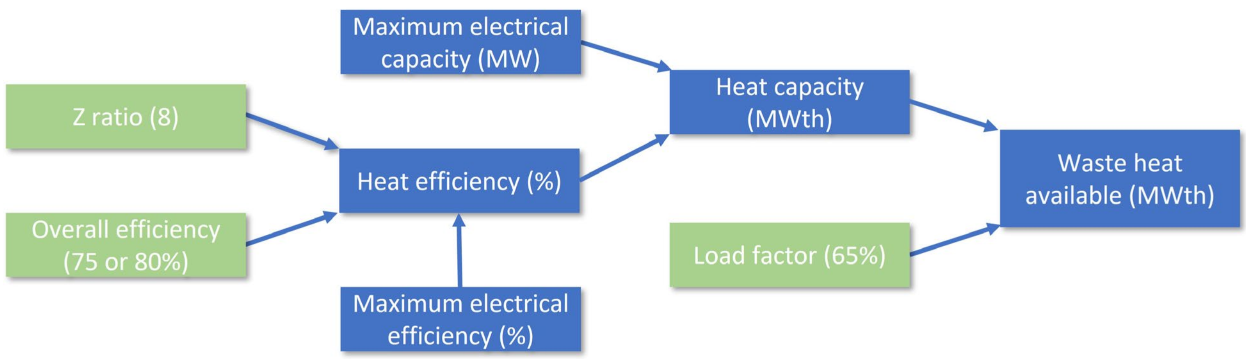

Figure 5: Waste heat from power station estimation methodology

3.1.3 Heat and power cogeneration

There are 315 CHP installations in Ireland, most of which consume natural gas. Services, such as airports and hospitals, make up 262 of these, whilst the rest (53 sites) are installed in industry. Of all these systems, the CHP at Aughinish Alumina is the only substantial producer of energy [15]. The Aughinish Alumina site uses large quantities of process heat to generate alumina and is already optimised to produce the heat needed for the site with no excess waste heat available for extraction.

3.1.4 Waste incineration plants

According to Annex I, Paragraph 2.2 of Commission Recommendation (EU) 2019/1659 [7], to be considered, energy from waste (EfW) sites must have a fuel input exceeding 20 MWth. We identified two EfW sites – one in Meath (operated by Indaver) and a second in Dublin (operated by Covanta). Based on a range of sources and assumptions (see Appendix C), we estimate the Meath site has a waste heat potential of 14 MWth and the Dublin EfW site a potential of 35 MWth.

3.1.5 Renewable energy installations

According to EU ETS data, there are several sites in Ireland that consume a mix of renewables and fossil fuels. However, none of these sites are solely renewable, and hence we consider them in the following section.

Of the 315 CHP installations in Ireland, there are two biomass and 20 biogas CHP sites. These are all small installations not achieving the threshold of 20 MW fuel input, therefore we excluded these from evaluation.

3.1.6 Heat recovery from industrial sites

Whilst the method for assessing heat recovery from power stations is well established, there is no such set of steps for industrial sites. We used an ETS dataset detailing the fuel consumption of the largest industrial fuel consumers in Ireland as the basis for estimating waste heat potential from industrial sites.

We grouped sites into the following major sectors: metal, cement, refining, wood products, other minerals, food and drink, lime, chemicals (including pharmaceutical) and other industry. It was possible to estimate the waste heat potential for industrial sites in Ireland from the fuel consumption of each site (given by ETS dataset) and utilising modelling undertaken by Element Energy on the potential for heat recovery from different industries [16]. We used the Element Energy UK modelling data to develop best-fit line relationships between waste heat recovery (MWh) and fuel consumption for various industries. We found a series of linear relationships (for cement, chemicals, refineries, and food and drink) to be the best line fit for the data available. To determine waste heat recovery potential, we applied these linear relationships to the ETS fuel consumption data available for Irish sites. However, UK data were not available for the pharmaceutical and lime production sectors. We estimated waste heat potential for the pharmaceutical sites in Ireland using the chemical sector linear relationship. For lime production, we derived waste heat potential based on the UK Steetly Dolomite lime producer in Thrislington, who recovers waste heat to generate 3,000 MWh of electricity per year [17].

3.1.7 Data centres

Data centres typically comprise racks of IT equipment arranged in rows. The electrical energy supplied to this IT equipment generates heat, which requires extracting from the system. The operation and safety of the system is at risk if IT equipment becomes too hot. Heat is usually extracted from this system using air [18]. The exhaust air is low grade heat, 35-45 °C, and hence the heat is often discharged into the atmosphere [19]. However, this heat can be recovered and transferred to a hot water stream using a heat exchanger for use in a DH network. This stream can be upgraded using a heat pump to obtain water temperatures more suitable for DH.

Waste heat recovery from data centres is not a well-established practice, and hence literature surrounding the topic is limited. Two important cases studies come from data centres in Stockholm, Bahnhof Thule and Bahnhof Pionen. Both sites extract waste heat from the system using a series of heat exchangers and supply it to a local DH scheme. These systems can recover 1.6 MWth (~14,000 MWh) and 0.6 MWth (~5,300 MWh) of heat, respectively [20].

The Energy Recovery Factor (ERF) is used to quantify the ratio between reused heat and all the energy consumed by the data centre, as shown in *Equation 1*. ERF typically ranges from 25% to 55%. To not overestimate the waste heat potential, we used an ERF value of 25% [18].

Equation 1:

$$\mathrm{ERF} = \frac{Reused\ Heat}{Total\ Energy\ Consumed\ by\ the\ Data\ Centre}$$

We assessed the electricity consumption of data centres as described in the *Heating and Cooling in Ireland Today*[8] report and found they consume 2,900 GWh of electricity each year. Combined with an ERF of 25%, there is the potential to recover 725 GWh (83 MWth) of waste heat from centres in Ireland. A review of several sources on data centres indicates there are currently 24 data centres across Ireland, most of which are based in Dublin [21]. However, there is a lack of public information regarding the size of each site, so we evenly distributed the total heat potential across all 24 centres. This method yields a heat potential of 30 GWh/year/site (3.5 MWth). Out of the 24 centres, we excluded four as they did not have publicly disclosed locations. We paired the remaining 20 centres with an SA for use within the DH model. Analysis only considered existing data centres.[9]

3.1.8 Other low-temperature waste heat sources

Annex I, Paragraph 2.2 of Commission Recommendation (EU) 2019/1659 does not provide guidance or recommendation on low-temperature waste heat sources (e.g. hospitals, bakeries, airports). Within the Irish data available, there were several non-industrial sites, but with very little literature regarding waste heat recovery for these kinds of facilities, it is difficult to make an accurate evaluation of waste heat potential. Furthermore, we expect the potential for waste heat recovery from these sites will be low.

For example, a 2019 study investigated two hospitals in Poland that recovered waste heat from grey water (via heat exchangers) to warm water for use on wards etc. On average, around 700 kWh of energy could be recovered per bed over a year [22]. An example of a high-consuming Irish hospital is University College Hospital Galway, which has approximately 698 beds [23]. Hence, we estimate that University College hospital Galway could recover 1.7 TJ/year (0.05 MWth). This quantity of waste heat recovery is considerably smaller than that calculated for power stations and industrial sites.

There most certainly is value in implanting heat recovery systems on a case-by-case basis at non-industrial sites but, given the relatively small quantities of heat energy they yield when compared to power stations and industrial sites, they fall outside the scope of this project.

3.1.9 Waste cold sources

Limited data are available on the sources of waste cold in Ireland and so analysis only considered potential for liquefied natural gas (LNG) terminals, which are likely to be a comparatively major source. However, at the time of writing this report, Ireland has no LNG terminals [24] [25].[10] Furthermore, as highlighted above in Section 1 and detailed in the *Heating and Cooling in Ireland Today* report, there is very little demand for cooling throughout Ireland. Also, due to lack of cost data on district cooling schemes, we have not considered district cooling within the model.

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[8] SEAI, 'Heating and Cooling in Ireland Today: Archetype Proles, Spatial Analysis, and Energy Efficiency Potential'. 2022 [Online]. Available: www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

[9] Since this analysis was performed, Host in Ireland released 'Ireland's Data Hosting Industry', a report in which 70 data centres are stated to be in operation throughout Ireland (65 in Dublin). However, the exact geographical location of these 70 data centres is not stated and hence they cannot be incorporated into the modelling work performed. It is expected that the 24 data centres considered in this analysis represent the most sizable data centres that were operational pre-2021. Therefore, whilst future modelling work should aim to locate and utilise all 70 data centres, this work provides a strong first analysis for the heat recovery potential of data centres in Ireland.

[10] The US company New Fortress Energy has planning permission to construct an LNG terminal called 'Shannon LNG' in Kerry. However, due to legal disputes, it is still uncertain at the time the report was written, as to whether this project will go ahead. If in future this site is built, then at that point an analysis of potential waste cold recovery should be performed based on specific site data.

3.1.10 Total heat extraction and waste heat potential

As described in previous sections, there are six power stations, two EfW facilities and 17 industrial sites that meet the EED-defined fuel input thresholds and are suitable for waste heat recovery, as shown in *Table 3*.

Table 3: Total heat potential

Installation name*	Type	Fuel input [MW]	Heat extraction / Heat recovery potential [MWth]
PS-1	Power Station	810	267
PS-2	Power Station	810	210
PS-3	Power Station	1,270	377
PS-4	Power Station	1,623	342
PS-5	Power Station	754	187
PS-6	Power Station	763	189
EfW-1	Energy from Waste	77	14
EfW-2	Energy from Waste	192	35
Ind-1	Refinery	173	67
Ind-2	Food & Drink	50	11
Ind-3	Food & Drink	34	7
Ind-4	Food & Drink	45	10
Ind-5	Food & Drink	54	11
Ind-6	Food & Drink	21	5
Ind-7	Food & Drink	40	8
Ind-8	Food & Drink	27	6
Ind-9	Food & Drink	31	7
Ind-10	Food & Drink	21	5
Ind-11	Food & Drink	35	7
Ind-12	Pharmaceutical	22	3
Ind-13	Cement	83	9
Ind-14	Cement	150	16
Ind-15	Cement	64	7
Ind-16	Cement	104	11

Installation name*	Type	Fuel input [MW]	Heat extraction / Heat recovery potential [MWth]
Ind-17	Magnesia	36	2

*In the interest of confidentiality, site names have been removed.

The total waste heat potential equates to 1,813 MWth. We based the estimates and assumptions for the six power stations on a well-established methodology; whilst for the two EfW sites and the 17 industrial sites, a less established methodology has been followed. As the heat recovery potential is mostly from power stations (86.7%), we are highly confident of the potential reported here.

The estimation of waste heat potential from the industrial sites has higher uncertainty. However, because the industrial sites show less of a potential for waste heat recovery, they are less likely to be selected for development. Ideally, waste heat analysis for industrial sites would include individual site surveys to evaluate the system and potential for waste heat recovery. As highlighted in the *Carbon Capture, Utilisation and Storage (CCUS)*[11] report, many of these sites may be candidates for carbon capture and storage (CCS) and potential for waste heat recovery will diminish further depending on which sites are selected for CCS. Note that the assessment of the total waste heat potential here assumed that, for sites where CCS is proposed, this will be satisfied through additional fuel consumption rather than by using a proportion or all of the waste heat available. As such, the amount of waste heat estimated above is independent of whether CO_2 capture is installed.

As mentioned previously, 20 data centres that have the potential for waste heat extraction were also located. Due to an inability to size the heat potential for each site, we assumed every centre has an equal waste heat potential (3.5 MWth). This is a notable limitation of the work and future efforts should aim to address this once there is greater public availability to Irish data centre operational information. However, since these data centres show considerably less potential than the power stations and industrial sites, it is less likely that they will be selected for development.

Figure 6 shows sites deemed suitable for heat extraction from power stations or waste heat recovery from industrial sites in Ireland. This map also presents the locations of 20 data centres that could be used for waste heat recovery, as well as the locations of existing and proposed DH schemes. This shows opportunities for future utilisation of waste heat, as well as heat extracted from power stations and EfW plants, into existing and future DH networks. Since several sites are in Dublin, *Figure 7* shows an enlarged map of Dublin.

[11] SEAI, 'Carbon Capture, Utilisation and Storage: Suitability, Costs and Deployment Options in Ireland'. 2022 [Online]. Available: www.seai.ie/publications/Carbon-Capture-Utilisation_and-Storage.pdf

Figure 6: Heat extraction/recovery sites and district heating sites in Ireland

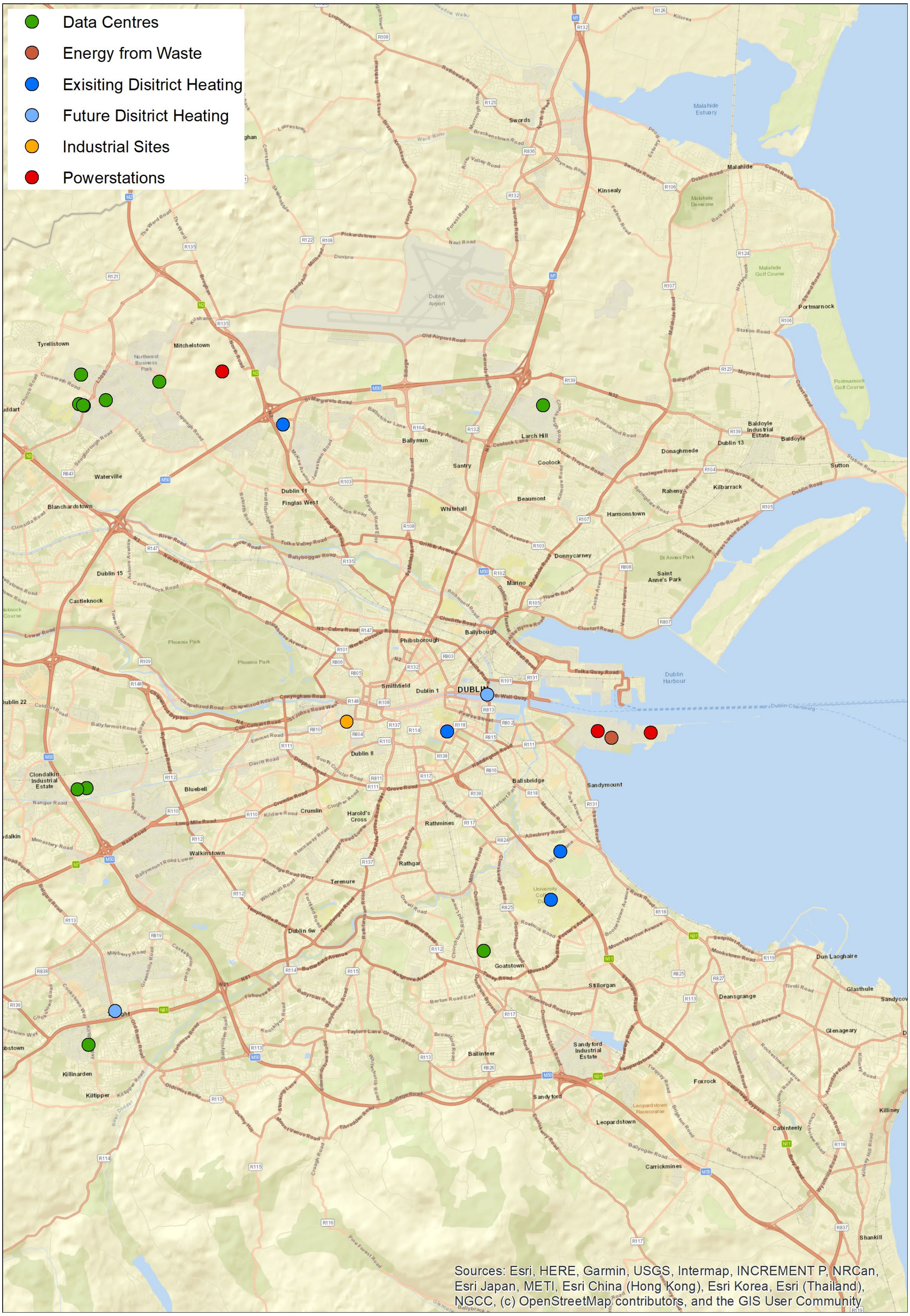

Figure 7: Heat extraction/recovery sites and district heating sites in Dublin

3.1.11 Cost of heat extraction and recovery

For existing power stations and EfW plants switching to CHP mode, a new investment will be required in steam turbine replacement (i.e. replacement of condensing steam turbine used to maximise power output with a pass-out (or extraction) steam turbine). For the model, we estimated this additional capital cost using Equation 2, plotted in *Figure 8* [26].

Equation 2:

$$\text{Capital Cost } [€/MW_e] = \text{A} \cdot \text{MW}_\text{e}{}^{n}$$

Where A and n are fitting parameters, and MW_e is the electrical capacity of the plant.

We assume the non-fuel operating cost of extracting heat from power stations to be negligible. Note, the cost of retrofitting a steam turbine is much greater than OCGT and CCGT because it requires the complete replacement of the turbine.

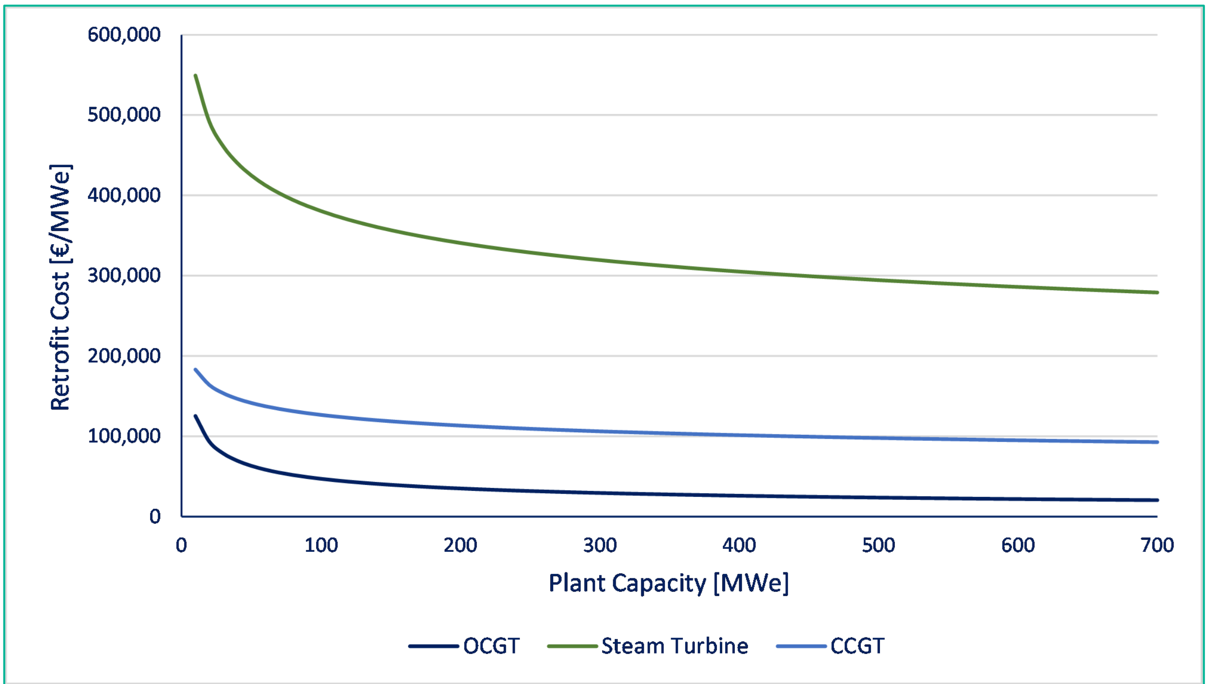

Figure 8: Cost of retrofitting prime movers to facilitate CHP

These costs will not exist for new power stations designed for heat extraction from the outset, so sites will be designed with an extraction steam turbine in place.

The cost of waste heat recovery from industrial sites varies depending on the sector, capex and opex. *Table 4* shows the sectors identified as having a waste heat potential and their respective costs.

Table 4: Cost of waste heat recovery from industrial sectors

Industrial sector	Capex [€/MWth]	Opex [€/year/MWth]
Refinery	2,152,970	22,864
Food & drink	6,334,609	64,415
Pharmaceutical	6,012,730	87,673
Cement/Magnesia	241,289	12,672

It is challenging to model the cost of connecting a datacentre to a DH network as it not common for such data centres to extract waste heat. We estimate the capital cost for recovering waste heat from small data centres to be €115,000 [27], equivalent to €70,000/MWth. We used a connection cost of €50,000 to 250,000 per datacentre with all costs inflated to 2019 and converted to Euros.

3.2 Option 2 – Biomass boiler

We consider a biomass boiler as one of the supply options for the DH network. We based performance and cost data in *Table 5* for a woodchip biomass boiler on the *Low Carbon Heating and Cooling Technologies*[12] report prepared as part of the present National Heat Study. We assume a technical lifetime of 25 years. Note that all operating costs presented in this section exclude fuel cost.

Table 5: Woodchip biomass boiler data

Fuel	Minimum size [kW]	Variable capex [€/kW$_{th}$]	Variable opex [€/kW$_{th}$/year]	Thermal efficiency
Wood chip	50	713.8	25.8	83%
	100	665.9	24.3	83%
	150	384.6	15.5	83%
	1000	329.4	13.8	84%

3.3 Option 3 – Biomass CHP with biomass boiler back-up

We also considered a biomass CHP as a supply option. We based performance and cost data in *Table 6* on *Low Carbon Heating and Cooling Technologies* report prepared as part of the present National Heat Study. Once again, we selected wood chip as the fuel. We sized and costed the back-up biomass boiler using the data in *Table 6*. CHP units typically cost more than boilers, but they also give the operator the option of generating and selling electricity. The literature review of existing DH schemes found both technologies are currently being utilised in Ireland.

Table 6: Woodchip biomass CHP data

Fuel	Minimum size [kW]	Variable capex [€/kW$_{th}$]	Variable opex [€/kW$_{th}$/year]	Thermal efficiency*
Wood chip	50	3304	132	50%
	100	3270	131	50%
	150	2977	120	50%
	1000	2552	105	50%

*The total efficiency of the CHP unit is the sum of the thermal efficiency and the power efficiency.

[12] SEAI, 'Low Carbon Heating and Cooling Technologies: Options, Costs, Performance, and Suitability'. 2022 [Online]. Available: www.seai.ie/publications/Low-Carbon-Heating-and-Cooling-Technologies.pdf

3.4 Option 4 – Air source heat pump

We considered an air source heat pump (ASHP) as a source of heat. *Table 7* shows the data for an ASHP feeding into district heating as used in the modelling described in the *Net Zero by 2050* report which was prepared as part of the present National Heat Study.

Table 7: ASHP data

Source	Minimum size [kW]	Variable capex [€/kW_{th}]	Variable opex [€/kW_{th}/year]	Thermal efficiency
Electricity	50	797	7	270%
	100	712	3	270%
	200	667	1.4	270%
	300	615	0.3	270%
	500	550	0.3	270%
	1000	492	0.3	270%

3.5 Option 5 – Ground source heat pump

As well as ASHPs, we also considered ground source heat pumps (GSHP) as a technology option within the model.[13] GSHPs are typically more expensive to install but offer a greater efficiency.

Table 8 shows the data for a GSHP feeding into district heating as used in the modelling described in the report *Net Zero by 2050* which was prepared as part of the present National Heat Study.

Table 8: GSHP data

Source	Minimum size [kW]	Variable capex [€/kW_{th}]	Variable opex [€/kW_{th}/year]	Thermal efficiency
Electricity	50	1891	4	510%
	100	1700	2	510%
	200	1597	1.4	510%
	300	1476	0.5	510%
	500	1327	0.5	510%
	1000	1192	0.5	510%

[13] The inclusion of GSHPs within heat networks has been facilitated within the full body of work as an option to inform the modelling and costings. Data from Geothermal Energy Use, Country Update for Ireland ECG 2019 [28] (indicate approximately 200 MWth was produced, in Ireland, by GSHPs in 2018 via just over 18,000 units with 85% being in residential, 14% in commercial and 4% industrial properties.

3.6 Option 6 – Low-carbon gas CHP with gas boiler back-up

We have also considered low-carbon gas CHP, again with a back-up gas boiler. The cost and performance data shown in *Table 9* is for a low-carbon gas CHP, based on the *Low Carbon Heating and Cooling Technologies* report prepared as part of the present National Heat Study.

Table 9: Low-carbon gas CHP data

Fuel	Minimum size [kW]	Variable capex [€/kW_{th}]	Variable opex [€/kW_{th}/year]	Thermal efficiency
Low-carbon gas	50	1301	52.052	52%
	100	1301	52.052	52%
	150	1301	52.052	52%
	1000	1301	52.052	52%

3.7 Option 7 - Geothermal energy potential as a heat source for depths up to 400 m

Geothermal potential is estimated by identifying the heat present at depths, that, when extracted to the surface, can provide useful heat either directly (if temperatures are high enough to provide useful heat) or with a heat pump if required. There are currently no geothermal DH schemes in Ireland; however, there is the potential for geothermal DH to be developed. There is a large amount of research and revision underway. For example, a recent study by GSI [4] indicates temperatures from 2000 m are expected to be higher than previously estimated [29] [30]. The accompanying slide deck on geothermal (Appendix D) includes a list of some of the recent Irish geothermal research.

GSI hosts maps for shallow geothermal that provide a framework for geological suitability, by location, but only to depths of 400 m [31] [32]. In the absence of suitability data for depths below 400 m, this study cannot quantify the potential for geothermal energy below this level. This is a significant limitation of this work. During the stakeholder consultation, the need to expand the suitability assessment to greater depths has been identified and work is underway to address it.

The assessment of ground temperature in Ireland has identified that depths of up to 400 m have estimated temperatures below 26 °C [33]. For the vast majority of geothermal applications, this requires a GSHP. Work is underway globally to use innovative technologies to utilise lower temperatures for direct heat. However, for this study, we have assumed that, due to the low-temperature estimates, heat from geothermal sources below 400 m is covered by the analysis of ground source heat pump technology, described under Option 5 above.

In conclusion, geothermal energy is an area where there is much current research, both on innovative heat extraction technologies and to better characterise the underlying geology. Further work aimed at the complete characterisation of the suitability of the geothermal resource across Ireland will allow a better understanding of its potential for district heating at various locations.

4 District heating modelling

As highlighted in previous sections, we developed a computational DH model for estimating capital and operating costs to analyse which areas in Ireland showed the most favourable capital investment.

In the model, we assume one centralised heat generation plant provides the domestic, commercial and public heat demand for each small area. This heat is then provided to every domestic, commercial and public property in each SA. In reality, not every property within an SA will be connected to a DH network; however, this model provides a national level analysis of which SAs in Ireland show the most favourable capital investment for DH and will integrate with NEMF modelling to assess areas where DH is most feasible.

The profile and characteristics of heat demand at an SA resolution in Ireland are key inputs to this model.[14] We paired the domestic, commercial and public heat demand for all 18,641 SAs in Ireland with our DH model. Pairing in this way allowed us to model the capital and operating cost of implementing a DH network for each SA.

The model includes four key costs: the generating technologies, thermal storage, the pipe network, and the connection of consumers to the network. Within the model, we explore the seven technology options detailed in Section 3. Note, Option 7 – Geothermal has now been removed, as discussed in Section 3.

4.1 Methodology

This section summarises the model developed. The model integrates the data in Sections 2 and 3 with SA data, spatial thermal demand across all SAs and hourly profile data for the technologies evaluated to map DH potential across all SAs in Ireland. Waste heat potential, geothermal potential (up to 400 m depth) and potential for heat recovery from datacentres are also mapped, as well as the existing DH infrastructure. This model serves as input to the NEMF to undertake the scenario modelling described in the *Net Zero by 2050* report.

4.1.1 Input data at a small area resolution

We obtained a basic set of data of 18,641 SAs, which were created by the National Institute of Regional and Spatial Analysis (NIRSA) on behalf of the Ordnance Survey Ireland (OSI). The SA database comprises a small area ID, county name and area (km^2). In addition, we obtained road lengths (km) for each of the SAs from the existing SEAI 2015 heat map.

4.1.2 Total heat demand and estimated heat densities by small area

The *Heating and Cooling in Ireland Today* report describes the detailed methodology for the spatial mapping of the residential, commercial and public heat demand. This data provided the input heat demand data for the model.

The first task involved estimating the total heat demand per SA (MWh/year). This is equal to the sum of water heating and spacing heating demand for the domestic, commercial and public sectors, see *Equation 3*.

Equation 3:

$$Small\ Area\ Heat\ Demand\ \left[\frac{MWh}{year}\right] = \left(\frac{1}{(1-\mathrm{HNL})}\right)\cdot(Domestic\ Demand + Commercial\ Demand + Public\ Demand)$$

Where HNL is the heat network losses (%) used to describe the quantity of heat that is lost to the environment while the water is being transported from the energy centre to the consumer. Note, the term ‘energy centre’ is

[14] Detailed analysis of the heat demand in Ireland was carried out as part of the National Heat Study and is described in the *Heating and Cooling in Ireland Today* report. Available from: www.seai.ie/publications/Heating-and-Cooling-in-Ireland-Today.pdf

used to describe the physical location where the heat is generated before distribution. Often, the generating technology and thermal storage are both positioned in the energy centre. The Heat Networks: Code of Practice for the UK states 'it is best practise for network heat losses to not exceed 10% of the annual consumption' [10]. A heat loss of 10% is used to account for heat losses from both the piping and the thermal storage vessel.

The model excluded industrial heat demand (hot water and space heating) as we have assumed it is not suitable for supply via DH. The temperatures required for industrial processes are much greater than for domestic use.

The pipework cost can be a significant proportion of the overall capital. Hence, accurate modelling of this component is important. We have assumed that the total heat network length equalled the total length of road in each SA, as this is the path the DH pipes would follow. This assumption means that every domestic, commercial and public property within each SA connects to the heat network. Whilst in reality, not every single road will be connected to a heat network, this approach estimates the maximum potential of DH deployment and we consider it to be the most appropriate method to evaluate each of the SAs for such high-level modelling. This is a commonly used assumption for modelling the cost of DH [5] [26]. However, this technique risks over inflating the connection and pipework costs per SA, but the risk becomes less important for SAs with a large heat density, as these locations could feasibly see every property connected to the network. This is important because high-density SAs are most likely to be selected for DH development.

An important variable when assessing the potential for DH in an SA is heat density. Heat densities can be calculated in several ways. Our model considered two types of heat density. Firstly, it calculated the linear heat density by dividing the total heat demand by the road length in each SA [MWh/km]. Secondly, it calculated an area-based heat density by dividing the heat demand by the land area of each SA [MWh/km^2].

4.1.3 Sizing the generating capacity and the thermal store capacity

When designing a system for supplying heat to an area, it is preferable to add thermal storage. By adding a vessel to store hot water, the capacity of the generating plant can be reduced, which usually reduces the overall capital cost.

The profile and characteristics of heat demand at an SA resolution in Ireland developed in the *Heating and Cooling in Ireland Today* report gave the heat demand per hour for the residential, commercial and public sectors. To incorporate thermal storage into the model, we used this data to develop flattened heat profiles for all 365 days and for all 18,641 SAs.

For an example of the profiles with thermal storage, see *Figure 9*. In the original profile, the heat demand oscillates throughout the day. The average hourly demand is 0.09 MWh (average 0.09 MW) and the maximum hourly demand is 0.125 MWh (average 0.125 MW during this peak hour). Without thermal storage, the generating plant would need to be sized at 0.125 MW based on average demand in the peak hour (or possibly more if monitoring demand at shorter time intervals). In the flattened profile, the plant operates for 24 hours at a constant output of 0.09 MW. So, a smaller 0.09 MW plant could meet the daily heat consumption. The area under the curve of both profiles is equal, and therefore both profiles deliver the same quantity of heat to the consumer. To create the flattened profile, the energy capacity of the thermal storage must be equal to the total area of the original profile, which is above the 0.09 MW average, as shown in orange on *Figure 10*.

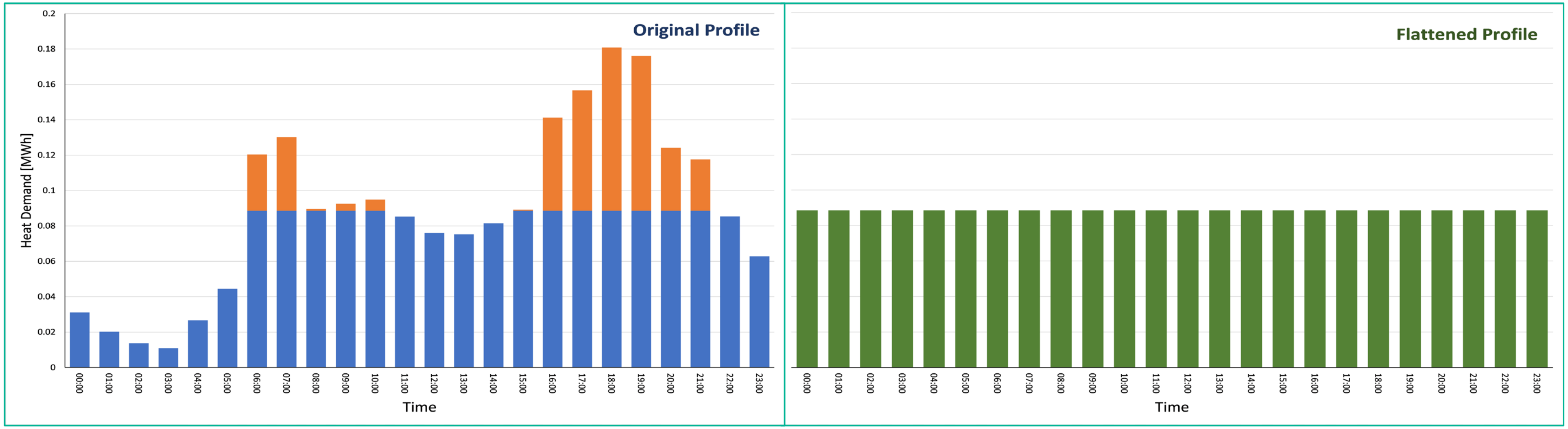

Figure 9: Original vs. flattened heat profiles (SA: 268096005 – 04/02/21 coldest day)

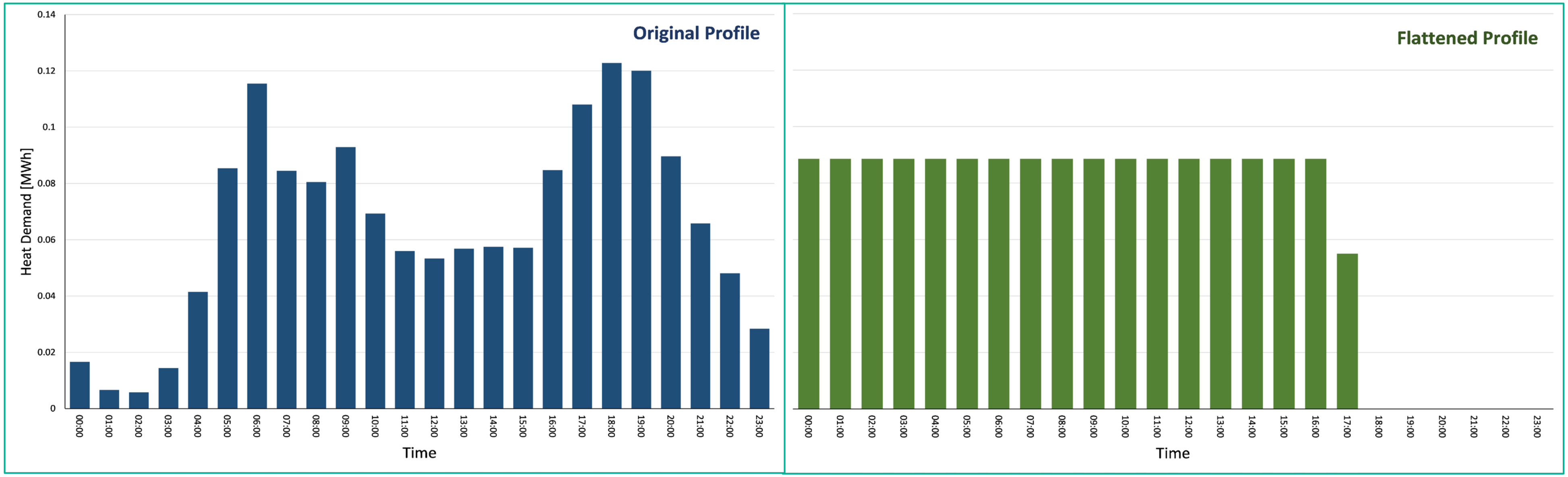

Figure 10: Original vs. flattened heat profiles (SA: 268096005 – 14/04/21)

On a warmer day, the plant would still operate at the rated output of 0.09 MW but only for 17.5 hours filling the thermal store, and then would turn off around 17:30 (*Figure 10*). Again, the area under the curve of both profiles is equal, and therefore both profiles deliver the same quantity of heat to the consumer.

For each SA, the model calculated the generating capacity and thermal store capacity based on the coldest day of operation in this way. Appendix B details the methodology and equations used in the model.

4.2 District heating system costs

There are four cost elements to consider when evaluating a DH network:

1. DH pipe network
2. Generating technology
3. Thermal storage
4. Connection of consumers to the network

4.2.1 Pipe network cost

A DH pipe network has a shrinking branch structure, with the largest pipes closest to the energy centre. As the network spreads to each consumer, the number of pipes increases, but the diameter of each becomes smaller. An exact pipeline structure is specific to each network and requires greater detail than available for this modelling. As an estimate, the model halved the generating capacity (MW) as calculated above, and determined a representative pipe diameter (mm) based on the pipework database developed in Section 2 (see also Appendix B). The model then calculated pipeline costs using the same data. This is a commonly used method for assessing network pipe cost for modelling [26]. It is a conservative method, but it ensures the system always meets heat demand, which is a high priority.

The model then multiplied the pipeline cost (€/m) by the total road length (km) in each SA to calculate the cost of purchasing and constructing the pipe network (€). Where the SA existed within a city, the model used an increased pipe cost to account for the increased trenching cost in inner-city areas, as explained in Section 2.

4.2.2 Generation technology cost

As outlined in Section 3, we have considered several generating options to feed into the heat network.

Option 1 – Heat extraction from power stations and industrial waste heat recovery

The model evaluated the cost of extracting waste heat from power stations and industrial sites using the data presented in Section 3. For power stations, it scaled the cost based on the electrical capacity of the plant, whereas it based industrial site cost based on the quantity of heat extracted. The waste heat potential from each of these sites is larger than the demand of any SA. Where two sites exist in one SA, the model prioritised power stations as they have a greater heat potential.

We modelled the cost of connecting a data centre to the heating network on an estimated €70,000/MWth, as described in Section 3. Where multiple data centres existed within one SA, data centres were connected until they met demand.

Option 2 – Biomass boiler

We specified renewable woodchip as the fuel for the boilers. Costs in €/kW vs. boiler size data determined the boiler costs, as shown by *Table 5* in Section 3. Looking up the correct thermal efficiency for a given size of boiler from the technology database, the model also estimated biomass fuel input (MWh/y) for use into the NEMF for scenario modelling.

Options 3 and 6 – Biomass CHP and low-carbon gas CHP

Option 3 assumes woodchip CHP (steam turbine) provides 75% of DH heat with a back-up biomass boiler providing the rest. We assumed a typical fixed CHP load factor of 64% based on 16-17 hours/day operation. The model calculated CHP and boiler costs based on costs in €/kW vs. CHP or boiler size data, as shown in *Table 5* and *Table 6* in Section 3. The total capital cost for Option 3 is the total boiler and CHP costs.

In Option 6, we considered low carbon CHP, but the model costs the generating technology using the same methodology as for Option 3.

Options 4 and 5 – ASHP and GSHP

The model estimated the total capacity of a single HP from the total capacity of heat supply. It estimated electricity consumption on a Coefficient of Performance (COP) of 2.7 for ASHP and 5.1 for GSHP (similar for the sizes evaluated) [34]. We undertook a more detailed analysis of DH including electricity consumption and costs as part of the *Net Zero by 2050* report. The model determined heat pump costs on costs in €/kW vs. HP size data, as shown in *Table 7* and *Table 8* in Section 3.

4.2.3 Thermal storage cost

As previously discussed, the model sized the thermal store capacity for each SA [MWh] while flattening the heat profiles. It took thermal store capital cost data from Assessment of the Costs, Performance, and Characteristics of UK Heat Networks, inflated to 2019 and converted to Euros [35].[15]

4.2.4 Connection costs (consumer property installation costs)

In order to connect the consumer to the DH network, there are three additional costs to consider: the heat interface unit (HIU), the heat meter and control system, and installation of pipe to connect that particular property to the overall network. The HIU allows energy to be taken out of the network and transferred into the consumer's property, for example this could be a heat exchanger. Costs vary depending on whether the consumer has a domestic or non-domestic property.

Domestic property

The residential dwelling size varies with building type, so we took an average figure that covers the combined cost of the HIU, heat meter and piping (€/dwelling). Hence, the model calculated the total cost of connecting every residential property in an SA by using this figure in combination with the number of residential properties in that SA as obtained from the building stock database. The model took this cost data from The Potential and Costs of District Heating Networks report [36], inflated them to 2019 and converted them to Euros. Note, stock is a term used to describe the total number of buildings within a defined group. Note also that we have not removed electrically heated properties from the database as part of this report's work. Conversion of electrically heated properties to be served by DH will require additional capital investment, so the method used here underestimates the costs for properties served by electric heaters.

Non-domestic property

The size of commercial and public properties varies considerably and so the costs of the HIU, the heat meter and piping also vary accordingly. The model determined the average heat demand of these properties in each SA (from both commercial and public peak heat demand), and used this to size and cost the HIUs, heat meters and piping. This approach follows the methodology used for the UK by Ricardo Energy and Environment [26]. Appendix B details the methodology and equations used in the model. We took cost data from The Potential and Costs of District Heating Networks [36] and Biomass Heat - A Practical Guide for Potential Users [37]. The analysis assumed that each non-residential property is connected to the network with a 20 m length of pipe. The model calculated an effective pipe diameter for the SA based on its non-domestic heat demand.

4.3 Total district heating capital cost

The total capital cost of constructing and implementing a DH scheme in each SA is equal to the sum of the pipe network cost, generating technology cost, thermal storage cost, domestic connection cost, and non-domestic connection cost.

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[15] The study gives a thermal storage cost of £962/m^3 of storage (2014 base year).

4.4 Operating costs

In addition to the capex, the model also calculated the opex associated with each technology, scaling the opex based on the demand in each SA (€/year/kWh). Only the opex of the central generating plant was considered. This did not include the cost of fuel. Opex used for each technology are in *Table 4* to *Table 9*. We have undertaken more comprehensive economic analysis, including fuel costs, as part of the NEMF and reported it in the *Net Zero by 2050* report.

5 Key results and conclusions

Ireland has one of the lowest shares of DH in Europe, with less than 1% of Ireland's heat market provided by DH. To date, there have been no large-scale DH schemes developed in Ireland.

The purpose of this work was to develop a computational DH model for assessing the costs and economic viability of DH at SA level in Ireland and for this model then to feed into the NEMF for scenario modelling as part of the National Heat Study. The DH model described in this report calculated the capital and operating costs associated with the construction and operation of DH networks in 18,641 distinct land areas in Ireland. The model compared different technologies that can generate heat for DH. The fundamental objective was to define, on a high level, which areas in Ireland show the greatest economic viability for DH, and which generating technologies should be utilised.

In this section, key findings from the model are presented and their significance discussed.

5.1 Heat density

An important variable when assessing the potential for DH in an SA is heat density. Heat densities can be calculated in several ways, but the model first considered the linear heat density. It divided the total heat demand by the road length in each SA [MWh/km].

Figure 11 and *Figure 12* show the distribution of heat densities across the SAs. Clearly, the vast majority of SAs have a heat density below 10,000 MWh/km. However, 287 SAs showed a heat density between 10,000 and 100,000 MWh/km, whilst 24 SAs demonstrated heat densities greater than 100,000 MWh/km. These combined 311 SAs represent the most economically viable DH locations in Ireland.

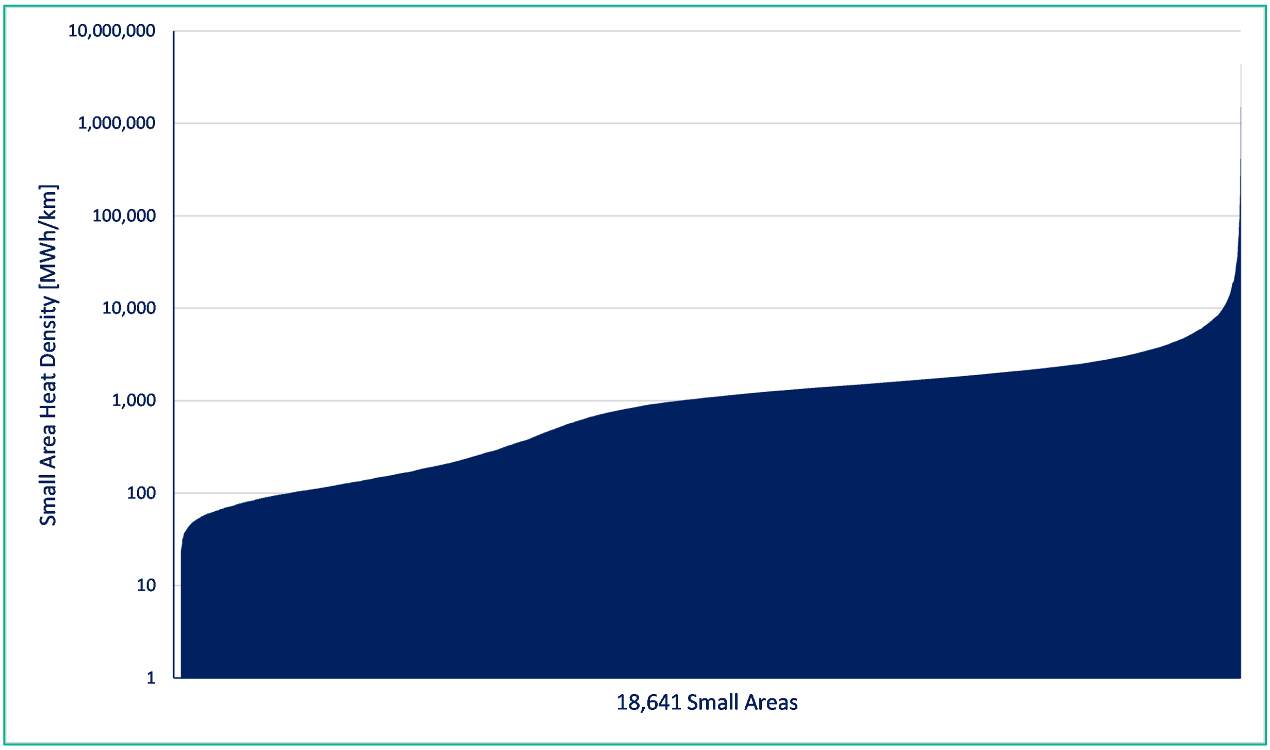

Figure 11: Distribution of small areas by linear heat density

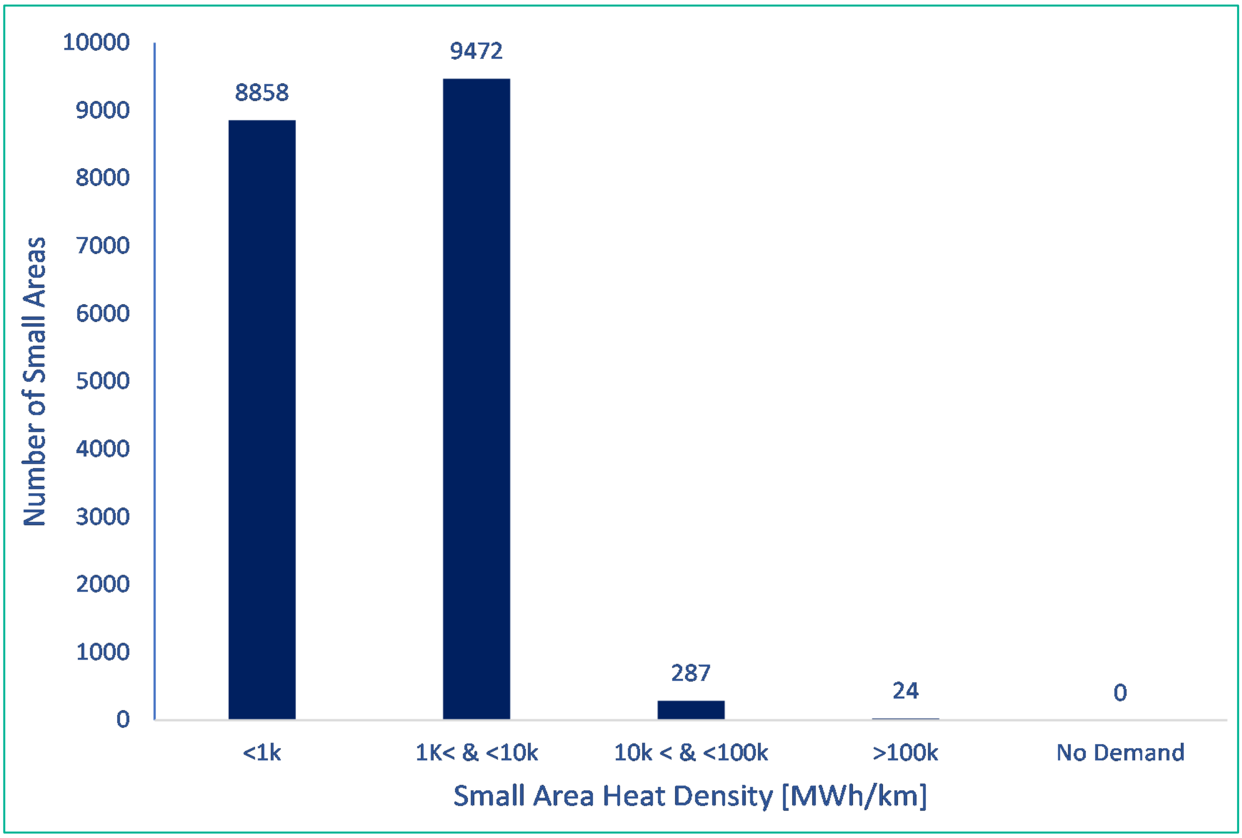

Figure 12: Break down of distribution of small areas by linear heat density

The total heat demand for the domestic, commercial and public sectors is approximately 28.6 TWh_{th}/year, distributed across the 18,641 SAs. Our analysis shows that around 2.5% of this total heat demand is within SAs with a high economical potential for DH (311 SAs with >10,000 MWh/km).

Of the total 18,641 SAs, only 23% exist within a city area. Whereas, 66% of SAs with a heat density greater than 10,000 MWh/km are within a city. From this perspective, this indicates that cities tend to be more suitable for DH.

Figure 13 shows that the capital cost begins to plateau once the heat density exceeds 1,000 MWh/km, indicating that the critical density threshold is 1,000 MWh/km. This relationship is seen for all technology options considered within the model. This is important because 51% of all SAs in Ireland have a heat density between 1,000 and 10,000 MWh/km. Given this cut-off, there are 9,783 SAs with the economic potential for DH in Ireland. This equates to 54% of the total heat demand. These preliminary findings are important but we have conducted a more comprehensive economic analysis, including fuel costs, as part of the NEMF and reported our findings in the Net Zero by 2050 report. Note that there is little variation in cost for any particular heat density. This is due to a range of factors, such as the number of properties, types of properties etc.

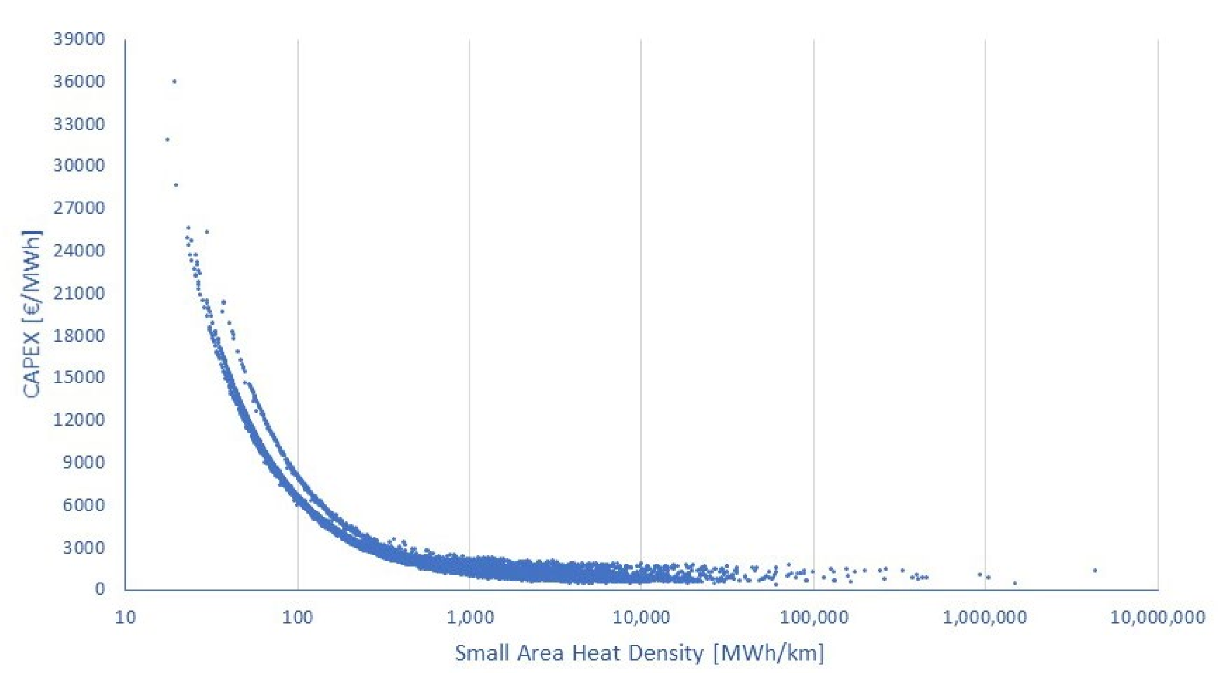

Figure 13: Capex vs linear heat density for Option 2 – biomass boilers

Rather than considering a linear heat density, we can use an area-based heat density instead, where the model divides heat demand by the land area of each SA [TJ/km^2]. As discussed in Appendix A, The Irish Heat Atlas assigned feasibility based on this density, ranging from very high potential to no potential. *Figure 14* shows the number of SAs fitting each of these feasibilities. There are 8,329 SAs deemed 'feasible' for DH (>50 TJ/km^2). This is in alignment with conducted analysis based on linear heat density.

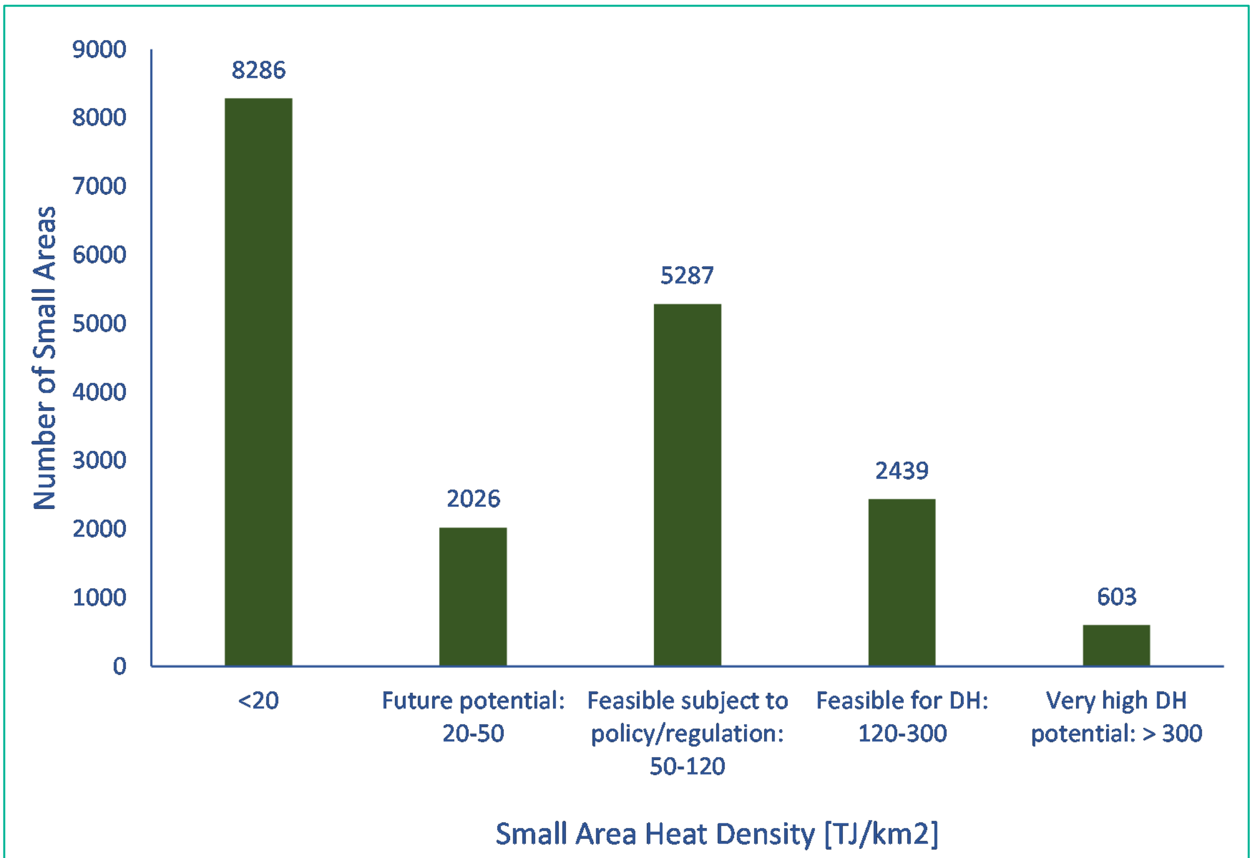

Figure 14: Distribution of small areas by area heat density

To reiterate, the model considered the following options:

- Option 1 – Heat extraction from power stations and industrial waste heat recovery (including data centres)
- Option 2 – Biomass boiler
- Option 3 – Biomass CHP with biomass boiler back-up
- Option 4 – Air source heat pump (ASHP)
- Option 5 – Ground source heat pump (GSHP)
- Option 6 – Low-carbon gas CHP

5.2 Option 1 - Heat extraction from power stations and industrial waste heat recovery

The first technology option considered was the extraction of waste heat. The average capital expenditure of constructing a DH network that utilises waste heat from an industrial site or extracts heat from a power station is €11,800/MWh. *Figure 15* shows just the capital costs associated with connecting the sites to the network. It is clear that this component is a significant driver to the overall cost. We can also see that recovery of heat from power stations is more expensive than from industry, with cement and magnesia being the cheapest options. Within the model, heat is only provided to the SA each site sits within; if heat is distributed to surrounding areas, it is expected that the cost per MWh would decrease.

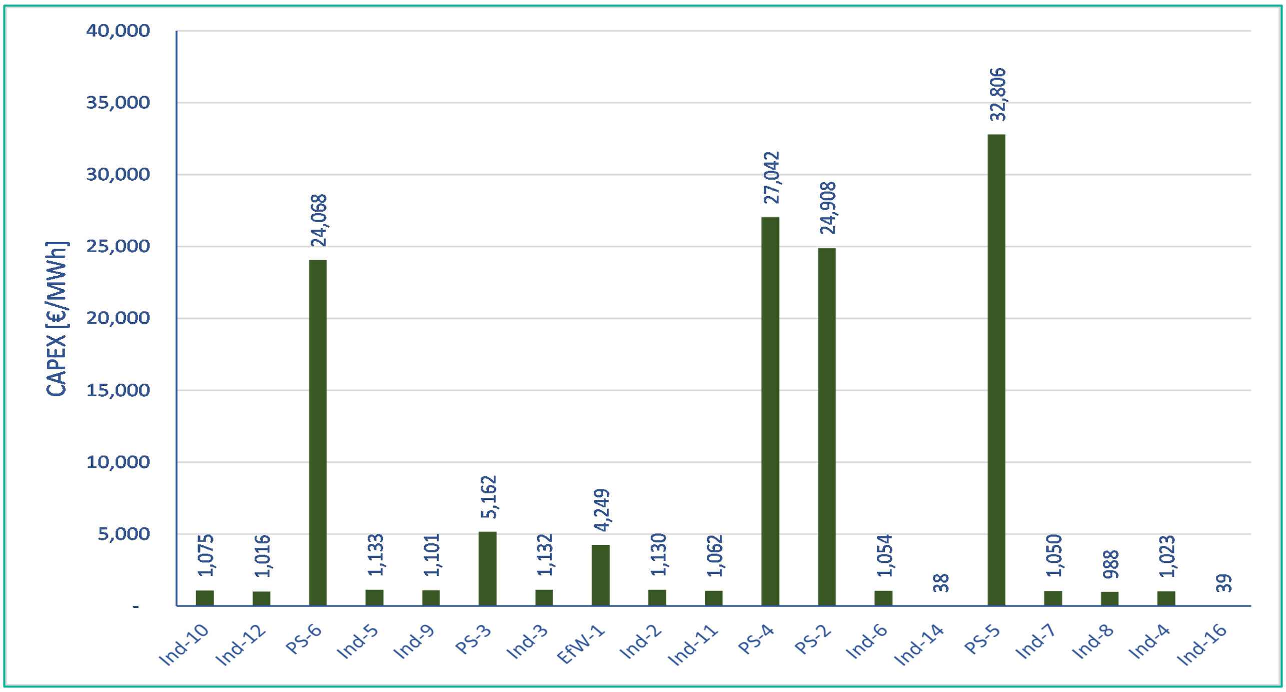

Figure 15: Cost of connecting industrial sites and power stations to the network

It should be noted that the cost of retrofitting power stations to extract heat is significant due to the need to replace existing condensing steam turbines with pass-out or extraction steam turbines. Should new power stations be built in the coming decade that are CHP-ready (e.g. a 2 GWe of new CCGT are planned in Ireland for the 2020s as reported in the Irish Times, August 2021 [38]), this would likely be significantly cheaper as the power station costs will include the cost of turbines.

The average capital cost of constructing a DH network that utilises waste heat from data centres is notably lower at €1,700/MWh. However, due to a lack of costing data within literature, these calculations carry a greater degree of uncertainty.

5.3 Options 2-6 - Biomass boilers, biomass CHP, ASHP, GSHP and low-carbon gas CHP

Figure 16 shows how the capital costs of each scenario vary depending on the heat density. It should also be noted that, regardless of the technology choice, capital costs for a given heat density are very similar. Biomass boilers and ASHPs are slightly cheaper than other options, as options with CHP (Options 3 and 6) require the purchase of a CHP and a boiler. Ultimately, the choice between a biomass boiler and an ASHP depends on the specific site circumstances and location (e.g. availability of biomass, availability of space to store the biomass feedstock, etc.), but this analysis indicates that the capital cost for either option is similar. As expected, where the SA heat density is less than 1,000 MWh/km, the capex for each unit of heat demand is considerably larger for all technology options.

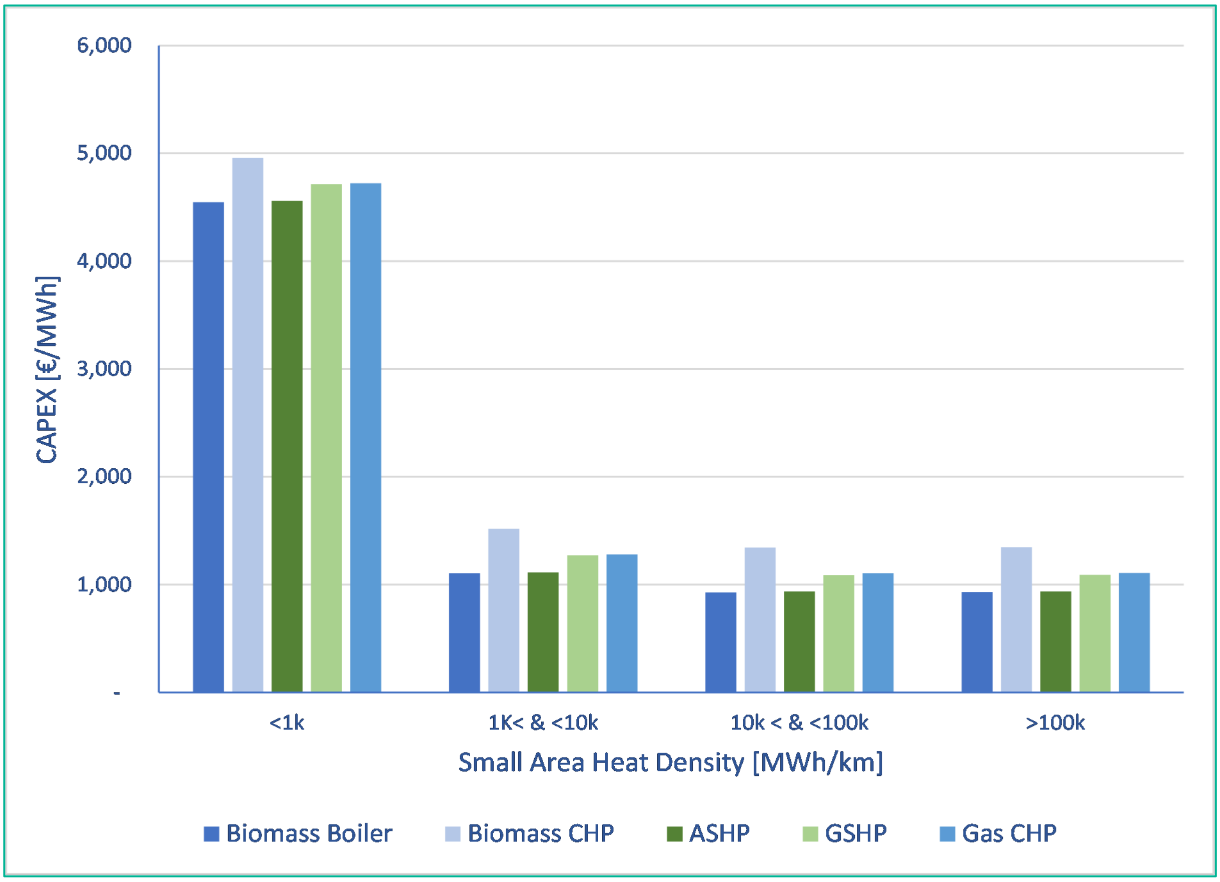

Figure 16: Capex for each technology option broken down by small area linear heat density

From a purely capital cost point of view, these results indicate it is likely to be more economically viable to generate heat using biomass boilers, CHP or heat pumps, rather than extracting heat from existing power stations or industrial sites which are not 'CHP-ready'.

Figure 17 presents the capex breakdown for SAs with heat densities ranging from 10k to 100k MWh/km under Option 2. It is clear to see that pipe costs and thermal storage represent the smallest fractions of the total capex. The cost of plant is significant and would certainly be a greater proportion under Options 3, 5 and 6. However, the greatest capital cost comes from connecting domestic and non-domestic dwellings to the network, representing almost 75% of the total capex. This gives merit to the idea that the number of properties being connected to a network should be carefully optimised. In this modelling work, every building in each SA was connected, but in reality, the network should only reach high-consuming costumers and dense domestic properties. Nevertheless, depending on location and specific circumstances of a DH scheme, pipe capex can still be an important variable.

Figure 18 presents the capex breakdown for SAs with <1 kMWh/km heat densities under Option 2. Contrary to before, the piping cost now represents the vast majority of the total capex. We can explain this behaviour by considering the nature of SAs. Each SA comprises typically 80-120 properties and there is little variation because SAs are fundamentally created in this way. However, there is large variation in the road length present in each SA of 0.1-100 km. The model connects to every property in an SA, so within low-density areas, the length of pipework required can be very large. This inflates the overall costs and yields the trends shown in *Figure 13* and *Figure 16*.

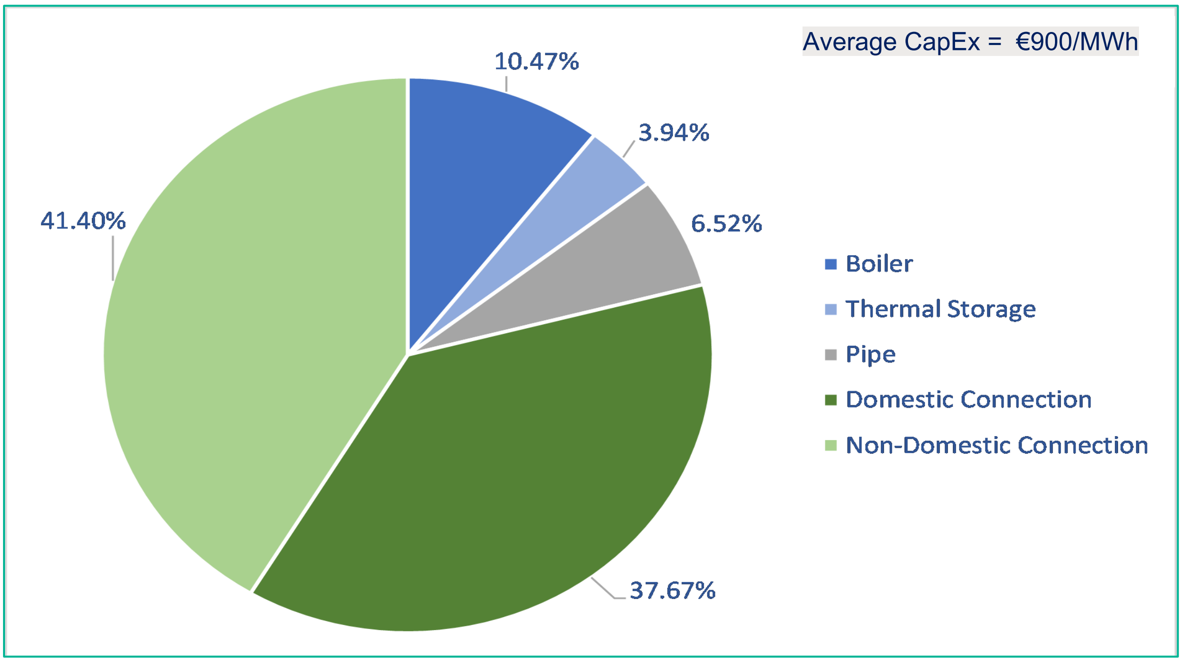

Figure 17: Capex break for Option 2 – biomass boilers for small area linear heat densities between 10k and 100k MWh/km

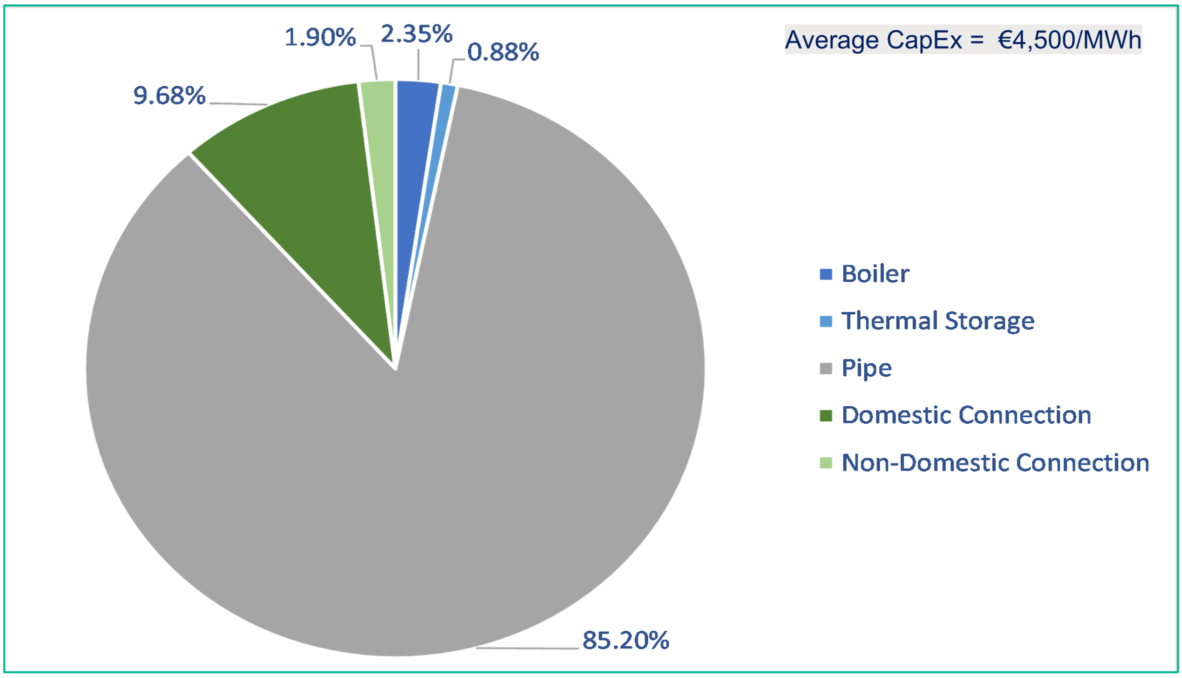

Figure 18: Capex break for Option 2 - biomass boilers for small area linear heat densities <1 kMWh/km

5.4 Comparison with previous work

The AECOM study defined heat density as heat demand divided by the total road length in each SA [MWh/km]. Heat densities of 3,000, 5,000 and 10,000 MWh/km were compared. The cost analysis performed indicated that DH networks are not economically viable unless the density is at least 10,000 MWh/km. The report stated that 1.5% of the national heat demand could be economically converted to DH [5].

Clearly, by revaluating an appropriate heat density cut-off (1,000 rather than 10,000 MWh/year), the DH model in this report has determined there is a much greater economic potential for DH in Ireland.

5.5 Key model limitation

Much like the 2015 AECOM model, this work also assumed the construction of the pipe network under every road within each SA. We also assumed connection to every property in an SA. These assumptions overestimate the connection and pipework costs per SA. Whilst we could have scaled the road lengths down with such high-level modelling, it was not possible to accurately estimate a scaling factor that could be confidently applied to every single SA. In reality, we need to consider the route for a DH network on a case-by-case basis, depending on which customers will be connected and what planning permits are likely to be granted. In the same way, there was no high-level way of determining which properties within an SA should be connected to the network. This method of applying a percentage of potential connections per SA can lead to high uncertainty. Likewise, assuming that the DH pipeline would follow the water or gas network pipeline is also a very rough estimate, which cannot be justified.

However, it should be noted that this assumption becomes less important for SAs with a large heat density, as these locations could feasibly see every property connected to the network. This is important because high-density SAs are most likely to be selected for DH development.

Moreover, separate cooling datasets should be developed for Ireland to allow district cooling to be considered for the next NCA review.

Finally, the analysis also attempted to cover the geothermal resource which clearly has significant potential in Ireland. The assessment of geothermal sources was done at depth up to 400 m due to the availability of a comprehensive dataset and suitability matrix at these depths. Further work is required for lower depths to ensure that the full geothermal potential is captured in future assessments.

5.6 Conclusions

The fundamental aim of this work was to define, at a national level, which areas in Ireland show the most favourable capital investment for DH, and which generating technologies to use.

We developed a DH model to evaluate the cost of constructing DH networks (including pipe costs, installation, thermal storage and connection) in 18,641 distinct areas throughout Ireland. Networks would supply heat to the domestic, commercial and public sectors. This work utilises a more comprehensive heat demand dataset that any previous work, and sheds greater insight into the potential of DH in Ireland. It is important to emphasise that this model is a first step and does not substitute for more detailed local-level design work.

Our analysis of DH potential in Ireland shows that 311 SAs out of 18,641 have a heat density greater than 10,000 MWh/km; it is these locations that show the greatest potential for DH. The 2015 SEAI District Heating Study, carried out by AECOM, proposed that SAs with a heat density of less than 10,000 MWh/km are not viable for DH. However, the results from this work suggest that the crucial cut-off is in fact lower, with construction costs (€/MWh) plateauing at 1,000 MWh/km. Hence, the cost (€/MWh) of constructing a network with a heat density of 1,000 MWh/km is very similar to a heat density of >10,000 MWh/km. This is important because 51% of all SAs in Ireland have a heat density between 1,000 and 10,000 MWh/km.

To put this into perspective, our analysis shows that around 2.5% of the total heat demand from the residential, commercial and public sectors has a high economic viability for DH (>10,000 MWh/km). However, up to 54% of heat demand could potentially be served by DH (>1,000 MWh/km).

If every property in an SA is provided with heat, the cost of connecting each property to the network is the greatest component of the total capital cost. Therefore, the number of consumers being connected to a DH scheme should be carefully optimised.

Results suggest that, in terms of capital costs, biomass boilers and ASHPs are the cheapest options for DH, though CHP and GSHPs are not substantially more expensive. It is also worth noting that CHP provides the ability to generate and sell electricity, which provides additional revenue.

We found extraction of heat from power stations and waste heat recovery from industrial sites to be notably more expensive than the other generation options considered. However, it should be noted that we only considered existing power stations in the analysis, and the costs of retrofitting power stations to extract heat are substantial. Should future power stations be built that are CHP-ready, this would likely be notably cheaper.

Data centres show promising potential, but we need more public information regarding the operation of Irish data centres to fully assess this option.

Appendix A: Current status of district heating in Ireland

Overview of review methodology

In undertaking this study, we undertook a review of the current status of heat networks in Ireland using existing literature and consulting with key stakeholders.

Appendix A provides:

- A summary of the studies reviewed.
- Further details of the two key previous works (the AECOM 2015 National Comprehensive Assessment (NCA) and the Irish Heat Atlas).
- An overview of existing and planned district heating (DH) schemes in Ireland.

We sent a tailored questionnaire to key stakeholders in Ireland. The responses received helped develop a comprehensive view of the existing and proposed future DH schemes in Ireland. In addition, capital and operating costs data received from stakeholders, albeit limited, were used to verify assumptions of costs used in modelling heat networks.

The review helped identify key sources of data and verify assumptions on the performance and costs of heat networks in Ireland. The review also showed which generation technologies are associated with current and proposed heat networks in Ireland.

Literature reviewed

Study reviewed	Description
A Guide to District Heating in Ireland (2016)	A Guide to District Heating in Ireland was a report produced as a collaboration between Codema and BioXL in 2016 on behalf of the Irish Bioenergy Association (IrBEA), funded by the SEAI Research, Development and Demonstration programme. This is a key piece of literature for reviewing the state of DH in Ireland [39].
2015 District Heating Assessment – AECOM	As part of the 2015 NCA of Ireland, AECOM developed a model for assessing the DH potential throughout Ireland. Findings were presented in Cost Benefit Analysis of the Potential for High-Efficiency Cogeneration and Efficient District Heating & Cooling in Ireland [5].
District Heating ‐ Consultation to Inform a Policy Framework for the Development of District Heating in Ireland (2019)	Consultation by the Department of Communications, Climate Action and Environment (DCCAE) (now Department of the Environment, Climate and Communication (DECC)) to meet Action 70 of the Climate Action Plan (2019) requirements on the need to develop a policy framework for the development of DH in Ireland. The public consultation focused on research, regulation, planning and financing [6].
An Assessment of Geothermal Energy for District Heating in Ireland	The report reviews Ireland's geothermal energy resources and, in particular, geothermal energy for DH [4]. GSI compiled the document to support the Department's Roadmap for a Policy and Regulatory Framework for Geothermal Energy in Ireland [40].
Scheme specific case studies	We also undertook a search of literature on specific studies related to DH schemes (e.g. Tralee, Elm Park, Stewarts Care and Cloughjordan Ecovillage Schemes).

In 2016, A Guide to District Heating in Ireland [39] reviewed potential for DH and provided case studies demonstrating actual and hypothetical application of DH schemes at specific locations in Ireland. Key findings from the techno-economic analyses and case studies were presented, summarised in *Table 10*.

Table 10: Key findings from A Guide to District Heating in Ireland report

Industry maturity	• Consumers are often unaware of DH as a utility • Lack of expertise regarding the design, construction, and operation of DH schemes. Technical mistakes lead to energy losses, additional costs and long-term maintenance issues
New consumer connections	• Instances found where consumers could have connected to a DH scheme but did not • Mandatory and voluntary methods have been effectively implemented in other countries to promote and support use of DH
Planning policy issues	• The reports states 'there are no energy planning practices carried out at a local authority level in Ireland and there is insufficient guidance on this process at a national level' • Lack of official policy and support limits use of DH
Pricing challenge	• Need for independent guidance and regulation for pricing of heat supplied via DH schemes
Long-term investment for DH infrastructure	• DH schemes need to be recognised and viewed as a long-term infrastructure investment • The initial cost of DH is higher than conventional boilers, but this is compensated for by the longer lifespan
Commercial viability	• Heat density is a key factor in the viability of DH schemes • Viability increases with connection to 'anchor loads', such as hospitals, leisure centres or large retail
Synergy with renewable heat and DH	• A renewable heat incentive is needed to promote the use of biofuel over natural gas, which is cheaper

Previous district heating modelling work performed in Ireland

AECOM – 2015 National Comprehensive Assessment

As part of the 2015 NCA of Ireland [5], AECOM developed a model for assessing the DH potential throughout Ireland. Findings were presented in Cost Benefit Analysis of the Potential for High-Efficiency Cogeneration and Efficient District Heating and Cooling in Ireland [5].

For the NCA, the AECOM model paired small area (SA) heat density mapping with various technologies under different scenarios to evaluate a range of factors, including energy demand, project cost and emissions. The model also considered how heat demand will evolve in the future. The model did not include cooling demand, as AECOM deemed it to be too small.

The AECOM work then led into a cost benefit analysis (CBA) to understand where DH is most viable, and which technologies show the greatest potential. Heat density is an important variable when assessing the viability of DH. The AECOM study defined heat density as heat demand divided by the total road length in each small [MWh/km]. The cost analysis compared heat densities of 3,000, 5,000 and 10,000 MWh/km, which indicated that DH networks are not economically viable unless the density is at least 10,000 MWh/km. The report continues to state that 1.5% of the national heat demand could be economically converted to DH [5].

The AECOM model utilised waste heat from industry, though the cost of doing so was likely underestimated. The DH model generated during this project evaluated and costed the waste heat available within each SA using more conservative data.

Finally, the AECOM model assumed that DH pipework will be constructed under every single road within each SA. This assumption inflates the overall pipework cost, as in reality not every single property is financially viable. For high-level modelling, the variability within each assessed area makes it difficult to accurately scale the piping network.

The Irish Heat Atlas

The Irish Heat Atlas is an interactive online heat map of Ireland [41]. The fundamental heat map data come from the 2015 study by Stratego, Mapping the Heating and Cooling Demand in Europe [42]. This report developed a heat map for residential and service heat demand in five European nations, including Ireland. Rather than evaluating the heat demand at an SA scale, this study used a 100 m resolution. This heat map was then used to assess the potential for DH in Ireland. Unlike the AECOM DH study, which defines the heat density as MWh/km, the Heat Atlas instead uses heat demand divided by the land area [TJ/km^2]. The Heat Atlas assesses potential for DH in each area based on this definition of heat density:

- Very high DH potential: > 300 TJ/km^2
- Feasible for DH: 120-300 TJ/km^2
- Feasible subject to policy/regulation: 50-120 TJ/km^2
- Future potential: 20-50 TJ/km^2

The 2019 District Heat – Consultation to Inform a Policy Framework for the Development of District Heating in Ireland report compared the AECOM and Heat Atlas DH potentials [6]. The Heat Atlas showed a greater potential than AECOM, which is thought to be due to the different heat densities used.

District heating networks in Ireland: Current status

Heat network infrastructure in Ireland is not widely deployed and tends to be small scale. More recently, larger municipal scale projects have made progress towards construction.

Key technologies for existing and proposed DH schemes include boilers and CHP as well as heat pumps, whilst key fuels are biomass and waste in addition to gas. Applications for DH include providing heat to residential premises, commercial centres, universities and hospitals, and include recovering heat from low-temperature sources such as data centres (e.g. Tallaght DH scheme). *Table 11* provides a list of existing and proposed schemes.

Table 11: Existing and proposed district heating projects in Ireland

	Name (County)	Plant	Fuel / Source	Consumers
Existing	Charlestown Mixed-Use Development (Dublin)	Biomass boiler Natural gas boiler Combined heat & power (Total: 4 MWth and 228 kWe)	Biomass/natural gas	285 Apartments 1 Shopping centre
	Glen District Heat Network (Cork)	Biomass boiler	Biomass	58 Houses 4 Apartments 1 Community centre
	Údarás na Gaeltachta – Gweedore Business Park (Donegal)	2 Wood pellet boilers & Solar thermal unit	Biomass	1 Office block
	Teagasc Mellowes Campus, Athenry (Galway)	Wood chip boiler (250 kW)	Biomass	1 Research & training facility
	Furbo Headquarters of Údarás na Gaeltachta (Galway)	Wood chip boiler (300 kW) Oil boiler (500 kW)	Biomass/Oil	1 Office block

	Name (County)	Plant	Fuel / Source	Consumers
	Leinster House DH (Dublin)	Wood pellet boiler (1 MW)	Biomass	2 Office buildings
	CRESCO, Callan (Kilkenny)	Wood chip biomass boiler (220 kW)	Biomass	Various buildings including a crèche, an arts centre, a friary and 4 small residences
	Tralee District Heating System (Kerry)	2 Wood chip boilers (1 MW)	Biomass	Apartments, houses and commercial buildings
	Elm Park (Dublin)	2 Biomass boilers (1.5 MW) 4 Condensing gas boilers (4.1 MW) 4 CHP gas engines (1.8 MW)	Biomass/Natural gas	Apartments & offices
	Stewarts Care, Palmerstown (Dublin)	2 Steam boilers 2 CHP units 1 Heat pump & solar thermal panels	Natural Gas	Communal & living spaces
	University College Dublin (Dublin)	2 Gas CHP 3 Gas boilers 1 Biomass boiler	Natural gas/biomass	Administrative, academic & science facilities among others
	Cloughjordan Ecovillage (Tipperary)	2 Biomass boilers (1MW total)	Biomass	55 Houses
Proposed/In development	Dublin District Heating Scheme (Dublin)	90 MW Dublin Waste to Energy Facility	Waste	Public sector, commercial, industrial and residential
	Tallaght District Heating Scheme (Dublin)	3 MW Heat Pump 3 MW Electric boiler	Electricity	Civic centre, library, 3rd level institution and residential apartments
	Clongriffin District Heating Network (Dublin)	Two 500 kWe CHP units	Natural gas	1950 (+250) apartments Commercial space
	Ringaskiddy Resource Recovery Centre (Cork)	240,000 tonnes per year waste recovery facility	Waste	Includes pharmaceutical plants and Port of Cork

Existing Irish district heating schemes

Charlestown Mixed-Use Development (County Dublin): This site in Dublin comprises 285 apartments and a shopping centre. Three pieces of generation equipment supply heat to the residential DH network: a biomass boiler, a natural gas boiler, and a combined heat and power (CHP) unit. The CHP unit provides the shopping centre with heat and electricity. During periods of off-peak demand, the CHP delivers excess electricity to the grid. The system generates 4 MWth and 228 kWe. Cost to consumers varies from 4 cent/kWh for commercial users and 6 cent/kWh for residential users. This includes all maintenance and management costs, as well as making provision for a sinking fund for the eventual renewal of key equipment [39].

Glen District DH (County Cork): This DH scheme in Cork comprises 58 houses, four residential spaces within a community centre and the actual community centre itself. One biomass boiler generates the heat. The report estimates there was an initial pipe network installation cost of €10,000 per customer. Once the network was established, the scheme predicted the cost of new connections to network would cost approximately €4,500 per customer. These costs were expected to reduce if the network connected apartments or large consumers, rather than houses [39].

Údarás na Gaeltachta – Gweedore Business Park (County Donegal) [43]: Two wood pellet boilers and a 46 m^2 solar thermal unit provide hot water to a three-storey office block. At the time the report was published, there were 19 end-users, who paid 4.2 cent/kWh of metered heat. As part of a feasibility study by Fichtner, air and ground source heat pumps were also evaluated [39].

Teagasc Mellowes Campus, Athenry (County Galway): A 250 kW wood chip boiler provides heating to an agricultural research and training facility [39].

Furbo Headquarters of Údarás na Gaeltachta (County Galway): A 300 kW wood chip boiler and a 500 kW oil boiler provide heating to an office complex [39].

Leinster House DH, Kildare St (County Dublin): A 1 MW wood pellet boiler provides 20% of the heat to Leinster House and Department of Agriculture, Food and the Marine building complex [39].

CRESCO, Callan (County Kilkenny): A small DH network, where a 220 kW wood chip biomass boiler serves several buildings [39].

Tralee DH System (County Kerry): Two wood chip boilers supply 1 MW of heat to apartments, houses, and commercial buildings. The system generates approximately 1,500 MWh of energy per year [44].

Elm Park (County Dublin): Two biomass boilers, four condensing gas boilers and four CHP gas engines provide heating to a mixture of apartments and offices [45].

Stewarts Care, Palmerstown (County Dublin): At this site heat is supplied to a mixture of communal and living spaces with two steam boilers, two CHP units, one heat pump and solar thermal panels [46] [47].

Cloughjordan Ecovillage (County Tipperary): Two 1 MW biomass boilers provide hot water and heating for the village (55 homes). There is also a back-up solar thermal system [48] [47].

University College Dublin (County Dublin): The DH network comprises two gas CHP, three gas boilers and one biomass boiler. The heat is used to provide heating for academic and administrative buildings, among others [49].

Proposed plans for future Irish district heating schemes

Dublin District Heating System (DDHS – County Dublin): The project is currently in the planning and development phase, and will provide heat to the south-east and dockland regions of the Dublin City Council area. Upon completion, the aim is to connect to customers in the public, commercial, industrial, and residential sectors. The design is based on a 90 MW Dublin waste to energy facility and a gas fired back-up burner. The network will have a 2-pipe system, delivering 85 °C flow and 45 °C return, with a total 14.4 km of piping.

Tallaght DH System (County Dublin): Once completed, the system will supply 6380 MWh of heat to the following buildings: a civic centre, library, 3rd level institution and residential apartments via a 3 MW heat pump (backed up with a 3 MW electric boiler). Both space heating and water heating will be provided. Space cooling will also be provided to a data centre in the local area. However, cooling will be provided directly from the heat pumps, not a DH network. Network flow temperature is weather compensated and will vary between 70 and 85°C, depending on ambient conditions. The return temperature will be 55°C.

Clongriffin DH Network (County Dublin): There are plans to provide heating to 15 apartment blocks, with the potential to also include an additional three commercial/residential blocks. If realised, electricity would also be supplied to the commercial consumers. This would cover 1,950 (+250) residential units and 22,272 m^2 of commercial space, which would require a network length of approximately 1,325 m. The energy centre would comprise two 500 kWe gas CHP units [50].

Ringaskiddy Resource Recovery Centre (County Cork): This waste recovery facility will treat 240,000 tonnes per year of residential, commercial, industrial, hazardous and non-hazardous waste. It is estimated the plant can provide 21 MWe and 12 MWth. The heat will be exported via a steam pipeline at 16.8 tonnes per hour and 10 bar(a). The existing heat infrastructure will provide back-up, with steam accumulators installed to allow time for back-up boilers to ramp up during unplanned interruptions. A heat demand of 157 GWh/year was identified within 10 km of the site, including pharmaceutical plants within a 3 km radius. The scheme estimates primary energy savings of 11.6% compared to separate generation of heat and power [51].

A CBA indicates negative values for both internal rate of return (IRR) and net present value (NPV), before financing and tax. Hence, the proposed scheme may not be economically viable. However, the CBA does not include any grants or subsidies, which may offset some costs of the scheme. Should support be available, the project could become financially viable.

Appendix B: The district heating cost database

Appendix B is available on the following SEAI National Heat Study webpage: https://www.seai.ie/data-and-insights/national-heat-study/district-heating-and-cool/ .

Appendix C – Assessment of the potential of waste heat in Ireland

Appendix C is available on the following SEAI National Heat Study webpage: : https://www.seai.ie/data-and-insights/national-heat-study/district-heating-and-cool/.

Appendix D – Assessment of the potential of geothermal energy in Ireland

Appendix D is available on the following SEAI National Heat Study webpage: : https://www.seai.ie/data-and-insights/national-heat-study/district-heating-and-cool/.

Glossary

Term	Description
Area-based heat density (TJ/km^2)	The heat demand per km^2 of land area.
ASHP	Air source heat pump
BER	Building energy rating
Capex	Capital expenditure
CBA	Cost benefit analysis
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CHP	Combined heat and power
CO_2	Carbon dioxide
COP	Coefficient of performance. A performance rating that indicates the effectiveness of a heat pump in transferring heat versus the amount of electrical power it consumes.
DECC	Department of the Environment, Climate and Communications
Demand (useful energy)	The amount of energy required to fulfil a demand. It does not take any losses into account (for example, due to technology conversion efficiency).
Delivered energy (final energy)	The actual amount of energy used to meet a demand (i.e. actual fuel used). These data are reported in aggregated form in the National Energy Balance. Also known as final energy. This corresponds to the energy consumption that usually appears on energy bills.
DH	District heating
Direct-fired heating equipment	Industrial heating equipment where combustion gases come into direct contact with the product being heated, such as in furnaces or kilns.
District heating and cooling	The distribution of thermal energy in the form of steam, hot water or chilled liquids, from a central source of production through a network to multiple buildings, for the use of space or process heating or cooling.
EED	The Energy Efficiency Directive is a framework for measuring and promoting energy efficiency, created by the European Parliament.
Efficient district heating and cooling	District heating or cooling according to the Energy Efficiency Directive is a DH system using at least 50% renewable energy, 50% waste heat, 75% cogenerated heat or 50% of a combination of such energy and heat.
EfW	Energy from waste
ERF	Energy recovery factor
ETS	Emissions Trading Scheme (in reference to the EU's emissions trading scheme)
GSHP	Ground source heat pump

Term	Description
GSI	Geological Survey Ireland
High grade heat	Industrial heat of temperature >500 °C
HIU	Heat interface unit
HNL (%)	Heat network losses
HP	Heat pump
Indirect heating	Industrial heating equipment where heat is supplied through a medium such as steam/hot water.
IrBEA	Irish Bioenergy Association
KWe	Kilowatt (1,000 watts) of electrical power
Linear heat density (MWh/km)	Heat demand per km of road
LNG	Liquefied natural gas
Low grade heat	Industrial heat of temperature <100 °C
Medium/Low grade heat	Industrial heat of temperature <100 °C and >150 °C
Medium grade heat	Industrial heat of temperature <150 °C and >500 °C
MW	Megawatt (equal to 1,000 kilowatts or one million watts)
MWh	Megawatt hours
MWth	Megawatt of thermal output
NCA	National Comprehensive Assessment
NEMF	National Energy Modelling Framework
NIRSA	National Institute of Regional and Spatial Analysis
Non-ETS	This refers to industrial sites which are not part of the EU's emission trading scheme.
NPV	Net present value
OCGT	Open cycle gas turbine
Opex	Operating expenditure
OSI	Ordnance Survey Ireland
SA	Smallest administrative land area in Ireland, over which Census data are published, typically containing 80 to 120 dwellings.
SEAI	Sustainable Energy Authority of Ireland

Term	Description
Stock	A term used to describe the total number of buildings within a defined group.
Technology efficiency	The conversion efficiency of a technology, which links useful and final energy.
TJ	Tera-joule
Z factor	The ratio of useful heat extracted from a cogeneration system to the reduction in electricity production caused by the heat offtake.

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