Large-scale climate neutral Energy Geostructures in District Heating & Cooling systems/networks (LEG-DHC)

The role and potential of energy geostructures in district heating in Dublin

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Briefing paper prepared by Codema on behalf of University College Cork

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Executive Summary

We often associate cities with vast swathes of buildings and infrastructure that decorate a skyline. Yet, like nature, cities are rooted in the earth below. Rarely do we appreciate the foundational elements that support the ground we stand on. Foundations are often thought to be static, unchanging, and consistently providing their as-built functionality; nothing more, nothing less. Yet the development of new technologies to extract energy from structures beneath the earth has led to the concept of **underground geostructures**.

Underground geostructures serve additional functionalities beyond structural support that one would traditionally expect from subsurface infrastructure. They include support elements such as **retaining walls**, **piles**, and **tunnels**. New technologies allow these substructures to be used to capture thermal energy stored in the ground or groundwater.

This report researches the applicability of **large-scale, climate-neutral energy geostructures in district heating and cooling systems/networks (LEG-DHC)** in Ireland, particularly in the Dublin region. This report has been structured as a feasibility study using guidance provided by the Sustainable Energy Authority of Ireland (SEAI).[1]

This study includes a state-of-the-art literature review and general feasibility analysis for different heat sources. The work conducted by Codema primarily consisted of a desktop study with three stakeholder interviews and technical analysis conducted across an eight-month project timeline. Codema met with UCC every month to share learnings, data, and previous experience from the analysis of Dublin's heat demand. While case studies across the European Union (EU) have been conducted, this study focuses on the Dublin region.

The scope of this study included the following:

- Incorporate the geothermal heat resource identified into heat source mapping work and relate it to the overall potential for District Heating in the Dublin area based on figures from Codema's Dublin Region Energy Masterplan.

- Compare this geothermal resource with other potential resources in relation to quality (temperature), availability, heating system efficiency, etc.

- Perform a high-level evaluation of key considerations in the use of the tunnel system to facilitate the installation of district heating distribution pipes.

[1] Sustainable Energy Authority of Ireland (SEAI). 2024 *District Heating Feasibility Study Standardised Template: A "How-To-Guide": In Support of Conducting Standardised District Heating Feasibility Studies*.

Based on engagement with relevant industry experts, Codema has several recommendations. These recommendations have been categorised in terms of applicability to different stakeholders:

General Recommendations for working with large-scale energy geostructures:

- From the techno-economic perspective, relative to the counterfactual, waste heat is the first consideration for incorporating into LEG-DHC networks due to dependability and scalability. The results of the techno-economic analysis in this report show that geostructures are preferable to the counterfactual (which is a single Air Source Heat Pump (ASHP). Interestingly, the Business-As-Usual (BAU) approach of maintaining existing gas boilers is on par with the incorporation of geostructures from a techno-economic perspective, despite no points awarded to the BAU approach for environmental considerations. A centralised ASHP followed in the rankings of this analysis and in last place from the five options considered was the counterfactual, an individual ASHP.
- Engagement with local councils in the project pre-development stage to raise awareness, share relevant data, and check alignment with planned works/highlight collaboration potential can ensure buy-in.
- Extensive understanding of the underground conditions of the site prior to construction (existing infrastructure, ground conditions, water table, etc.) is essential.
- Develop the boundary conditions of the pipe sizing before contacting a specialist to assess a scenario (expected diameters and lengths).
- In instances where horizontal directional drilling is being undertaken, a coffer dam should be dug adjacent to the network site to install piping. This will have an associated land use requirement which will need to be considered.
- *'You can't manage what you can't measure.'* Best practice would be to conduct a dimensional analysis of any underground site prior to a shovel going in the ground. This should be followed by constant monitoring of the geotechnical structures from a thermal and mechanical perspective.
- The site-specific risk of flooding should be considered through relevant hydrological modelling.

Recommendations to UCC:

- Incorporate the key considerations and recommendations (found in Section 11 of this report) into future works, highlighting the criteria that need to be met in order to ensure functionality.
- Relay information derived from the interview process in this report to interested parties and relevant stakeholders. The dissemination of these interviews can be found in Section 3.
- Incorporate Codema's key considerations found below into any future research publications/guidance documents/white papers.
- Raise awareness on the potential applicability of LEG-DHC in Dublin and across Ireland as a novel form of energy through:
    - Hosting webinars;
    - Publishing reports/datasets;
    - Giving presentations to interested parties; and/or
    - Organise meetings with government or industry.

When it comes to working with energy geostructures, specifically energy tunnels, the key considerations of this report are listed below:

Key considerations

- ***Energy geostructures require significant upfront investment. This means that ensuring buy-in through engagement with local councils and stakeholders in the network's region during the feasibility stage will be critical to delivery of these projects. While they are a renewable and sustainable source of heat, the site-specific conditions (temperatures, flow rates, etc.) will need to be well understood in order to determine their overall viability.***

- ***Health and safety is of the utmost importance when operating in and around underground structures. Thorough site assessments and safety considerations from the Code of Practice For Avoiding Danger From Underground Services.***[2]

- ***Active monitoring of the site and a full survey of above and below-ground conditions must be established prior to the commencement of works. Thermo-hydro-mechanical behaviour of underground structures should be monitored.***

- ***The ground conditions such as the type of soil, presence of utilities, and water table should be thoroughly understood through modelling and surveying prior to any digging.***

[2] Heatlh and Safety Authority (HSA) 2010. "Code of Practice For Avoiding Danger From Underground Services"

1. Introduction

Project description

Harnessing this thermal energy can allow for the heating/cooling of nearby structures through the distribution of heat energy through District Heating (DH). The extraction of heat energy through these subsurface constructions is known as Energy Geostructures (EGS). Despite recent advances in this technology and increasing global interest, there are still barriers to implementation/integration.

This report delivers Codema's supporting expertise for University College Cork (UCC) in the Clean Energy Transition Partnership (CETP) 2022 funded project: LEG-DHC - Large-scale climate-neutral Energy Geostructures in District Heating & Cooling systems/networks. This document was developed by Codema for a team of researchers within UCC's Civil Engineering Department.

The LEG-DHC project has identified three technical barriers on the route of implementation and integration of EGS at a large scale:

- There is a lack of visibility on positive thermal and mechanical feedback from stakeholders. Uncertainty remains around whether stakeholders are satisfied with their shallow geothermal sites.

- Challenges in the integration of EGS into DH systems at a regional level. It seems that most EGS are operated individually. This study looks to see if they can be installed into DH systems or via tunnels or pipelines, particularly the waste heat from data centres.

- The complexity of managing and balancing multiple energy sources such as geothermal, solar, and other local energy sources for a climate-neutral regional community.

To break down these barriers, the LEG-DHC project will aim to:

➔ Show the global feasibility in terms of thermal efficiency and mechanical impact on existing complex infrastructure when using these as heat collectors. In particular, the energy production potential, carbon reduction potential and other existing data will be analysed to demonstrate the environmental benefits.

➔ Provide a structured, easily accessible and clear database presenting feedback on thermomechanical behaviour, energy performance, overall efficiency, durability, etc.

The current national situation

Ireland has committed to cutting greenhouse gas (GHG) emissions by 51% by 2030 and reaching net-zero emissions by 2050 as the part of the Climate Action Plan 2025 (CAP25).[3] This means an average 7% annual reduction in emissions between 2018 and 2030.

Heating is a major contributor to Ireland's emissions, accounting for 33% of total energy use and around 20% of GHG emissions.[4] Currently, more than 90% of Ireland's heat demand is met by fossil fuels, with 78% of this imported.[5] As Ireland's domestic gas supply from the Corrib and Kinsale fields declines, reliance on imports will increase, raising concerns about energy security.

Ireland's use of renewable energy for heating has increased but remains low compared to other EU countries. In 2023, 8.0% of heat demand was met by renewable sources, up from 5.2% in 2013. However, Ireland still remains one of the worst performing countries in Europe when it comes to the share of renewables in the heating sector with fossil fuels still supplying over 90% of Ireland's heat demand, highlighting the urgent need for cleaner alternatives. [6] Despite national and EU targets, Ireland fell short of its 2020 goal of 12% renewable heat, achieving only 6% at the time. While progress has been made, further action is needed to expand the use of renewable heat technologies, such as District Heating (DH), to meet climate targets and reduce reliance on imported fossil fuels.

According to the SEAI's 2022 National Heat Study,[7] district heating could supply over 50% of Ireland's heat demand, particularly in cities and large towns where heat demand density is high and renewable and waste heat sources are available. Reports have consistently highlighted district heating as a realistic solution to cut emissions and improve energy security by reducing fossil fuel dependence and using more local energy sources.

Although district heating is still in its early stages in Ireland, progress has been made. The Tallaght District Heating Scheme, [8] which became operational in 2023, is Ireland's first large-scale district heating network. It captures waste heat from an Amazon Web Services (AWS) data centre and supplies South Dublin County Council buildings, Technological University Dublin's Tallaght campus, and local affordable housing. The network is set to expand further. The Dublin District Heating Project (DDHP) is also being developed in Dublin to use waste heat from the Dublin Waste-to-Energy Plant (Poolbeg Incinerator) to supply homes, businesses, and public buildings. Several other local authorities are actively developing feasibility studies and pilot projects for district heating networks, with the goal of rolling out sustainable heating in their regions.

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[3] Government of Ireland (2025). *Climate Action Plan 2025*.
[4] SEAI (2025). *Energy-related greenhouse gas (GHG) emissions* [Accessed 28th July 2025].
[5] SEAI (2024). *Energy in Ireland 2024 Report*.
[6] SEAI (2025). *Renewables* [Accessed 29th July 2025].
[7] SEAI (2022). *National Heat Study* [Accessed 29th July 2025]
[8] Heatworks (2025). *Tallaght District Heating Scheme* [Accessed 29th July 2025]

Project objective

Codema has developed this report outlining the role and potential of energy geostructures in district heating in Dublin, including a comparative analysis between energy geostructures and other heat sources compatible with district heating as detailed in Section 6.

The objectives of Codema's involvement in the project are to:

- Incorporate the geothermal heat resource identified into heat source mapping work and relate it to the overall potential for District Heating (DH) in the Dublin area based on figures from Codema's Dublin Region Energy Masterplan (DREM).

- Compare this geothermal resource with other potential resources concerning quality (temperature), availability, heating system efficiency, etc.

- Perform a high-level evaluation of key considerations in the use of the tunnel system to facilitate the installation of district heating distribution pipes

Implementation of DH on a local, national, and international level will contribute to energy security and sustainability. DH can have a direct positive effect on the emissions from the heating sector, and an indirect positive effect on emissions from the electricity sector when optimised within an overall smart energy system. When utilising waste heat and low-grade heat sources, DH systems also allow more valuable sustainable resources (e.g. high-exergy green fuels like biomethane) to be allocated for use in other hard to decarbonise sectors such as heavy transport. DH can therefore play a key role in reducing energy-related emissions across all sectors and help to meet EU, national, and local level climate change targets.

The development of a DH project involves detailed project development phases beginning with a pre-feasibility phase as shown below in Figure 1. Within the feasibility stage, the goal is to involve key stakeholders throughout the process to evaluate the viable heat sources in the region, size the pipe network and heat plant for the initial phases with the preliminary data available. This assesses the financial viability of the network given the results of the sizing, and assesses the risks associated with the project overall given the full funding of the study. With these key outputs complete, the future of the project can be assessed, and a decision on whether or not it passes the necessary hurdles to warrant further development can be made.

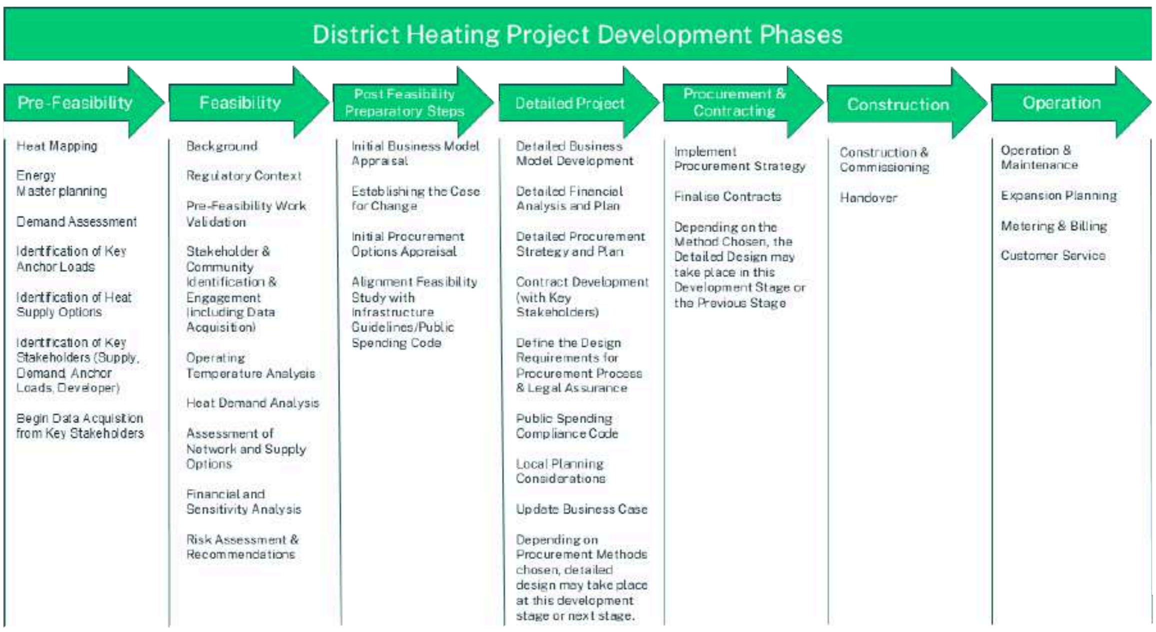

Figure 1: District Heating development phases

A comprehensive feasibility study covers several key elements, including:

- **Demand Assessment**
  - Evaluate the heat demand in the area.
  - Identify potential heat customers and their energy needs.
  - Considers building types, heating systems, and operating temperatures.
- **Energy Supply Options**
  - Identifies a long list of potential energy sources (e.g. waste heat, renewables, geothermal).
  - Shortlists the most feasible options based on cost, reliability, and sustainability.
  - Assesses carbon emissions and regulatory compliance.
- **Heat Distribution & Network Design**
  - Determines the optimal pipe network route.
  - Estimates construction and operational costs.
  - Evaluates technical feasibility, including pumping requirements and thermal losses.
- **Techno-Economic Feasibility Analysis**
  - Compares different DH scenarios against a counterfactual (Business-As-Usual) scenario.
  - Uses a weighted multi-criteria analysis to assess financial, operational, and environmental viability.
  - Conducts financial modelling, including Net Present Value (NPV), Internal Rate of Return (IRR), and sensitivity analysis.
- **Risk Assessment**
  - Identifies technical, financial, and regulatory risks.
  - Proposes mitigation strategies to reduce risks and improve project success.
- **Recommendations & Next Steps**
  - Summarises key findings.
  - Provides recommendations for further project development.

This research document applies the steps above as a framework for generalised recommendations of energy geostructures within the Dublin region.

2. Background

Regulatory and legislative context

This section offers an overview of the regulatory and legislative frameworks that influence DH project in Dublin. This information is crucial to aligning the project with current laws and policies.

European Union context

European Union (EU) legislation has defined how constituent countries will contribute to reducing their energy consumption. The Energy Efficiency Directive is a key driver of Europe's energy transition.[9] The revised directive raises the EU's ambition on energy efficiency. Article 26 of the directive sets out a fully decarbonised district heating and cooling supply by 2050. EU countries must promote local heating and cooling plans in large municipalities (with a population >45,000).

The European Green Deal aims for Europe to be the first climate-neutral continent in the world as is binding under the EU Climate Law. The Renewable Energy Directive is the cornerstone of the European Green Deal[10] and REPowerEU [11] strategies to reach the Union's ambition to fight climate change and reduce fossil fuel dependence. Meeting the new minimum EU target of 42.5% for 2030 will demand doubling the rates of renewables deployment seen over the past decade and a deeper transformation of the European energy system (Figure 2).

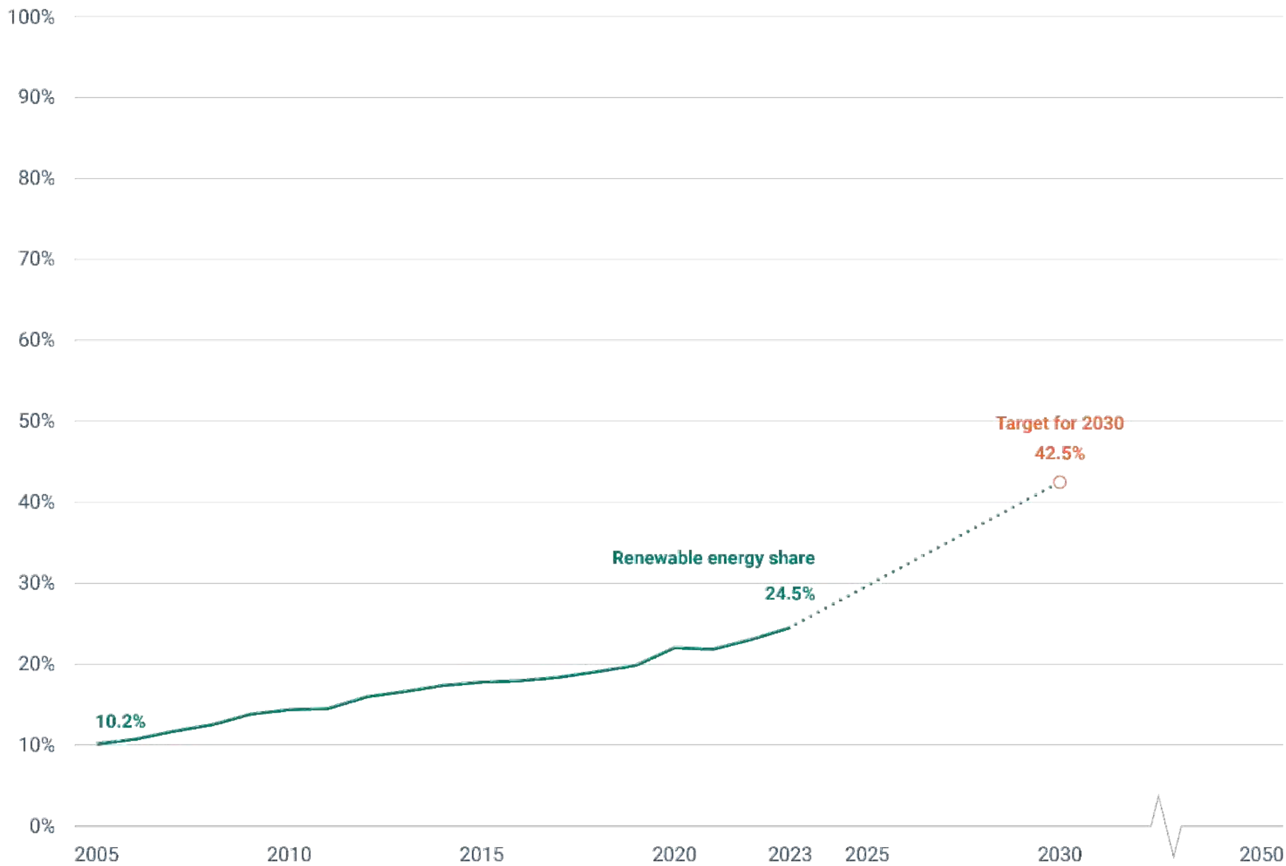

Figure 2: Progress towards renewable energy source targets EU-27

[9] European Commission (2025). *Energy Efficiency Directive* [Accessed 29th July 2025].
[10] European Commission (2025). *The European Green Deal* [Accessed 29th July 2025].
[11] European Commission (2025). *REPowerEU* [Accessed 29th July 2025].

Ireland is one of the worst-performing countries in the EU in terms of renewable energy share, which was at 15.3% as of 2023 (Figure 3). This was less than the average of the EU-27, which stood at around 25% as of 2023.[12]

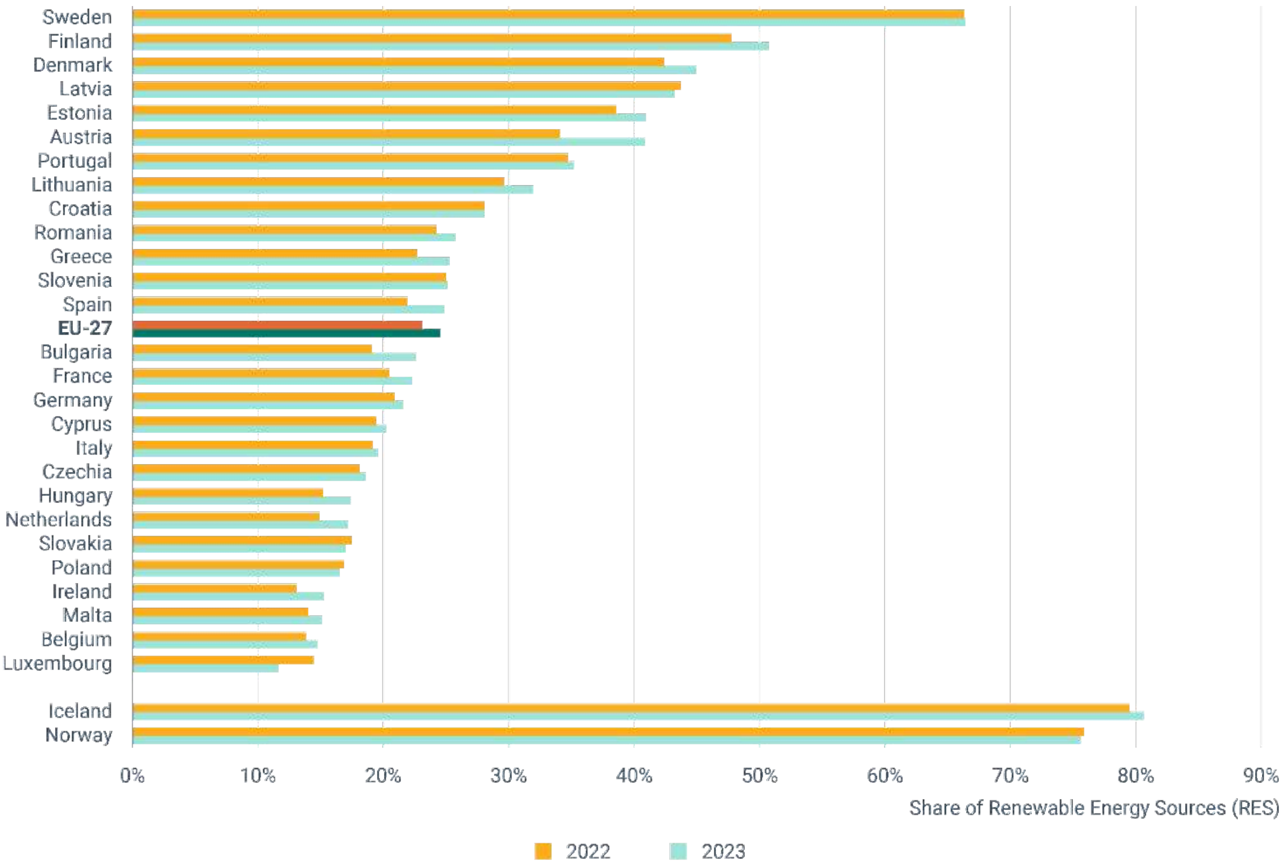

Figure 3: Share of energy from renewable sources, by country

National level context

Strategic documents that shape the landscape of DH in Dublin include the most recent Climate Action Plans (CAPs) published by the Irish government. The CAPs of 2023 and 2024 set out strategic initiatives for DH development, focusing on expanding infrastructure to meet heat demand targets and deploying systems in strategically identified areas. [13] [14]

These plans aim to enhance the integration of renewable heat into the DH mix and establish frameworks for planning, permitting, and regulation to ensure effective implementation and consumer protection. Up to **0.8 TWh** of DH is to be installed across both the residential, public and commercial building stock by 2025, and up to **2.7 TWh by 2030**.

Action CP/25/5 of the 2025 CAP highlights the need to continue to design National Planning Policy to appropriately support DH. [15]

"The deployment of district heating at scale, particularly in densely populated areas with readymade heat sources located nearby, is a key Government objective under the Climate Action Plan and a component in meeting the built environment sectoral emissions ceiling."

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[12] European Environment Agency (EEA) (2025). *Share of energy consumption from renewable sources in Europe* [Accessed 29th July 2025]
[13] Government of Ireland (2023). *Climate Action Plan 2023*.
[14] Government of Ireland (2024). *Climate Action Plan 2024*.
[15] Government of Ireland (2025). *Climate Action Plan 2025*.

The earlier CAPs also stated that there will be a comprehensive heating strategy, and a policy framework developed to encourage DH development. The heating strategy is the resulting National Heat Study, and the policy framework, the Heat Bill.

The General Scheme of the Heat (Networks and Miscellaneous Provisions) Bill 2024[16] has been approved by the government, marking a key step in establishing a regulatory framework for district heating in Ireland. The Bill, which is expected to be drafted in full in 2025, aims to address barriers to DH development, provide legal certainty for developers and consumers and support the expansion of DH networks nationwide. It is part of the government's wider strategy to decarbonise heating and improve energy efficiency.

The main areas covered by the Bill are:

- **Regulation & Consumer Protection: The** Bill establishes a regulatory framework to protect DH consumers, ensuring fair pricing and service standards.
- Mandating Connections: Public sector buildings will be required to connect to available DH networks where feasible, supporting system expansion.
- **Facilitating Development:** The Bill provides legal powers for DH developers to install and operate networks, including rights to access land for pipe infrastructure.
- **Licensing & Oversight:** The new Heat Network Authority will oversee licensing to ensure reliability, transparency, and compliance with sustainability targets.
- **Supporting Waste Heat Use**: Large industrial sites generating over 1MW of waste heat may be required to make it available for DH networks.
- **Enabling Investment:** The legislation aims to provide certainty for investors by setting clear rules and responsibilities, encouraging private sector involvement in DH expansion.

Another key provision of the Bill is the establishment of a Heat Network Authority, which will oversee licensing, regulation, and consumer protection within the DH sector. This Authority will play a central role in ensuring the sector's long-term viability and alignment with national climate targets.

Additionally, the SEAI Centre of Excellence for District Heating will provide critical expertise and technical support to accelerate the rollout of DH projects across Ireland. Acting as a central hub for best practices, the Centre will assist local authorities and developers with planning, financing, and implementing DH schemes. It will also play a key role in standardising DH infrastructure and facilitating investment.

Local level context

In June 2015, Codema, in partnership with Dublin City Council, published the Dublin City Spatial Energy Demand Analysis (SEDA) [17], the first city-level study in Ireland. The SEDA maps local energy demand and aligns it with available resources to promote sustainable energy solutions. This approach enables Dublin City Council to make informed decisions on energy provision, aiming to reduce CO_2 emissions and meet EU energy efficiency targets. Following the SEDA report published in June 2015, several policy developments and plans were introduced to address the findings and promote sustainable energy solutions in Dublin:

The Dublin City Development Plan 2016–2022 [18] incorporated objectives to enhance energy efficiency and integrate renewable energy sources within the city's infrastructure. It emphasised the identification of areas with high heat demand densities, suitable for large-scale district heating systems, as highlighted in the SEDA.

The Dublin City Development Plan 2022–2028 requires major new developments to be district heating (DH) enabled, ensuring they can connect to a communal heat network in the future without significant retrofitting.

[16] Government of Ireland (2024). *General Scheme of the Heat (Networks and Miscellaneous Provisions) Bill 2024*.
[17] Codema. 2015 *Dublin City Spatial Energy Demand Analysis*.
[18] Dublin City Council (DCC) (2016). *Strategic Context for the City Development Plan 2016–2022* [Accessed 29th July 2025]

Within Strategic Development and Regeneration Areas (SDRAs)—particularly Poolbeg/Docklands—developers must show how their scheme will connect to the planned Dublin District Heating Project, with provisions such as centralised wet heating systems, plant room space for heat exchangers, and pipework routeways. Outside SDRAs, DH enablement is expected where feasible, or an alternative low-carbon heating solution must be provided. These measures aim to futureproof Dublin's building stock and accelerate the roll-out of low-carbon heat networks. [19]

CETPartnership

The Clean Energy Transition Partnership (CETP) is a multilateral initiative linking national and regional RDI programs across EU Member States and Associated Countries. Its goal is to support the implementation of the SET Plan by coordinating research, development, and innovation strategies, aligning activities, and engaging key stakeholders. Launched under Horizon Europe (2021-2027), CETP unites the European Commission and public partners to address Europe's energy transition challenges and reduce research fragmentation.[20]

CETP countries agree to focus on challenge-driven RDI, directly involving *"problem owners"* (buyers, procurers, and users of solutions). This approach is embedded in the Strategic Research and Innovation Agenda (SRIA), which defines objectives, expected impacts, and priority RDI challenges. CETP's ambition supports the EU's climate targets and strengthens the European Research Area while fostering international cooperation.

LEG-DHC

For a low-carbon sustainable city, large-scale climate neutral Energy Geostructures for District Heating and Cooling (LEG-DHC) systems/networks harness the ambient heat surrounding underground structures.

In the light of low-carbon sustainable cities, underground structures, such as retaining walls, piles, tunnels etc., can be equipped with ground heat exchangers to harness thermal energy stored by the ground for heating and/or cooling buildings, leading to a friendly technology namely Energy Geostructures (EGS). Previous investigations over the decades have significantly advanced the technological readiness level (TRL) of some EGS (thermo-active piles) to a higher 4+ level with a number of pilot sites.

The institutions shown in Figure 4 are the relevant partners on the LEG-DHC project.

Figure 4: LEG-DHC Partners

The encapsulating LEG-DHC project has been subdivided into several work packages in line with British Standard European Norm (BS EN 13941).

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[19] DCC (2022). Development Plan 2022 – 2028 [Accessed 29th July 2025]
[20] Clean Energy Transition Partnership (2023). *CETP SRIA v1.0 – Endorsed*.

3. Literature review

To fulfil the project objectives, Codema conducted a comprehensive state-of-the-art literature review. The review below begins with a definition of the technologies considered. Following this, Codema identified key relevant policies from a European Union (EU) level down to local implementation.

District heating

Ireland's heating sector is the worst-performing in Europe regarding renewable heat sources. As a result, we face a huge challenge in decarbonising our heating sector. When we look at the best-performing countries for renewable heating, we can see they have high shares of efficient district heating supplying homes and businesses. 54% of Ireland's heat could be most cost-effectively supplied through DH networks based on results from the SEAI national heat study. 87% of Dublin's heat could be most cost-effectively supplied through DH networks based on figures from the Dublin Region Energy Masterplan.

Dublin has become a pioneer in Ireland for local level energy planning and DHC implementation, both of which are completely new practices in Ireland. Codema, as the energy agency for Dublin, has been building these skills and practices with the Dublin municipalities through numerous EU & national level projects. [21]

A District Heating (DH) scheme consists of a super-insulated pipe network, which allows heat generated from a single or several larger centralised source(s) (energy centres) to be delivered to multiple buildings to provide space heating and hot water. DH is a proven technology which has heated towns and cities in Europe since the 1930s and serves over 70 million people across Europe today . Since the first generation of systems was put in place, the technology, methods and practices surrounding the effective use of DH systems have improved significantly with many new networks being 4th generation systems which can utilise a wide range of lower temperature renewable and waste heat sources.

District heating is a proven technology widely used across Europe, supplying over 90% of heat demand in cities like Copenhagen and Stockholm. As a result, district heating is seen as a key technology to decarbonising heat across Europe and in Ireland and is supported through both EU and national policy. Scandinavian countries are leading the way and finding innovative ways to use and improve DH networks to decrease emissions levels, increase efficiencies and decrease fossil fuel use in the energy system.

4th Generation district heating

4th Generation District heating is a heating system that heats multiple buildings from a large, centralised energy hub. This system distributes heat in the form of hot water or steam through a network of insulated pipes. This network can be connected to residential, commercial, and/or public buildings. Instead of each building having its own boiler, they all tap into this shared system, which efficiently provides heat and hot water. This is similar to how electricity is delivered to homes and businesses via the national electricity grid. This approach is not only more energy-efficient but also reduces local air and noise pollution, offering a greener and more cost-effective heating solution for entire communities.

Waste or surplus heat is a by-product of manufacturing processes or generating electricity. This heat would normally be released into the air, sewers or waterways as a waste product. In DH systems, this waste heat can be captured and sent through insulated pipes to help warm up buildings and provide hot water to nearby homes and businesses. For example, heat from factories, power plants, or even large data centres can be reused to heat local neighbourhoods. This method is cost-effective and good for the environment as it uses energy that would be wasted otherwise. In Dublin alone, there is enough waste heat and renewable heat sources to heat the equivalent of over 1.6 million homes. For example, the Tallaght District Heating Scheme (TDHS) uses waste heat from the nearby Amazon data centre to supply the heat to the network.

[21] Codema. 2023 *Transition Roadmap City of Dublin*.

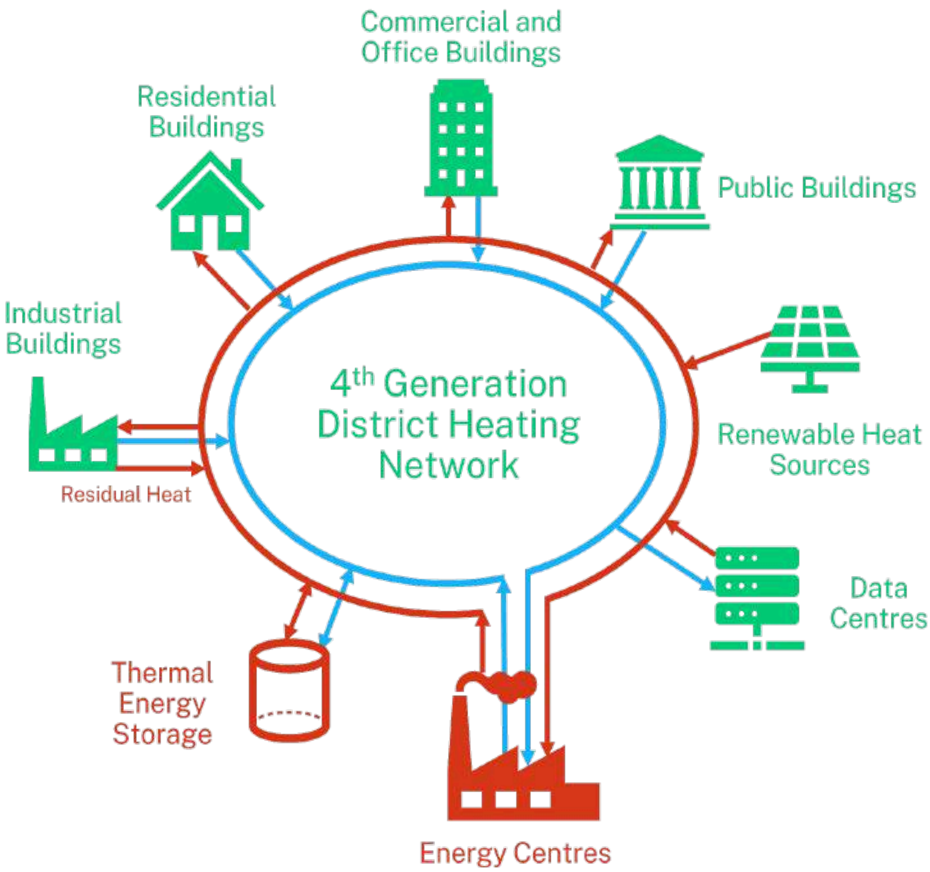


Figure 5: Conceptual 4th Generation District Heating Network

DH networks benefit from economies of scale, the reduced coincidence of heat demand between different customers leading to lower capacity requirements (when compared with multiple building-level units), increased efficiency of larger heat generation units and the reduction in maintenance costs of having a centralised plant. These benefits allow heat to be generated more efficiently and at a lower cost. Having fewer, larger heat generation units when compared with having an individual, building-level heating plant also allows for easier decarbonisation of heat in the long term, as it requires fewer individual heating units to be replaced when adopting newer technologies. These large-scale heating systems can also dramatically reduce the carbon emissions associated with heating without the need for significant retrofitting of buildings.

DH is technology-agnostic and has the inherent flexibility to utilise multiple, diverse, locally available, renewable, and low-carbon heat sources. This means customers are not dependent upon a single source of supply. This can help ensure reliability and continuity of service and introduce an element of competition into the supply chain, as desired. DH can also capture waste heat (e.g., from electricity generation, industrial processes, etc.), which is often lost, and use it to supply heat to homes and businesses, thereby reducing the need to consume further fuel and significantly lowering carbon emissions and the cost of heat.

Greater utilisation of green electricity can also be achieved through the development of DH networks. For example, heat pumps allow electricity to be converted into heat, which can be stored as thermal energy in the district heating network's pipes and thermal storage vessels, effectively acting as a large thermal battery. This flexible demand also reduces stress on the electricity grid and can provide services such as frequency response to the grid to keep it stable.
This is done at a fraction of the cost of other electrical storage methods and allows the electrical grid to be balanced during periods of low electrical demand (night-time). This off-peak demand allows intermittent, renewable generation technologies such as wind turbines to run during these periods, where they could not previously, thereby increasing the green contribution to the local energy system. It is for these reasons that

many of the most sustainably powered countries have a large proportion of heat supplied by district heating systems.

Thermal source networks

When combining the technologies of DH and the elements of underground substructures, the result is 5th Generation District Heating and Cooling, also known as Thermal Source Networks (TSN). These systems are **bidirectional**, **low-temperature thermal grids** designed to **simultaneously deliver heating and cooling** using **distributed heat pumps** at the building level. Unlike 4DHC, they do not rely on centralised high-temperature production.[22]

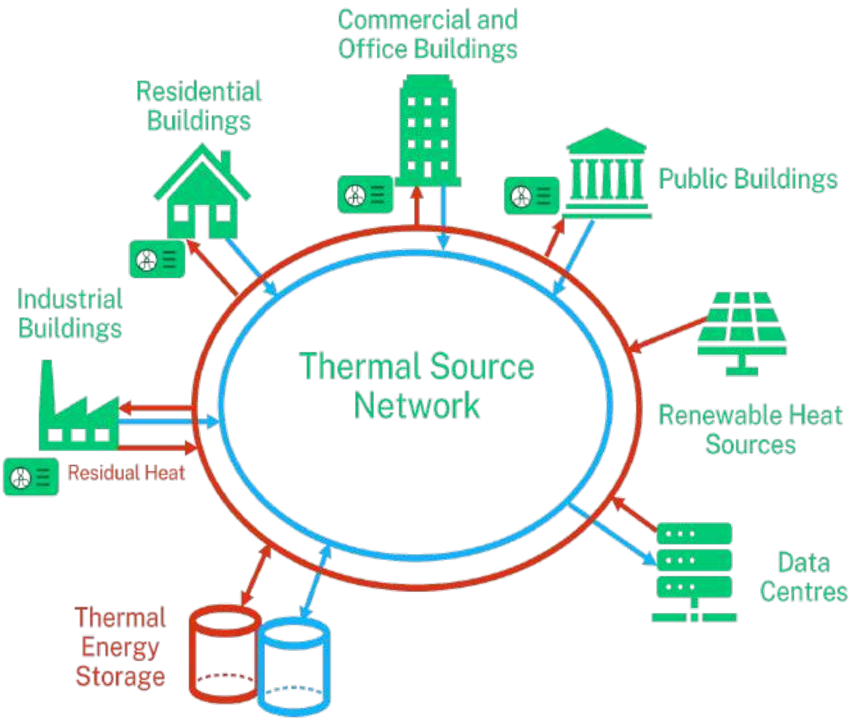


Figure 6: Conceptual Thermal Source Network

A Thermal Source Network can draw heat from multiple low-temperature heat sources some of which are listed below:

Table 1: Potential District Thermal Source Network heat source options

Heat Source	Typical Temperature (°C)
District Thermal Source Network heat source options	
Low Grade Waste Heat (i.e. data centre)	<25
Ground	~12
Ambient Air	~7
Lake/River/Sea Water	~11

Various heat sources could be made available on the island of Ireland to integrate with a TSN system (Figure 8).

[22] Buffa, Simone, Marco Cozzini, Matteo D'Antoni, Marco Baratieri, and Roberto Fedrizzi. 2019 *"5th Generation District Heating and Cooling Systems: A Review of Existing Cases in Europe."* Renewable and Sustainable Energy Reviews 104 (2019): 504–522. https://doi.org/10.1016/j.rser.2018.12.059.

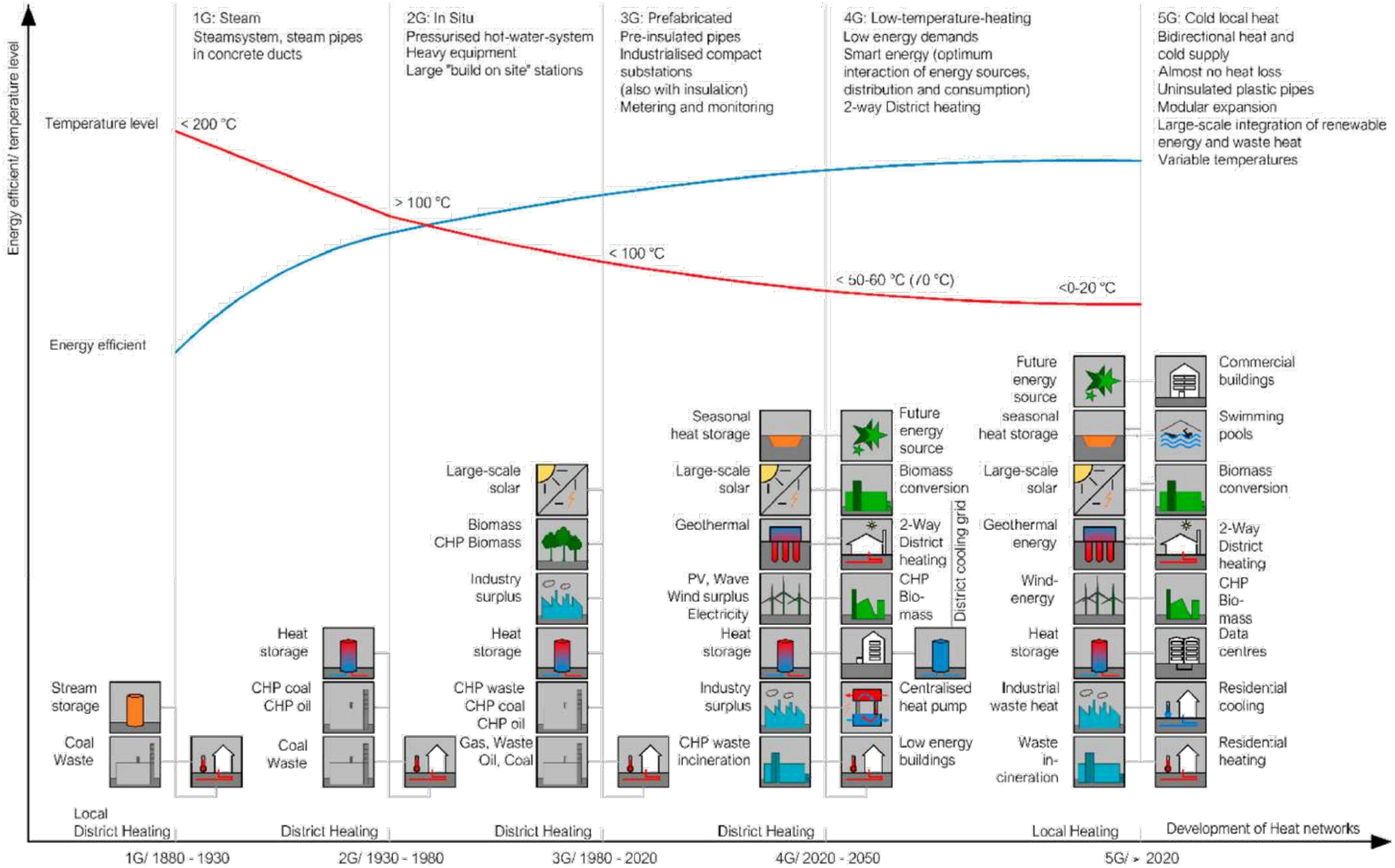


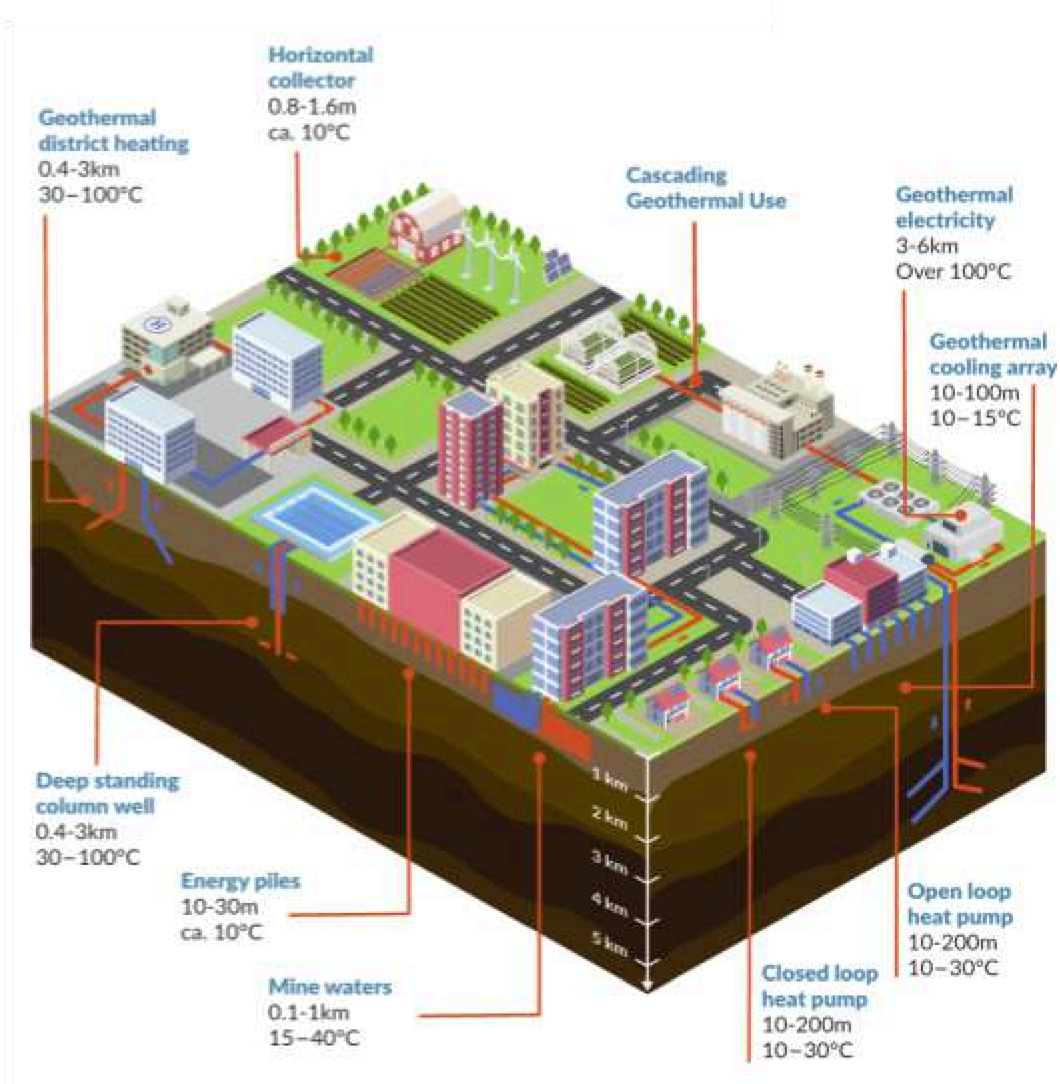
Figure 7: District heating networks from the first to the 5th generation over the last 150 years (Zeh, R.; Ohlsen, B.; Philipp, D.; Bertermann, D.; Kotz, T.; Joci´ c, N.; Stockinger, V. Large-Scale Geothermal Collector Systems for 5th Generation District Heating and Cooling Networks. Sustainability 2021, 13, 6035. https://doi.org/10.3390/ su1311603)

Geothermal energy

Geothermal energy resources are secure, environmentally sustainable, effectively carbon-neutral and cost-effective over long-term periods. In recent decades, improvements in drilling and geothermal technologies, coupled with policy-driven pursuit of secure and low-carbon energy sources, has led to the development of geothermal district heating in several low temperature geothermal settings in the EU (e.g., France, the UK, Denmark and the Netherlands).

The complete security of supply of geothermal energy makes it a particularly attractive energy solution as this aligns with an important EU objective to significantly reduce our reliance on third country suppliers of fuel. The near-zero carbon emissions strongly support Ireland's goal of reaching EU 2030 and 2050 emissions targets.

Ireland has a recognised potential for low-to-medium temperature geothermal energy resources (> 400 m deep) suitable for large-scale or district heating and cooling in municipal, residential and industrial areas. [23]



[23] Geological Survey Ireland (GSI) (2020). An Assessment of Geothermal Energy for District Heating in Ireland

Energy geostructures

Geotechnical structures are increasingly being deployed as energy geostructures across Europe and worldwide.[24] Energy geostructures refer to conventional geotechnical structural elements such as piles, diaphragm walls, retaining walls, and tunnels, that are equipped with embedded heat exchanger loops or groundwater collection to enable thermal energy exchange with the ground. These dual-purpose systems serve both structural and geothermal functions, making them ideal for urban settings where land is limited and infrastructure density is high.

The integration of thermo-active foundations into building and district-scale energy systems enables the extraction or rejection of low-grade thermal energy from the shallow subsurface. When combined with heat pump technology, energy geostructures can support both heating and cooling demands, contributing to net-zero carbon objectives without additional land or aesthetic footprint.

Their performance is largely influenced by:

- Thermal conductivity of the surrounding soil or rock or ground/drainage water flow rates;
- Geometry and material of the structure and;
- Operational strategies, particularly flow temperature and duration.

Recent research highlights their viability within low-temperature and bidirectional networks, particularly TSN systems, where their ability to supply ambient heat for distributed heat pump use aligns with modern DH objectives. In addition to thermal performance, life cycle assessments show that energy geostructures have lower environmental impacts compared to borehole fields due to shared capital and embodied energy.

In LEG-DHC applications, energy geostructures offer unique benefits:

- Urban suitability with minimal land use;
- Scalability across infrastructure projects (e.g. metro stations, car parks) and;
- Synergy with DHC networks, particularly as passive sources in thermal source networks.

Their inclusion supports decentralised and modular DH network design, particularly in new builds or urban redevelopment zones, making them suitable for Dublin's emerging clusters of DH energy.

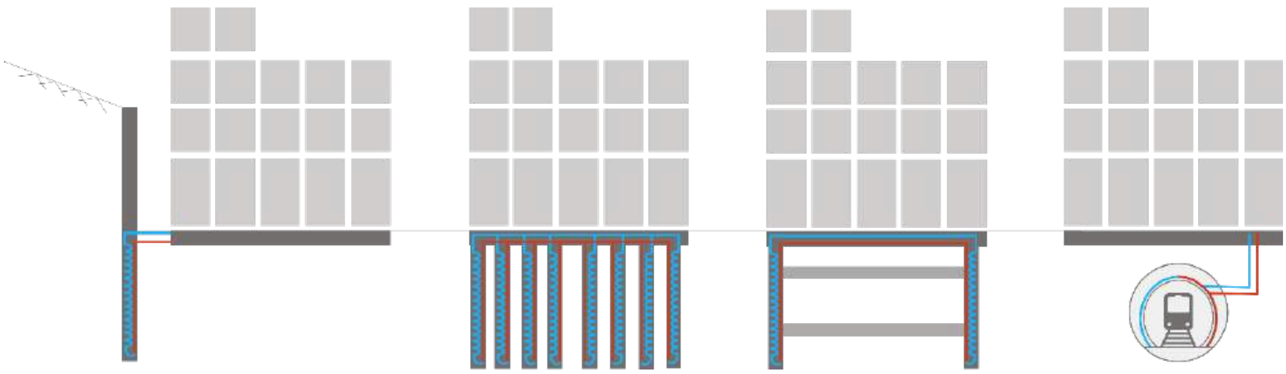


Figure 9: Energy Geostructures (From left to right: retaining wall, energy piles, energy diaphragm walls, energy tunnel)

[24] Marco Barla, Alice Di Donna (2018). *"Energy Tunnels: concept and design aspect".* Department of Structural, Building and Geotechnical Engineering, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy https://doi.org/10.1016/j.undsp.2018.03.003

Energy Tunnels

With levels of worldwide pollution increasing and a global need for more green space, more and more cities are turning to underground transportation and utilities. There is also a need to develop low environmental impact and sustainable energy sources. In this context, shallow geothermal systems, used for domestic heating and cooling, may play an important role and their growth potential should be investigated. [25]

Energy tunnels are a relatively novel form of heat extraction. The main advantage of these types of energy extraction forms is that the tunnels are often being built anyway, thus reducing costs. In general, a geotechnical structure can be thermally activated by embedding polyethylene pipes in its concrete body. The fluid flowing in the pipes constitutes the means for transferring heat from the ground to the buildings or vice versa through heat pumps.

Stakeholder engagement

As part of this research project, Codema reached out to several industry experts to gain insight into the practicalities of implementing EGS, specifically in the Dublin region. Codema engaged with three key expert stakeholders in planning and construction of DH. Each of these experts provided their unique perspective to the novel challenge of developing LEG-DHC projects in Ireland. Below are detailed considerations and recommendations from these specialists. The names and details of each individual and organisation have been kept anonymous but these stakeholders cover the areas of pipe network installation, DH network development and subsurface surveying.

Building specialist interview

Codema reached out to district heating pipe network specialists to glean valuable insights on the integration of DH pipework into underground structures. Installation of DH infrastructure in this manner has been done before, notably in countries within the Nordic region of Europe such as Sweden.

In the specific case of tunnels, a major consideration is whether the tunnel in question is accessible. Inaccessible tunnels restrict the potential of the infrastructure that can be put in place whereas accessible tunnels are more of a ‘blank canvas’. The measurement of the tunnel is of paramount importance as working in underground conditions requires accurate information of site layout and has different safety considerations and practical installation methodologies when talking about work that may be undertaken in confined spaces.

There are multiple methods of approaching the installation of pipes into concrete ducts. For the purpose of this feasibility study, it was assumed that the DH pipes could be sized anywhere between 50mm - 400mm in pipe diameter.

In terms of sizing the network, the vertical leg of the pipe is an elusive consideration. The specifics of the pipe layout, diameter, and other parameters should be known prior to approaching a specialist. Initial boundary conditions on the parameters of the network are essential to providing adequate assumptions about the structure of the network. Also the temperature variance during installation and operation along with the type of pipe fixings will have an impact on the viable pipe lengths with can be installed.

Construction tolerances are an important consideration; this will be discussed further in the technical analysis.

Local authority interview

Codema works closely with the four Dublin Local Authorities (DLAs) to help monitor their energy output, manage their decarbonisation strategies, and mitigate emissions across the Dublin region. Codema engaged with the local authority team working on the installation of DH pipework in tunnels to gain real world

[25] Marco Barla, Alice Di Donna (2016). Editorial. *Environmental Geotechnics*; 3 (4): 188–189. https://doi.org/10.1680/jenge.2016.3.4.188

insight into the implementation process of a DH system within the Dublin region to understand what barriers stood in the way of the development of tunnel energy geostructures.

When developing underground structures, the use of waste heat should be considered in the initial application; Underground structures are expensive, and the magnitude of those costs has more unknown factors than above-ground construction. For any one project, one must consider the capacity to install geostructures in the first place. Existing tunnels, such as the Dublin Port Tunnel, have not been designed for geostructures but do have heat capture potential through the harnessing of heat from the tunnels drainage system.

While tunnelling is expensive, deep shafts for pipes and services can increase project costs even further and should only be considered if no other options are available. One must ensure the longevity and maintenance of any underground heating system is sound as the consequences of a malfunction / damage by 3rd party would have an impact on its operation and surrounding environment. Actively monitoring the entire process with monitoring devices will be mandatory.

The key issue with directional drilling to accommodate pipework under existing obstacles is that the ground conditions are unknown. Beyond 2m in depth, trench boxes or tunnel access are essential. For working in accessible tunnels, Codema reached out to experts in the geospatial industry.

Geospatial surveyor interview

The navigation of an accessible geostructures require sufficient understanding of said structure's dimensions and measurements. Codema spoke with an expert geospatial surveyor to discern the health and safety requirements of operating within the confined spaces that energy geostructures inhabit.

For tunnels, the accessibility would demand sufficient consideration for health and safety precautions. A 0.8m tunnel is considered 'accessible'. Most tunnels are smaller than one would like for manned entry, so cage drones and rovers equipped with LIDAR can be deployed to access tough-to-navigate areas and generate a 3D digital profile and dimensional cross-section of the underground. Consideration must be made for other services in the underground structure (pipes, cables, etc.)

Retrofitting any geostructures system into an underground means that it is critical to know exactly where the tunnel is in terms of its dimensions. Understanding the dimensions of the tunnel is of the utmost importance for the installation of any geostructures system. Care must be taken in the realm of occupational health, operational safety, and structural integrity

One case study that will be discussed, the Dublin MetroLink, is a unique situation as it is one tunnel instead of two bores.

International case studies

France

The *'Grand Paris Project'* forecasts from 2018 to 2033, around 200km of tunnels will be built around Paris to increase the capacity of the existing metro and the transport efficiency. The added cost of the thermal structures is limited with respect to the overall costs of the project. The potential thermoactive structure can provide economic and environmental benefits.

Several geotechnical barriers as part of an energy tunnel project; namely the need for thermal modelling, ground characterisation, and smart monitoring to exploit these new energy facilities. As a notable metro project, numerous lessons learnt from this project could be incorporated into the Dublin MetroLink should energy tunnels be considered as part of the project.[26]

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[26] Yvon Delerablée, Dina Rammal, Hussein Mroueh, Sébastian Burlon, Julien Habert and Charline Froitier (2018). *"Integration of Thermoactive Metro Stations in a Smart Energy System: Feedback from the Grand Paris Project"* 10.3390/infrastructures3040056

Italy

The Turn Metro Lines 1 and 2 in Italy were experimental sites whereby thermally active segmental lining was installed into the tunnel. The objective for Metro Line 1 was to evaluate energy, geotechnical, and structural efficiency. Metro Line 2 used a Finite Element Model (FEM) to analyse the heat exchange between the ground and the structure.

In Metro Line 1, Monitoring tools, such as pressure cells, vibrating wire, strain transducers, thermistors, fibre optics strain and temperature sensors embedded in the concrete lining are used to evaluate the thermo-mechanical behaviour of the system during testing.

Investigations found that 1MW of thermal energy can be exploited per kilometre of tunnel, satisfying the thermal energy demand of residential dwellings. In this context, the Metro lines can be seen as their own local district heating and cooling network. [27] [28]

National case studies

Energy geostructures do not exist yet in any significant capacity within Ireland. From a national perspective, Codema has reviewed three of the most prominent district heating projects currently in development or expansion in Dublin, the Dublin District Heating Project (DDHP), the Blanchardstown District Heating Scheme (BDHS) and the Tallaght District Heating Scheme (TDHS). *In Dublin, there is currently a critical project development assistance funding gap to take DH projects from the feasibility stage to procurement.*

Figure 10: Map of Dublin County showing the locations of key case studies

[27] Marco Barla, Alessandra Insana (2018) *"Energy Tunnel Segmental Lining: An Experimental Site in Turin Metro"*
[28] Barla, Marco & Baralis, Matteo & Insana, Alessandra & Zacco, F. & Aiassa, S. & Antolini, F. & Azzarone, F. & Marchetti, P. (2020). *"Feasibility study for the thermal activation of Turin Metro Line 2".* 10.4324/9781003029724-2.

Figure 11: District Heating Pipes

Dublin District Heating Project

The Dublin District Heating Project (DDHP) is a transformative initiative led by Dublin City Council (DCC) aimed at establishing a sustainable and efficient heating network across Dublin City. The project seeks to harness waste heat generated at the Dublin Waste to Energy (DWtE) facility located in Poolbeg and redistribute it through a network of insulated pipelines to heat residential, commercial, and civic buildings in the Poolbeg, Ringsend, and Docklands areas. The objectives of the DDHP are;

- Contribute to Ireland's Climate and Energy Targets
- Enhancing the security of Energy Supply to the City of Dublin
- Providing pathway for future expansion of DH in Dublin/Ireland
- Improve Air Quality in Dublin City.

The DDHP design is a primary heat source, capable of producing 90 MW of Heat, namely the DWtE Facility, (two independent boiler lines with an overall 92% boiler availability requirement)– 100% redundancy back-up, provided by a series of boilers, which also offer peaking capacity to the network, – and a thermal storage tank, which will allow the optimisation of the network operation and provide back-up for circa four hours at peak demand. The distribution network is an underground distribution network (DH pipe system of a flow and a return) with comparable reliability to equivalent utility networks.

Blanchardstown District Heating Scheme

Fingal County Council (FCC) is proposing to implement the Blanchardstown District Heating Scheme (BDHS). The proposed system seeks to utilise a low-temperature waste heat source from a nearby data centre through a large-scale heat pump to supply space heating and hot water to a university campus, public hospital, and a national sports facilities campus in its first delivery phase. The system will also have the capacity to supply other nearby interested customers in the public and private sector in the following phases.

This innovative district heating scheme will provide low-carbon, low-cost heat to the Blanchardstown area, and will be only the second of its kind in Ireland, following the example of the Tallaght District Heating Scheme in South County Dublin.

The results of this feasibility study, which was delivered in 2023, indicate that the scheme is both technically and economically viable and provides more benefits than the alternative (individual air-source heat pumps). This study delivers a high-level strategy. A technical detailed design would need to be completed before the recommendations are implemented.

Tallaght District Heating Scheme

Codema supported South Dublin County Council in developing the Tallaght District Heating Scheme (TDHS), the first large-scale district heating network in Ireland. Phase 1 of the scheme has been operational since 2023. Operating under Heat Works, Ireland's first not-for-profit energy utility, the TDHS will significantly contribute to reducing carbon emissions in the area, saving almost 1,100 tonnes of CO_2 in 2023 and establishing Tallaght as a leader in innovation in climate change.

Located in South Dublin, the scheme utilises waste heat from a local Amazon data centre, which would otherwise be rejected to the atmosphere, to provide reliable space heating and hot water to public and residential buildings in the area.

The system currently supplies the nearby TUD campus, South Dublin County Council's offices, the county library, the nearby Innovation Centre, and residential apartments within the vicinity. A centralised energy centre with heat exchangers and thermal storage buffers the recovered heat and distributes it via the the network at between 70°C and 85°C (weather compensated system). The scheme is modular and scalable, designed to expand toward the Tallaght Innovation Quarter and surrounding developments and make full use of the data centre waste heat available. Additional exploration boreholes have also been drilled in the TUD campus in order to help determine the viability of deep geothermal resource in the area with a view to diversifying the heat supply to the network into the future.

Figure 12: The Tallaght District Heating Scheme (TDHS), Dublin 24

These three case studies are examples of domestic and commercial district heating in Dublin, Ireland, taking waste heat from primarily above ground infrastructure (data centres, waste-to-energy plants etc.). They have not considered the full potential of underground energy geostructures as yet.

Potential geostructures projects

Dublin Port Tunnel

Dublin City Council (DCC) was the client for the Dublin Port Tunnel Project, the largest every roads transportation project in Ireland. The final scheme from north to south consists of 750m surface of works connecting to the M1 motorway, 1,600m of cut and cover and retained cut at the Northern end, 350m of twin-bored tunnel (through boulder clay), a 56.6m internal diameter launch shaft, and 2,250m of twin-bored tunnel (predominantly through limestone).[29]

Dublin MetroLink

The Dublin MetroLink is a proposed metro line intended to enhance Dublin's public transport by connecting the city's north and south, running from the Estuary near Swords to Charlemont. Key stops along the route include Dublin Airport, O'Connell Street, and St. Stephen's Green. As of writing, the project is in the design phase, pending planning permission approval. Construction is anticipated to commence in 2025, with project operation projected to begin by 2034. DH was not initially considered in the official planning submission to the relevant Dublin local authorities.

As a high-profile project in Ireland, the Dublin MetroLink could provide a good opportunity to promote energy geostructures as part of increasing renewable heat share in the country.

The full map of the proposed project can be seen in Figure 13.

[29] Microsoft Word - Press Documentt.doc

Figure 13: Proposed Dublin MetroLink route

4. Research methodology

This study involved a state-of-the-art literature review, stakeholder interviews, and a technical analysis:

- ***The literature review consists of a desktop study guided by Codema's prior expertise in DH systems feasibility in Dublin. Stakeholder interviews were conducted through unstructured conversations with interested parties that Codema deemed to be relevant for this project.***

- ***The step-by-step technical analysis deployed in this report used a format developed by Codema and published by the Sustainable Energy Authority of Ireland (SEAI).***

- ***A list of recommendations to different industry stakeholders have been made.***

5. Demand assessment

Heat Demand

While it would be preferable to connect as much demand as possible to the DH network to maximise it's linear heat density and therefore its viability, there exists some constraints. Building use, ownership and the type of secondary heating system are the primary means of determining the likelihood of connection. Publicly owned buildings, such as the hospital, are under an obligation to decarbonise their heat, and so have a high certainty of connection. On the opposite end, private rentals have a limited capacity to influence connection.

As such, the potential customers of the DH scheme have been separated into different levels of connection likelihood (Table 2). Also buildings which do not have a centralised heating system or which have a direct electric heating system (e.g. electric radiators or storage heaters) are more difficult to connect due to the additional cost of retrofitting the building with a wet heating system that is compatible with a DH connection.

The Dublin Region Energy Master Plan (DREM) establishes a host of facts and figures regarding the potential of DH to the Dublin region. The report includes a demand assessment of the entirety of Dublin as of the report's publishing (2021) in Appendix D.

When acquiring heat demand data, the following figure (Figure 10) illustrates the quality which one should strive to achieve. The DREM outlines in which case each of the four levels of quality are utilised to paint a picture of Dublin's heat demand.

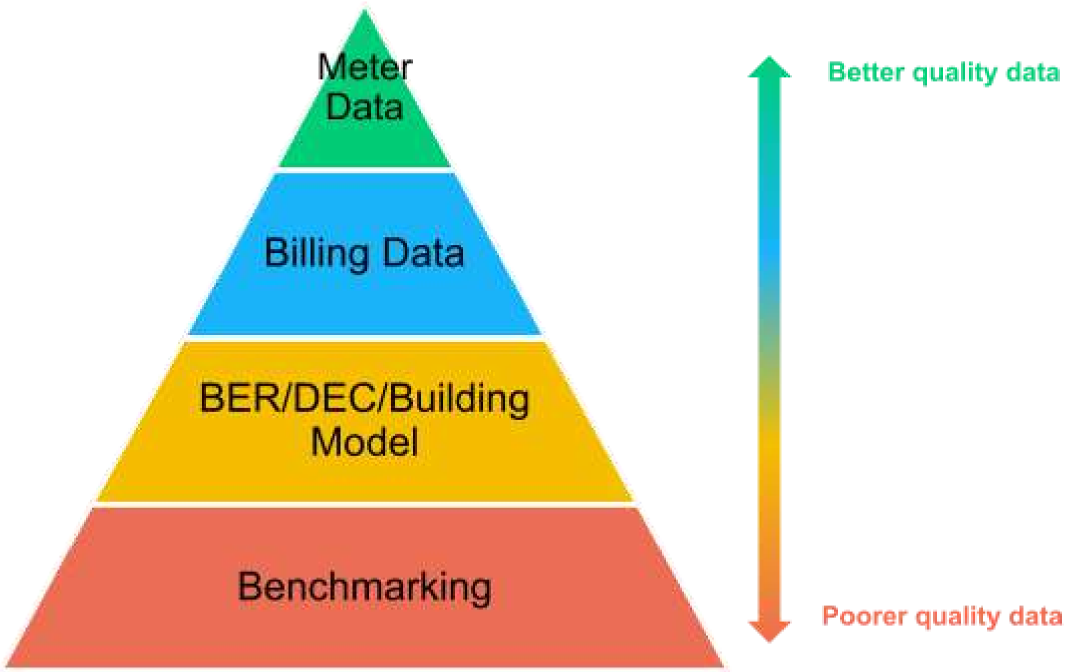

Figure 14: Hierarchy of heat demand data

Connection Likelihood	Description	Building Type(s)
Heat demand categorised by connection likelihood		
High	Publicly owned buildings with a centralised wet heating system, high certainty of connection	Leisure centres, hospitals, prisons, University buildings, etc.
Medium	Buildings with energy efficiency obligations/objectives and new developments that must meet new building energy regulations have an increased likelihood of connection.	Hotels, new residential developments, and social housing
Low	Private buildings/rentals, limited ability to influence connection. Buildings with heating systems that are less compatible with DH i.e. systems that are not water-based and/or are not centralised.	Apartments with storage heaters or electric radiators, existing rented dwellings

Table 2: Heat demand categorised by connection likelihood

Where heat demand data was not made available through billed consumption, meters, or public sources (such as the SEAI Monitoring and Reporting (M&R) system, heat demand benchmarks should be used in conjunction with degree day (DD) connections, weather-dependent fractions (WDF), and accounting for typical boiler efficiencies (85%) should be used. An example of this calculation is shown in Equation 1 below:

$$Heat\ Demand\ (kWh) = \left(\left(\frac{kWh}{m^2}\right) * (DD) * (WDF)\right) + \left(\left(\frac{kWh}{m^2}\right) * (1 - WDF)\right) * Floor\ Area\ *\ Boiler\ Eff\ \%\ (1)$$

Customers identified can be classified into three tiers based on the probability of their connection. Entities such as universities, hospitals, and other public sector bodies fall within the high likelihood of connection tier due to their mandatory decarbonisation obligations. Social housing and residential apartments represent a medium likelihood tier, considering the local authority (LA) typically owns the social housing stock, affording substantial influence over their potential collection.

6. Assessment of energy supply options

Supply Options Longlist

DH network infrastructure is fuel agnostic. That is, it can deliver heat from a variety of heat supply sources available. This is much like the electricity network which draws from different sources of energy. The priorities in terms of the heat supply are the competitiveness (cost of supply) and the sustainability (efficiency and carbon content) of the source. This section gives a breakdown of existing heat sources in the Dublin region and provides a comparison of each in a source analysis matrix.

Ambient air

Air source heat pumps (ASHPs) extract heat from the ambient air and upgrade it to a usable temperature for district heating via a refrigeration cycle. ASHPs can be deployed in nearly any location with suitable electrical capacity and adequate space for collectors, making them a flexible and scalable option. Centralised ASHP systems aggregate heat production, improving efficiency and simplifying maintenance.

ASHPs perform best in moderate climates like Ireland's but become less efficient in colder temperatures, requiring backup heating solutions during peak demand. While they require electricity to operate, they can be powered by renewable energy sources, further enhancing their sustainability. Their scalability allows incremental capacity expansion

Water source

A Water Source Heat Pump (WSHP) can be used to extract energy from a river either indirectly by circulating heat transfer fluid through a pipe network in a riverbed or lakebed or directly by extracting and reinjecting the water itself. In the indirect system the heat transfer fluid absorbs the heat from the body of water and transfers it to the refrigerant in the heat pump. The refrigerant is then compressed and heated. This heat is used to heat the water entering the DH scheme. These systems require less space than ASHPs due to the greater ability of water to carry/transfer heat than air requiring smaller collectors and are also generally more efficient particularly in winter when water temperatures are slightly higher than air temperatures.

Geothermal

Geothermal energy is a renewable and continuous source of heat derived from the Earth's internal thermal energy. It can be classified into shallow and deep geothermal systems, both of which have potential applications for district heating. Unlike other renewable sources, geothermal energy is not subject to weather fluctuations, making it a highly reliable heat source.

However, high initial investment costs and the need for geological assessments are key challenges that must be addressed before deployment. Geological studies conducted by Geological Survey Ireland (GSI) indicate that Ireland has potential for low-to-medium temperature geothermal resources suitable for DH.

Shallow geothermal (<400m depth)

Shallow geothermal energy systems extract heat from the upper layers of soil, rock, or groundwater, typically up to depths of 400 m. These systems rely on ground source heat pumps (GSHPs) to transfer heat from the earth into buildings or district heating networks. The near-surface temperatures in Ireland range from approximately 9.5°C to 11.5°C, providing a stable and consistent heat source year-round.

Two primary shallow geothermal configurations exist: closed-loop and open-loop systems.

Closed-loop systems circulate a heat-transfer fluid through buried pipes, absorbing heat from the ground, while open-loop systems use groundwater directly as a heat source before returning it to the environment.

Deep geothermal (>400m depth)

Deep geothermal energy involves extracting heat from depths exceeding 400 m, where temperatures are significantly higher, allowing for more efficient heat transfer. This method is widely used in geothermally active regions such as Iceland and Italy, where high-temperature resources are readily available. In Ireland, deep geothermal resources are less well-characterised, necessitating extensive geological surveys and test drilling to confirm their viability.

Unlike shallow geothermal systems, which require heat pumps, deep geothermal can potentially provide direct heating at higher temperatures, reducing the need for additional energy input. The primary challenges associated with deep geothermal energy in Ireland include drilling costs, geological uncertainty, and the lack of established infrastructure.

Wastewater treatment plant

Wastewater treatment plants (WWTPs) process sewage to remove contaminants through a series of biological, chemical, and mechanical treatments. During these processes, wastewater retains significant thermal energy, particularly from household and industrial hot water discharges. This heat can be captured using heat exchangers, which extract the thermal energy from the treated effluent before it is discharged. Heat pumps can then elevate the temperature of the recovered heat to a suitable level for district heating applications, providing a sustainable and consistent source of thermal energy. This heat can be captured and transferred to a DH network via heat exchangers and pumps.

Commercial low-grade waste heat

Supermarkets and commercial buildings generate waste heat from refrigeration systems, which can be recovered and supplied to a DH network. While commercial waste heat offers a nearby source of energy, it presents several significant challenges that limit its viability as a primary heat source for district heating. The primary issue is that many of these buildings often have relatively low heat output.

Bioenergy

Bioenergy consists of fuels that have been sourced from a renewable source. Instead of coming from a deposit underground, it comes from processing plants that have captured carbon throughout their farming process. The final product, biogas and biomass, is burned in a boiler or CHP plant to generate heat, which will need to be built along with the energy centre and other DH infrastructure.

Data centres

Data centres generate substantial amounts of heat as a byproduct of their operations, requiring advanced cooling systems to maintain optimal functionality. The waste heat from data centres typically has a temperature profile ranging from 25°C to 35°C if using air cooling rather than liquid cooling, which, while considered low-grade, is highly suitable for integration into a district heating system when paired with heat pumps. Unlike ambient air, which can be highly variable in temperature, data centre waste heat provides a stable and continuous thermal output. This consistency improves the efficiency of heat pump systems, reducing operational costs and energy losses.

Heat Source Options	Ambient Air ASHP	Water Source WSHP	Shallow Geothermal (<400m)	Deep Geothermal (>400m)	Wastewater Treatment Plant	Commercial Low-Grade Waste Heat	Bioenergy	Data Centres
Longlist Source Options								
General Description	Air Source Heat Pumps (ASHP) can be integrated into DH systems to extract ambient air heat, which is then upgraded to a higher temperature and distributed through the DH network for space heating and hot water supply in connected buildings.	A water source heat pump (WSHP) extracts energy from a nearby river by circulating a heat transfer fluid through pipes in the riverbed. This fluid absorbs heat and transfers it to the refrigerant in the heat pump, which is then compressed and heated. The resulting heat is circulated to the buildings in the DH scheme.	Shallow geothermal energy is the heat extracted from the earth's near surface, typically up to 400m deep. According to Geological Survey Ireland (GSI). Ireland has a recognised potential for low-to-medium temperature geothermal energy resources (>400m deep) suitable for large-scale or district heating and cooling in municipal, residential, and industrial areas.	Deep geothermal energy is the heat extracted from the earth's deeper subsurface, typically beyond 400m, for use in heating, cooling, and electricity generation.	Recovered heat from Wastewater Treatment Plants (WWTP) can be integrated into DH schemes by using post-treatment sewage water through heat exchange and heat pump systems.	Waste heat can be captured from supermarkets by using heat recovery systems that extract thermal energy from refrigeration and HVAC systems, which can then be transferred to a DH network or used for heating the store.	Bioenergy can be used in DH by burning biomass or biogas in boilers or Combined Heat and Power (CHP) plants to generate heat, which is then distributed through a network of pipes to provide space heating and hot water to connected buildings.	Data centres generate substantial amounts of heat as a byproduct of their operations, requiring advanced cooling systems to maintain optimal functionality.
Proximity to a Network	ASHPs can be installed in any location provided there is sufficient space and utility to house the equipment at the site.	The proximity of water sources is site dependent.	Shallow geothermal arrays can be installed at many locations, the feasibility and practicality depend on specific geological, regulatory, and site-specific factors (such as land availability).	Extensive geological surveys, engineering studies, and cost-benefit analyses are necessary to determine the suitability and viability of deep geothermal projects in a particular location.	WWTPs sparsely populate the county as can be seen in Figure 13.	There are numerous supermarkets in the Dublin region in randomised locations. It would be difficult to aggregate the waste heat to supply any one area.	Bioenergy resources may be available in rural areas. Limiting factors for utilisation include contracting complexities (double contracts for security of supply), increased traffic of large trucks into city locations, and a need for ongoing operational supply management.	Data centres are traditionally situated away from town centres in industrial parks.
Heat Capacity (MW)	The capacity of a centralised ASHP used in a district heating system is sized based on the anticipated heat demand that will be connected to the scheme.	For a river, the flow rate and assumed temperature produces heat using a heat pump.	High resolution and robust data is available in Ireland to depths of 400m. However, the capacity of a shallow geothermal array is dependent on the number of energy geostructures, and as such the system is typically sized based on anticipated heat demand of the DH system.	Capacity data not available. This will depend on factors such as available temperatures and the permeability of the subsurface.	The EU waste heat map shows the heat production of different WWTPs. This can also be estimated based on population equivalent that the WWTP is serving.	This will vary greatly for different sites. The average anticipated heat recovery per facility in Ireland is 3TJ/annum. Estimates of such figures can be found in the various heat source maps shared in this report.	While there is a potential bioenergy resource available in Ireland, the resource has scalability limits in comparison with other resources, as the lowest carbon bioenergy sources will have many competing use cases.	Server waste heat capacity is equivalent to the server electrical load
Heat Source Temperature (°C)	Ireland has a temperate maritime climate, which means it experiences relatively mild seasons (Mean daily winter temperatures vary from 4.0°C to 7.6°C. Mean daily summer temperatures vary from 12.3°C to 15.7°C.	The temperature of a river can fluctuate between ~2°C and ~24°C. The Environmental Protection Agency (EPA) provides figures on this.	Ireland has an estimated crustal geothermal gradient of 25 - 30°C/kms. The assessment of ground temperature in Ireland has identified that depths of up to 400m have estimated temperatures below 26°C. At 100m the estimated temperature is up to 22°C.	Temperature data not available but typical rule of thumb for the temperature gradient is for temperature to increase by 30°C per km depth.	Treated wastewater typically has an annual average temperature of 12°C, ranging from 8°C to 15°C, and occasionally higher in summer.	-	High temperature heat available from bioenergy combustion.	The waste heat from data centres typically has a temperature profile ranging from 25°C to 35°C if using air cooling rather than liquid cooling, which, while considered low-grade, is highly suitable for integration into a district heating system when paired with heat pumps.

Table 3: Longlist supply options

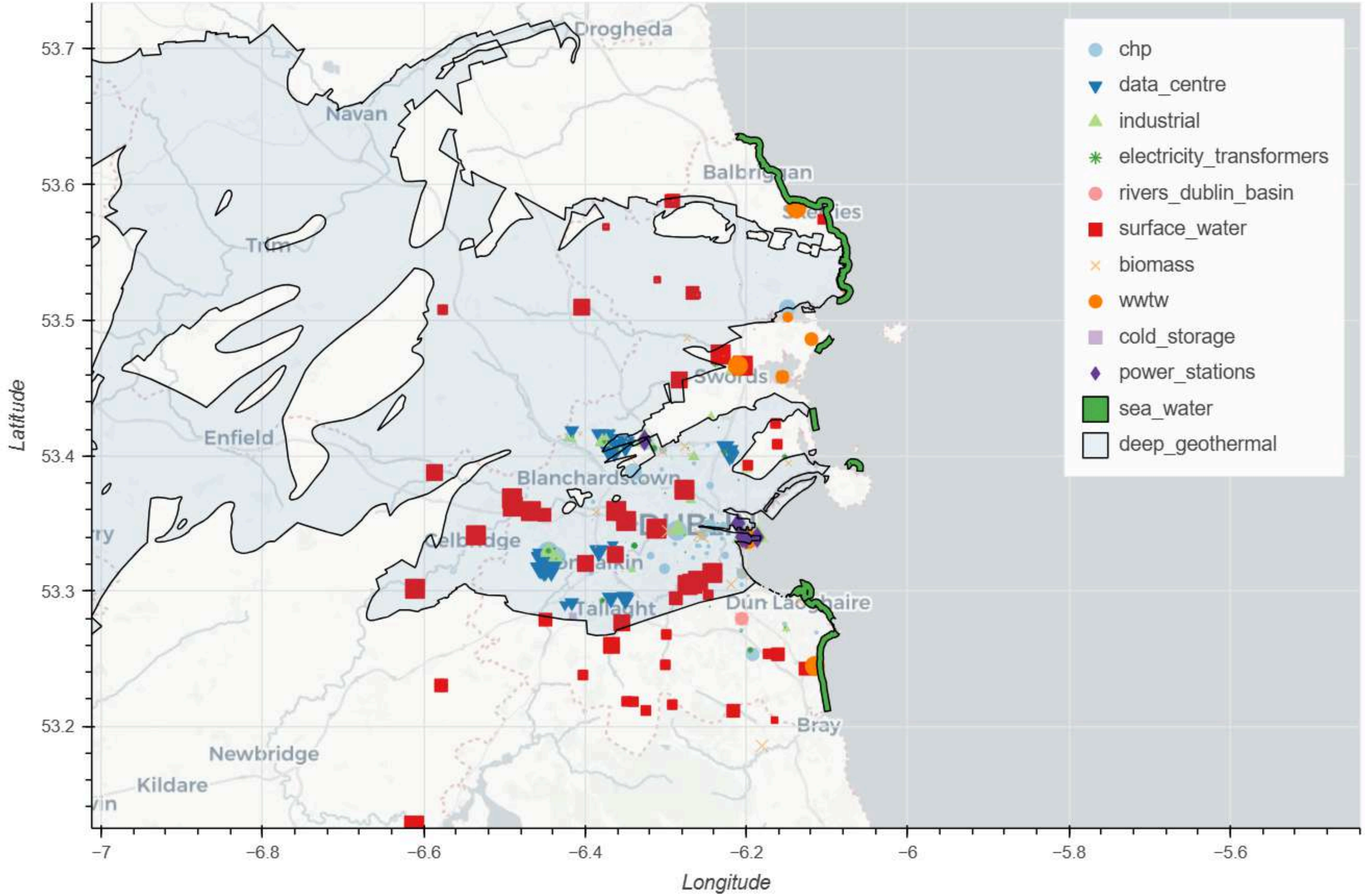

Figure 15: Map of Dublin waste heat sources as of 2021 (analysis by Codema)

7. Heat distribution system

Design of district heating pipe systems shall ensure that the system is given:

1) Sufficient durability, robustness, and reliability in relation to the internal and external loads and impacts, to which it is likely to be subjected in normal operation;
2) sufficient safety not to endanger persons or the environment;
3) good energy economy;
4) good overall economy (total life-cycle costs);
5) good operating properties;
6) safety of supply and;
7) good possibilities of inspection and maintenance

Pipeline construction

Like traditional DH systems, heat is distributed through a network of pipes in a LEG-DHC project. As the pipeline will be integrated with the underground geostructures (a tunnel in this instance), consideration should be made as to the structural compensation for the system. The three options below give an indication of the maximum allowable length of pipe that could be between different types of end fixings, based on a number of scenarios. Project specific checks are required in all cases. The temperature considered in these scenarios is shown below in Equation 2:

$$T_{ins} = 10°C;\ T_{max} = 85°C;\ \therefore \Delta T = 75°C \quad (2)$$

Option 1-A: Buried Z bends in ground at either end

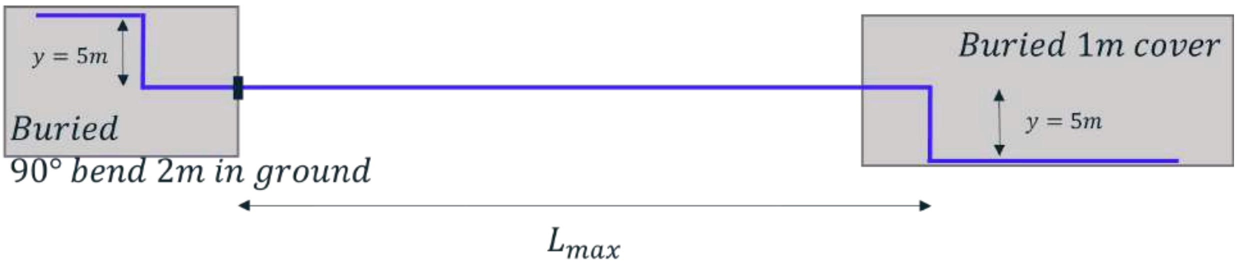

Figure 16: Plan view diagram of Option 1-A

Table 4: Scenarios for Option 1-A: Buried Z bends in ground either side

Nominal Diameter (DN)	20m Horizontal	200m Horizontal	1000m Horizontal	Max L_m @ y=5m
Scenarios for Option 1-A: Buried Z bends in ground at either side				
DN 50	OK	97mm	Excessive Movement	235m*
DN 200	OK	95mm	Excessive Movement	230m*
DN 500	OK	96mm	Excessive Movement	220m*

The maximum length of pipe is governed by the ability of foam pads to absorb expansion. Scenarios modelled in yellow are above the limit of 3 foam pad layers. However, subject to check of the localised heat buildup, could use 4 layer pads. The cover in this instance is 1m. More cover leads to less movement to be absorbed in the foam pads but greater stress in the buried section of pipework. For the DN 500 pipe, at 2m cover and a maximum length of 225m, stress builds up in the short, buried section.

Option 1-B: Anchored at one end, freely suspended at the other end

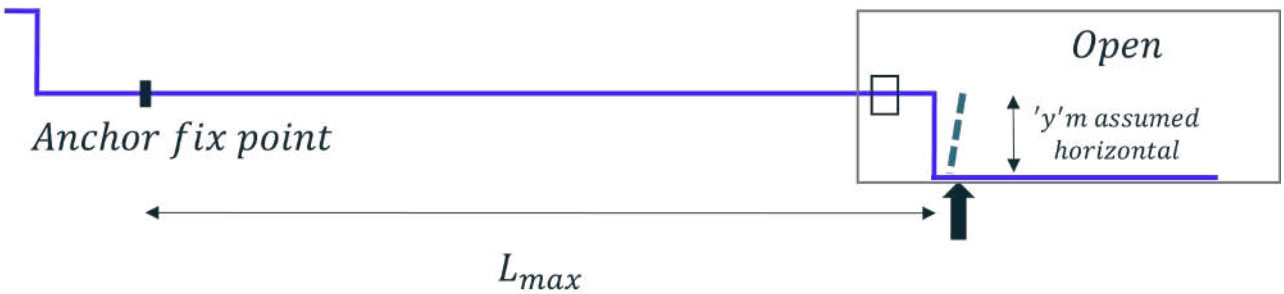

Figure 17: Plan view diagram of Option 1-B

Table 5: Scenarios for Option 1-B: Anchored at one end, freely suspended at the other end

Nominal Diameter (DN)	20m Horizontal	200m Horizontal	1000m Horizontal	Max L_m @ 'y'm	Max L_m @ alternative 'y'm
Scenarios for Option 1-B: Anchored at one end, freely suspended at the other end					
DN 50	OK	Bend over utilised	Bend over utilised	200m@5m	120m@2m
DN 200	OK	Bend over utilised	Bend over utilised	80m@5m	50m@2m
DN 500	OK	Bend over utilised	Bend over utilised	90m@5m	40m@2.4m

In this option, the maximum 'y'm value is governed by the utilisation of the elbow (which is free to move so there is no limit on the foam pads).

Option 2: Axial compensator PN 16, 1 compensator

For a pipeline anchored at one end, the pipeline displacements can be calculated through Equation 3 (duct networks):

$$(3)\ \Delta L = L * \alpha * \Delta T \ where$$
$$\Delta L = Extending\ the\ free\ end\ of\ the\ pipe$$
$$L = Length\ of\ the\ pipeline\ section$$
$$\alpha = Thermal\ elongation\ coefficient\ at\ operating\ temperature$$
$$\Delta T = Temperature\ difference$$

Using the following rule above, we can consider the pipe diagrams below:

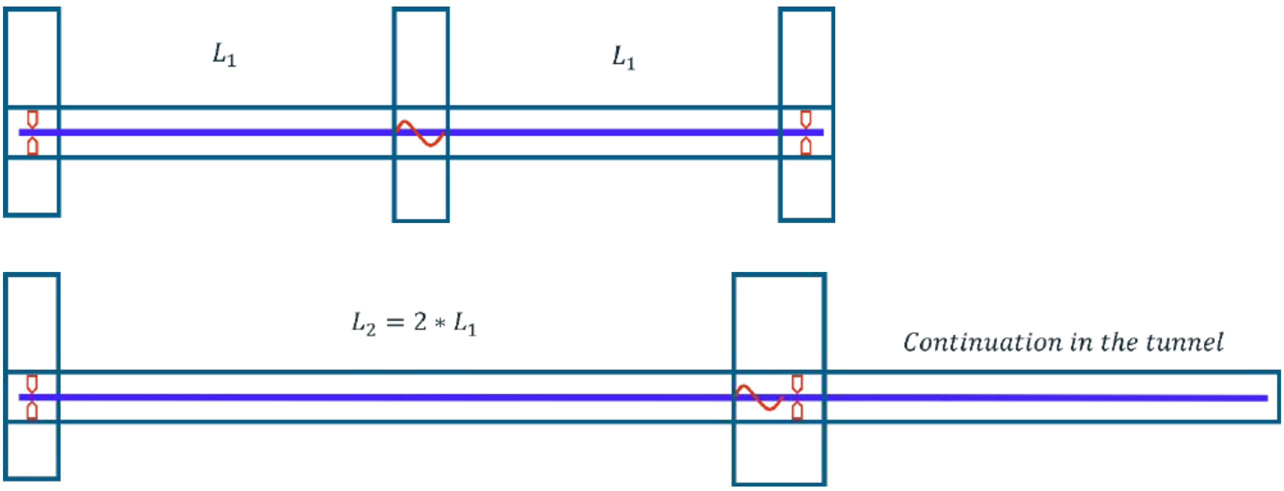

Figure 18: Option 2 example of two pipe lengths when considering compensators

Table 6: Scenarios for Option 2: Axial Compensators

Nominal Diameter (DN)	Axial Movement	L_2	L_1
Axial compensator PN 16, 1 compensator			
DN 40	100 mm	100 m	50 m
DN 50	100 mm	100 m	50 m
DN 65	100 mm	100 m	50 m
DN 80	100 mm	100 m	50 m
DN 100	125 mm	100 m	63 m
DN 125	125 mm	125 m	63 m
DN 150	125 mm	125 m	63 m
DN 200	125 mm	125 m	63 m
DN 250	125 mm	125 m	63 m
DN 300	125 mm	125 m	63 m
DN 350	125 mm	125 m	63 m
DN 400	125 mm	125 m	63 m
DN 450	125 mm	125 m	63 m
DN 500	125 mm	125 m	63 m
DN 600	125 mm	125 m	63 m

8. Detailed energy supply options assessment

LEG-DHC network development scenarios

To comprehensively assess the LEG-DHC development scenario, a techno-economic analysis (TEA) must be undertaken to understand a project's technical feasibility and financial viability and therefore will act as the main evidence base to allow DH developers to make an informed decision on their role in developing a DH project.

The TEA looks at the impact of technical design decisions on the business case for a project. It helps ensure that the scheme is optimised to deliver the required level of heat at the lowest cost with the lowest CO_2 emissions. In the case of EGS, each potential source of heat was compared to a counterfactual scenario (individual Air Source Heat Pump (ASHP)) and a Business as Usual (BAU) scenario (individual gas boilers).

The counterfactual scenario

The counterfactual scenario serves as a benchmark for comparing the LEG-DHC scenario. Given Ireland's national targets to reduce emissions by 51% by 2030 and achieve carbon neutrality by 2050, any proposed counterfactual must also feature low-carbon heating solutions.

The Business as Usual (BAU) or 'Do Nothing' scenario

Making no change to the heating supply in a region can be a potential option, especially if there is no obligation to establish a DH system. The strategic objectives outlines may not be sufficient enough to secure public sector support. If no DH system is developed, the status quo will remain, and a region will continue to be supplied by oil, gas, and electricity to meet most of its heating demands, with national level supporting policies for biofuel and heat pumps likely to have a moderate effect in the future.

These alternative heating solutions may achieve similar energy and environmental benefits to setting up and operating a DH system over time, but this would rely on a significant uptake of biofuels. However, relying on biofuels would continue to leave customers exposed to fuel price volatility.

9. Techno-economic feasibility analysis

Heat Supply Analysis Criteria

This section of the study provides a structured evaluation of the shortlisted DH supply options by applying a *Weighted Multicriteria Analysis*. The aim is to identify the most viable option by assessing technical, economic, environmental, and strategic considerations. The analysis ensures a holistic decision-making approach that accounts for both quantitative and qualitative factors, balancing financial feasibility with sustainability and long-term operational efficiency.

Table 7: Multivariable matrix

Criteria Categories	Sub-Criteria	Centralised Air source heat pump	Low-Grade Waste Heat	Shallow Geothermal/ Geostructures	Counterfactual (Individual ASHP)	Business as Usual
Multi-criteria analysis of heat sources						
Financial Considerations. Life Cycle Costs	Capital Expenditure	Moderate	Moderate	Moderate	High	Low
	Maintenance & Operations Expenditure (OPEX)	Moderate	Moderate	Moderate	Moderate	Low
	Energy/Fuel Cost Expenditure	Moderate	Low	Moderate	Moderate	Low
	Dependability & Flexibility	High	High	High	Medium	Medium
Implementation & Operability	Installation impact	Moderate	Moderate	Moderate	Moderate	Moderate
	Set-up time	2-4 Years	2-4 Years	2-4 years	< 1 Year	<1 Year
	Space/Footprint requirements	High	Low	Low	High	Low
Strategic/Market Vision	Scalability Potential	Moderate	Moderate	Moderate[30]	Moderate	Moderate
	Consumer Cost Impact	Moderate	High	High	High	Moderate
Environmental	Carbon Emission Mitigation	High	High	High	High	Low
	Environmental Impact	Moderate	Low	Moderate	Moderate	Significant

Building on this quantitative assessment, the Weighted Multi Criteria Matrix applies a structured scoring system to compare the overall feasibility of each heat source. Each sub-criterion is assigned a score based on its relative performance (1 is poor, 5 is excellent), considering both numerical values and qualitative factors such as reliability, scalability, and regulatory alignment. These scores are then weighted according to their strategic importance, reflecting project priorities and stakeholder considerations. Table 18 provides a clear ranking of the district heating options, identifying the most viable solution for further financial and sensitivity analysis.

[30] The scalability of shallow geothermal is dependent on the ground characteristics for which further testing is still needed

Table 8: Weighted Multi-Criteria Analysis

Criteria Categories	Sub-Criteria	Weight (%)	Centralised Air Source Heat Pump (ASHP) Score	Low-Grade Waste Heat Score	Shallow Geothermal / Geostructure Score	Counterfactual (Individual ASHP) Score	Business as Usual Score
Multi-criteria analysis of heat sources							
Financial Considerations. Life Cycle Costs	Capital Expenditure	**12.50%**	3	3	3	2	5
	Maintenance & Operations Expenditure (OPEX)	**5%**	3	3	3	2	5
	Energy/Fuel cost Expenditure	**12.50%**	3	4	3	2	5
	Dependability & Flexibility	**10%**	5	5	5	3	3
Implementation & Operability	Installation impact	**10%**	3	3	2	3	3
	Set-up time	**5%**	3	3	3	4	5
	Space/Footprint requirements	**5%**	2	4	5	2	4
Strategic/Market Vision	Scalability Potential	**5%**	3	4	3	3	3
	Consumer Cost Impact	**15%**	3	3	3	2	4
Environmental	Carbon Emission Mitigation	**10%**	4	5	4	3	0
	Environmental Impact	**10%**	3	4	3	3	0
Total Score	**-**	**100%**	**65%**	**75%**	**66%**	**51%**	**66%**
Ranking	**-**	**-**	**3**	**1**	**2**	**4**	**2**

The result show that waste heat presents the most attractive option under the multi-criteria analysis, ranking first with 76%. This is due to notable benefits such as carbon emissions mitigation, scalability potential and high dependability/flexibility. The second ranked option is a centralised ASHP which also ranks high for dependability.

The BAU and shallow geothermal scenarios are ranked third and fourth respectively. However, their scores are quite close. Shallow geothermal falls down in the implementation criteria, scoring low in sub-criteria such as installation time and space/footprint required.

10. Risk assessment

The risks of working on geostructures can be considered as more significant than traditional above-ground infrastructure. Following the completion of the technical, economical multivariable analysis and the detailed technical economical (financial) analysis, the risk assessment focuses on the preferred option. This involves creating a risk register to categorise and assess risks related to technical, environmental, financial, and other aspects. Risks are evaluated by their likelihood and impact, with corresponding mitigation strategies develop.

Project risks generally fall into one of the following categories:

- **Technical risks** (generally these can be broken down into heat supply, heat distribution and heat demand/customer) e.g. performance of heating plant and heat loss in the network;
- **Health and Safety** e.g construction working conditions;
- **Environmental risks** e.g. noise, cold nuisance and vibrations from heat pumps;
- **Financial/Economic risks** e.g. loss of funding, increasing interest rates on loans, increasing fuel prices, increased capital costs;
- **Reputational risk** e.g. heat price required is too high for connected customers, customer acceptance of availability, level of service is poor, etc.;
- **Commercial risk** e.g. demand risk, customer connection risk and
- **Planning risk** e.g. Planning permission, land availability, etc.

Risk assessments are site-specific, and a scoring methodology has been provided in Appendix A.

11. Conclusions and recommendations

Conclusions

Energy geostructures (EGS) allow thermal networks to tap into and take advantage of heat that is right below our feet. They are a novel and sustainable source of energy for future generations to capture and fuel our societies. Yet they are cumbersome by nature; they require a significant amount of investment, design considerations and risk management. The considerations in this report should be implemented for any future thermoactive geotechnical project planned within Dublin or beyond.

Recommendations for Local Authorities

- Upskill on the possibility of energy geostructures implementation as a means of providing heating, cooling and energy storagein future public projects such as the Dublin Metro.
- The Dublin Metro is the largest geostructure to be built in the region over the coming years. Finding ways to implement LEG-DHC should be considered due to the scale of the project.
- Develop a repository of information on relevant heat sources across your municipality. Through energy planning and demand mapping, a sufficient justification for a LEG-DHC network can be provided.

Recommendations to Industry

- In any project that involves structural foundations or tunnels, consider the potential for energy geostructures to provide heating and cooling.
- Understand that the performance characteristics of LEG-DHC is dependent on:
  - Thermal conductivity of the surrounding soil or rock or ground/drainage water flow rates;
  - Geometry and material of the structure and;
  - Operational strategies, particularly flow temperature and duration.
- Consult the *Code of Practice For Avoiding Danger From Underground Services* prior to the commencement of works.
- Deep excavation shafts for initialising the project should only be considered if no other options are available.
- In the techno-economic analysis, waste heat was found to be the highest scoring source of heating for a LEG-DHC project. This was due to high dependability and scalability potential.

Recommendations for Codema

- Waste heat is often considered in the pre-feasibility and feasibility stages of a DH network. Upskilling on the use cases of LEG-DHC to integrate with existing feasibility study work.
- Develop a repository of information on relevant heat sources across the Dublin region and beyond.
- Establish the confidentiality of this research report and share permissible findings.

Recommendations for UCC

- Incorporate the key considerations for *‘energy tunnels’* (found in Section 3 of this report) into future works, highlighting the criteria which need to be met in order to ensure functionality.
- Relay information derived from the interview process in this report to interested parties and relevant stakeholders. The dissemination of these interviews can be found in Section 3.
- Incorporate Codema’s key considerations found below into any future research publications/guidance documents/white papers.
- Raise awareness on the potential applicability of LEG-DHC in Dublin and across Ireland as a novel form of energy through:
  - Hosting webinars;

- Publishing reports/datasets;
- Giving presentations to interested parties; and/or
- Organise meetings with government or industry.

Next Steps

In this paper, Codema looked to uncover the applicability of energy geostructures (EGS) within the Dublin region with consideration for public projects and our local authority stakeholders. Insights for our partner organisation, University College Cork (UCC) have also been provided in this report.

The following steps are recommended by Codema for all stakeholders involved in DH or sustainable energy within the Dublin region:

- **Increase awareness:** Make EGS a household name for industry professionals, like DH. While they are in many ways one in the same, the difference between traditional DH and LEG-DHC is cost, challenge, and unpredictability. Openly sharing findings and the essential insights for EGS will ensure it can become just as manageable as traditional DH. Sharing this paper across industry confidentially will greatly assist in spreading awareness.
- **Embed understanding:** LEG-DHC is a different animal to the more common DH. The scale is bigger, and the stakes are greater. It is imperative that industry stakeholders, investors, and the public understand the risks involved for appropriate mitigation and elimination. Appropriate training for stakeholders should be delivered by bodies such as Engineers Ireland (EI) or by Codema.
- **Open collaboration:** Ireland is a laggard when it comes to climate measures, yet it could become an early adopter of well-executed EGS should these measures be followed. As was done in this project, looking to other EU member states for guidance will be important in understanding the barriers to design and implementation.

12. Appendix A: Risk Assessment Scoring

Weighting rationale and scoring criteria

Table 9: Impact Scoring Description

Score	Impact	Description
Impact Scoring Description		
1	Negligible	Insignificant impact
2	Low	Cost of impact is minor and, in most cases, can be easily absorbed by the project.
3	Moderate	Cost of impact is noticeable, but in most cases can be absorbed by the project. Project requirements would still be met.
4	High	Cost of impact is major. Ability to achieve secondary project requirements may not be achieved.
5	Severe	Result in inability to achieve the minimum project requirements.

Table 10: Likelihood Scoring Description

Score	Impact	Description
Likelihood Scoring Description		
1	Rare	Will likely never happen.
2	Unlikely	Not expected to happen but could do so.
3	Possible	Might happen occasionally.
4	Likely	Will probably happen.
5	Almost certain	Will almost certainly happen.

The combined severity score for each risk is a function of both the likelihood and the impact of the risk as described in the tables above (the scores for likelihood and impact are multiplied by each other). This gives the overall risk score and determines the level of action required with respect to each risk.

Table 11: Combined Risk Severity Scoring Table

Combined Severity Score		Likelihood				
Combined Risk Severity Scoring Table						
Impact		Rare (1)	Unlikely (2)	Possible (3)	Likely (4)	Almost Certain (5)
	1	1	2	3	4	5
	2	2	4	6	8	10
	3	3	6	9	12	15
	4	4	8	12	16	20
	5	5	10	15	20	25

The combined severity scores relate to the required level of action to be taken. The table below indicates the level of action relevant to each severity level.

13. Appendix B: Tables and Nomenclature

Figures and tables

Abbreviations

5GDHC	5th Generation District Heating and Cooling
AEC	Architecture, Engineering and Construction
ASHP	Air Source Heat Pump
BER	Building Energy Rating
CAPEX	Capital Expenditure
CETP	Clean Energy Transition Partnership
COP	Conference of the Parties
DCC	Dublin City Council
DEC	Display Energy Certificate
DH	District Heating
DREM	Dublin Region Energy Masterplan
EI	Engineers Ireland
EGS	Energy Geostructures
EP	Energy Planning
LEG-DHC	Large-scale climate neutral Energy Geostructures in District Heating and Cooling systems/networks
GHG	Greenhouse Gas
GSI	Geological Survey Ireland
RDI	Research, Development and Innovation
RHI	Renewable Heat Incentive
SEDA	Spatial Energy Demand Analysis
TDHS	Tallaght District Heating Scheme
TSN	Thermal Source Network
UCC	University College Cork
WSHP	Water Source Heat Pump
WWTP	Wastewater Treatment Plant

14. Appendix C: Stakeholder Interviews

Throughout this study, stakeholder interviews were held to engage the industry and procure both data and guidance. As technical experts, UCC were consulted throughout the course of the project to understand the applicability of EGS within the Dublin region.

Date	Tuesday, 13th February 2025
Attendees	Codema: James Lawson, John O'Shea Building Specialists: Expert 1, Expert 2, Expert 3
Goal(s)	Uncover insights on integrating DH into underground structures.
Agenda	• Introduction • Explanation of the LEG-DHC Project • Methods of installation • Considerations for working with underground structures • Costs • Identification of scenarios
Notable Points	• Retrofitting and installation of geostructure pipes is not a novel concept. Work has been done before, notably in the Nordic countries such as Sweden. • Installing DH pipes in underground structures requires a "multi-utility approach", dependent on whether the tunnel caters for multiple utilities, such as the Liffey Tunnel. • There are multiple methods to approach installing pipes in concrete ducts. • Construction tolerances must be considered. • The specifics of the pipe layout, diameter, and other parameters should be known prior to approaching a specialist. • There is a limit to the length of pipe – anchored pipes will only allow shorter run pipes. Maximum length varies with depth and diameter. The expansion of the DH pipes should also be taken into consideration. • Tunnelling costs are high in comparison to traditional open-cut trenching methods, so the project's commercial viability should include these costs. • Room will be required for the tunnel shaft construction, along with sufficient length to lower the push sections of the DH pipe. • Repairs can be expensive, so rigorous weld Non-Destructive Testing (NDT) and double casing joints should be considered. • An active leak detection system should be employed (with potentially four wires rather than the usual two).

Date	24th February 2025
Attendees	Codema: James Lawson, John O'Shea Dublin Local Authority Engineer
Goal(s)	Discuss the barriers to implementation of energy geostructures in Dublin
Agenda	• Introduction • Explanation of the LEG-DHC Project • Applicable case studies • Considerations of working with real-life examples
Notable Points	• Using waste heat from the underground for heat networks should be considered in the initial application. • Shallow open-cut excavations are easier. The key issue with trenchless excavations is "that you don't know what the ground conditions are like." • Trench boxes or tunnel access are essential for any excavation beyond 2m in depth.

	● Underground structures are expensive: For any project, one must consider the capacity to install geostructures in the first place. ● Existing tunnels, such as the Dublin Port Tunnel, have not been designed for geostructures. ● “While tunnelling can be expensive, deep shafts [for pipes/services] can increase the project costs.” It is only considered if no other options are available. ● One must ensure the longevity and maintenance of any underground heating system is sound as the consequences of a malfunction/damage by a third party would have an impact on its operation and the surrounding environment. ● The magnitude of costs is more uncertain with underground structures. ● A tunnel is supposed to be dry – appropriate measures must be put in place in case of flooding. ● If there is no set standard in Ireland and it is common practice to use the relevant British standards. ● Actively monitoring the entire process with monitoring devices will be mandatory.

Date	5th March 2025
Attendees	Codema: James Lawson Geospatial Surveyors: Expert 1, Expert 2
Goal(s)	Discern the health and safety requirements of operating within a confined space
Agenda	● Introduction ● Explanation of the LEG-DHC Project ● Discuss the health and safety necessities of working in tunnels
Notable Points	● Understanding the dimensions of the tunnel is of the utmost importance for the installation of any geostructures system. ● The accessibility of a tunnel would demand consideration for health and safety precautions. A 0.8m tunnel is considered ‘accessible’. The majority of tunnels are smaller than one would like for manned entry. ● Cage drones or rovers equipped with LIDAR can be deployed to access tough-to-navigate areas and generate a 3D digital profile and dimensional cross-section of the underground. ● Retrofitting any geostructures system into an underground means that it is critical to know exactly where the tunnel is in terms of its dimensions. ● Consideration must be made for other services in the underground structure (pipes, cables, etc.) ● Care must be taken in the realm of occupational health, operational safety, and structural integrity. ● The Dublin MetroLink is a very unique situation as it is one tunnel instead of two bores. ● Underground structures take “a long road” to get approval.

15. Appendix D: Demand Assessment

Table 12: Dublin City DH feasibility per small area

Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Dublin City District Heating feasibility per small area					
Not Feasible	23733	7803	31535	< 20	0.7
Future Potential	89688	34996	124683	20-50	2.7
Feasible with Supporting Regulation	430562	172766	603327	50-120	13.1
Feasible	2229477	431259	2660736	120-300	57.7
Very Feasible	627162	561711	1188872	>300	25.8

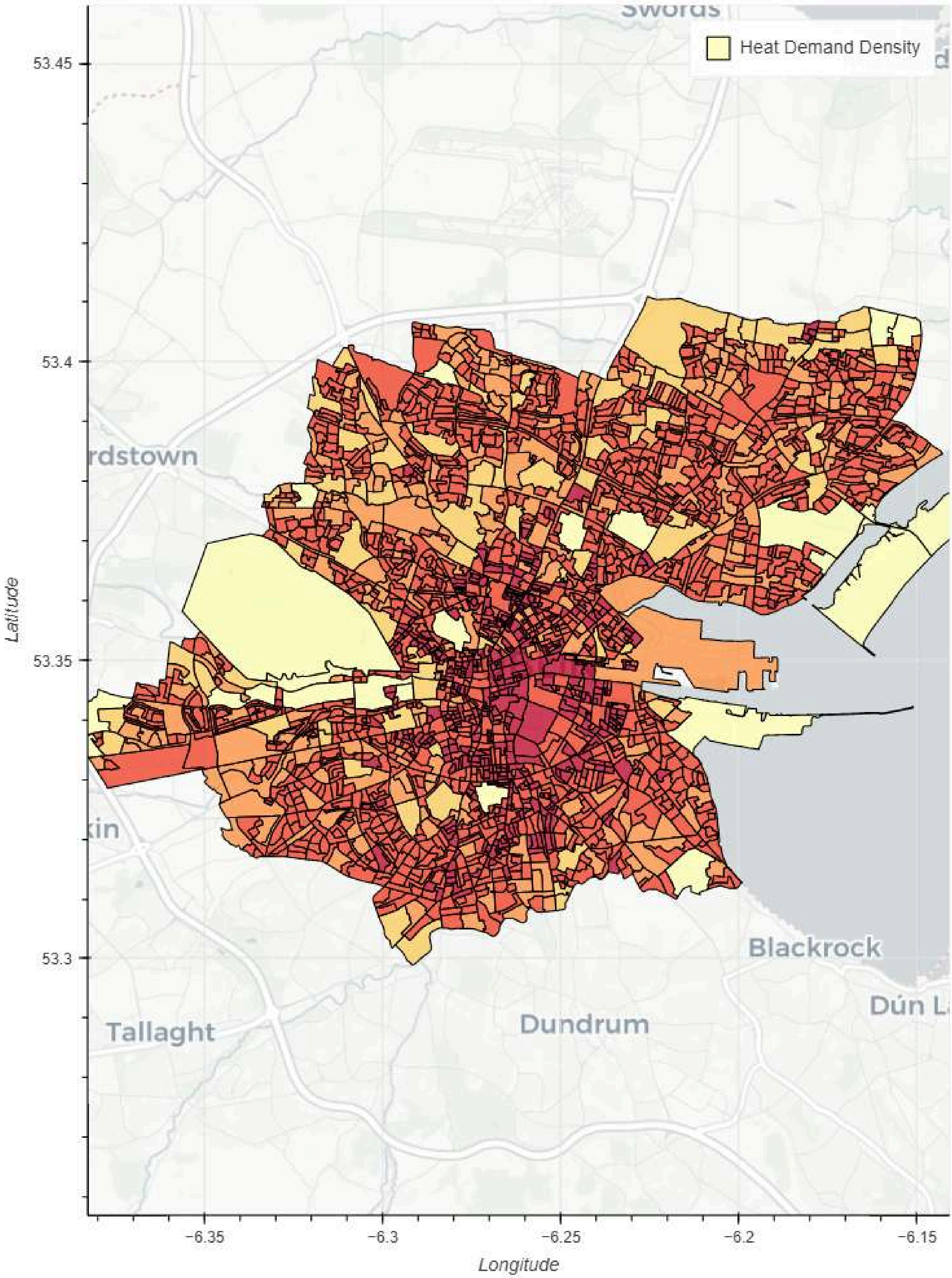

Figure 19: Dublin City DH feasibility per small area

Table 13: South Dublin DH feasibility per small area

Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
South Dublin District Heating feasibility per small area					
Not Feasible	68612	94245	162857	<20	7.6
Future Potential	91650	58127	149777	20-50	6.9
Feasible with Supporting Regulation	420262	317177	737439	50-120	34.2
Feasible	999177	81127	1080305	120-300	50.1
Very Feasible	13797	11785	25582	>300	1.2

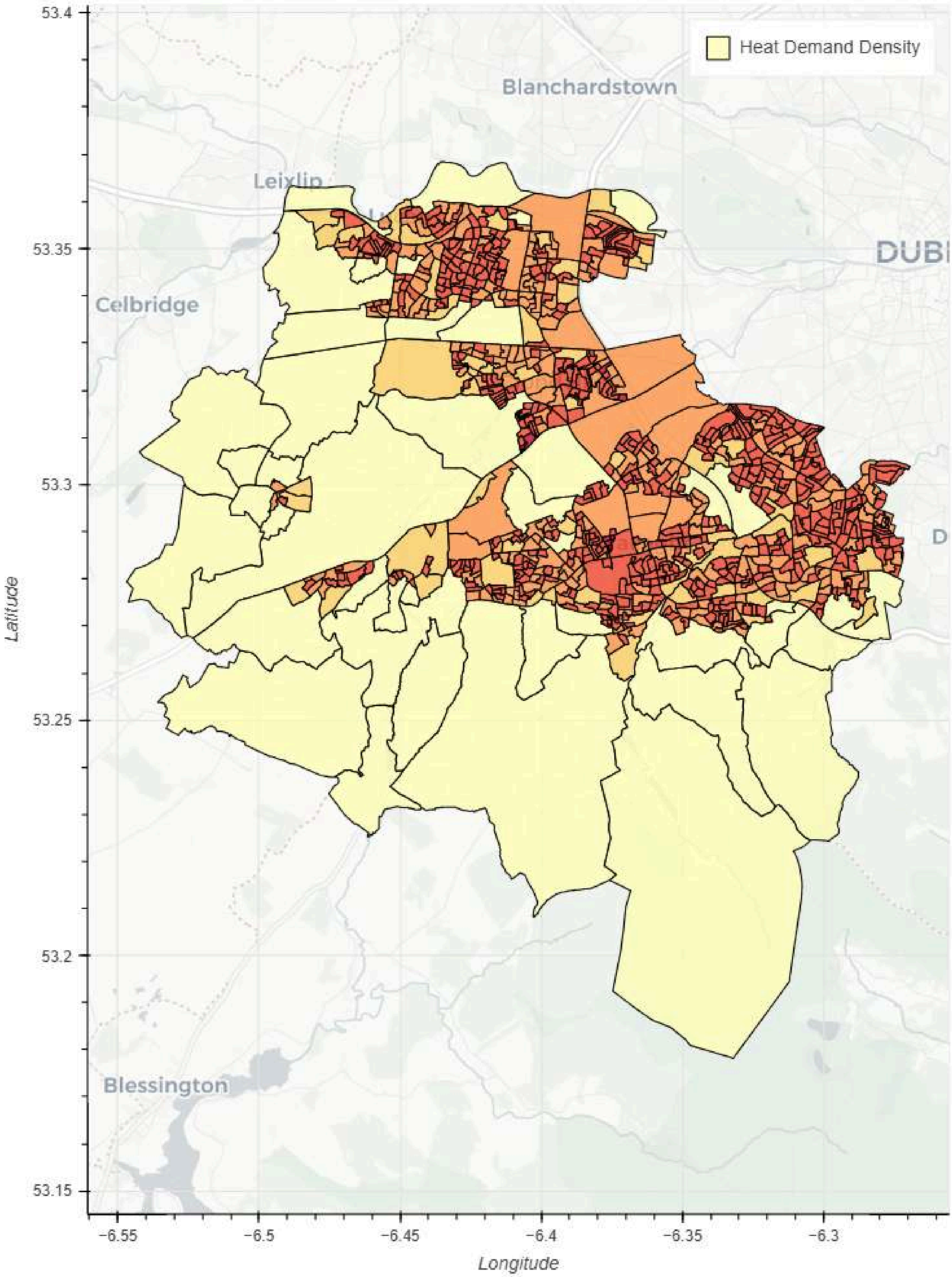

Figure 20: South Dublin DH feasibility per small area

Table 14: Fingal County DH feasibility per small area

Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Fingal County District Heating feasibility per small area					
Not Feasible	202340	216774	419114	<20	18.7
Future Potential	111750	97646	209396	20-50	9.3
Feasible with Supporting Regulation	493013	205626	698639	50-120	31.1
Feasible	772538	70229	842767	120-300	37.5
Very Feasible	12996	62182	75177	>300	3.3

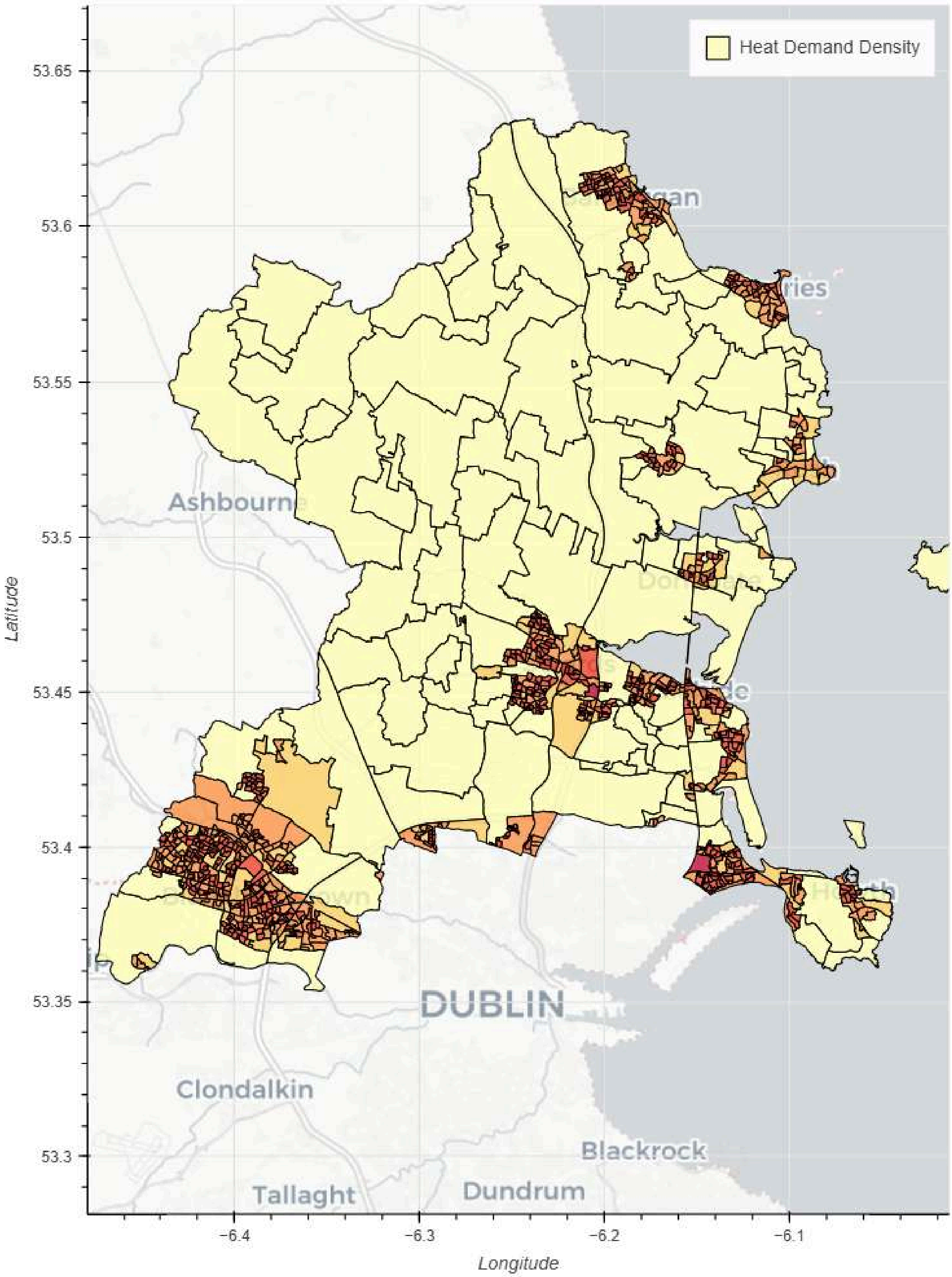

Figure 21: Fingal County District Heating feasibility per small area

Table 15: Dún Laoghaire-Rathdown DH feasibility per small area

Feasibility	Residential [MWh/year]	Non-Residential [MWh/year]	Total [MWh/year]	Band [TJ/km²year]	% Share [MWh/year]
Dún Laoghaire-Rathdown District Heating feasibility per small area					
Not Feasible	68612	94245	162857	<20	7.6
Future Potential	91650	58127	149777	20-50	6.9
Feasible with Supporting Regulation	420262	317177	737439	50-120	34.2
Feasible	999177	81127	1080305	120-300	50.1
Very Feasible	13797	11785	25582	>300	1.2

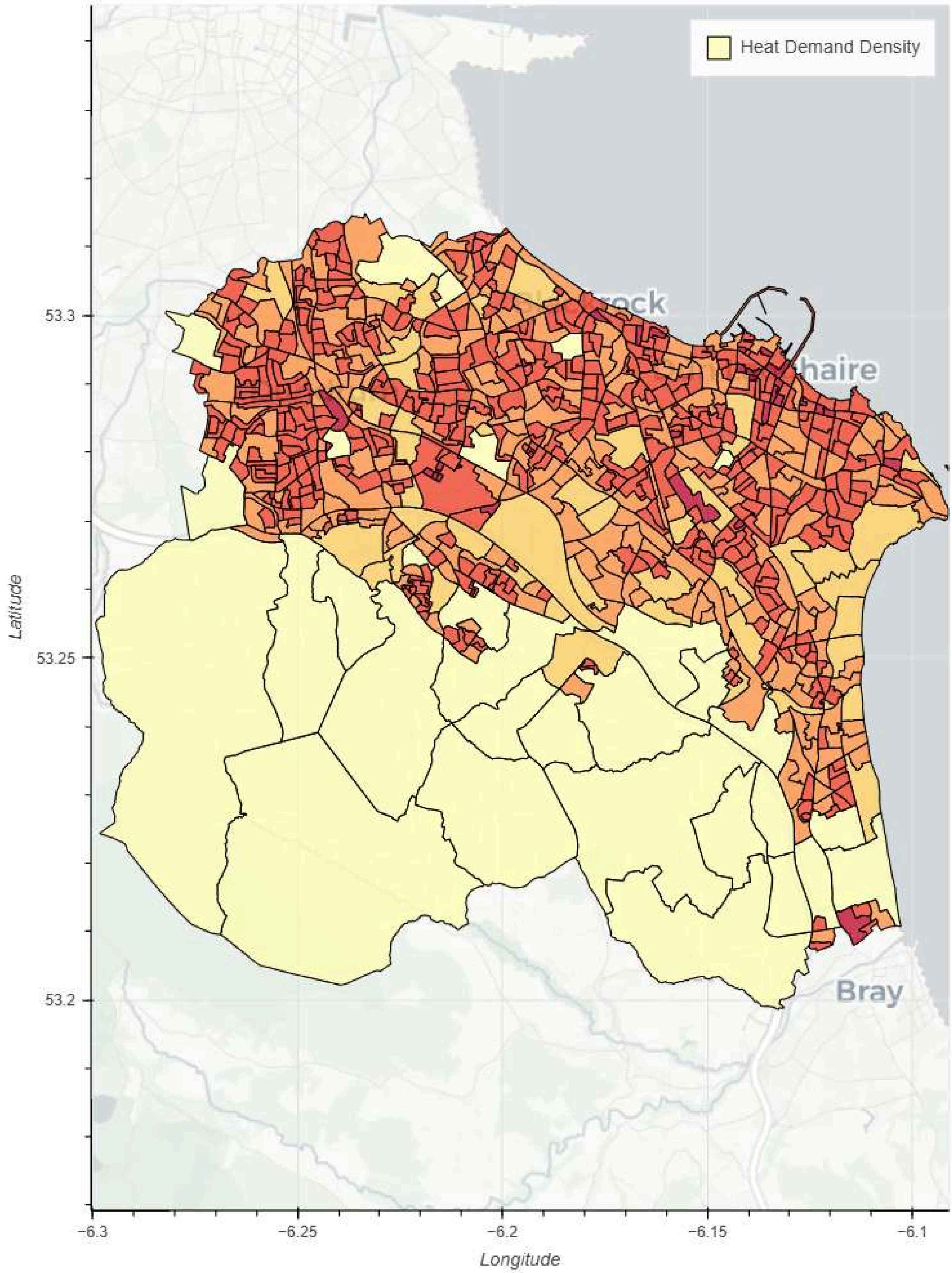

Figure 22: Dún Laoghaire-Rathdown District Heating feasibility per small area

16. Appendix E: Acknowledgements

This report was produced by Codema in collaboration with University College Cork (UCC). Codema provided non-confidential data insights for an academic team within UCC's Civil Engineering Department. The team at UCC gave Codema insight into cutting-edge research in the field of energy geostructures and enabled the development of this comprehensive report.

The team at UCC consisted of a senior lecturer and two PhD students:

Table 16: List of UCC team members and contact details

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The team at Codema consisted of members from the Research, Development, and Innovation (RDI) cell, Energy Planning (EP) cell and DH cell:

Table 17: List of contributors to this research project

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Codema would also like to thank the specialists and clients we reached out to at the early stages of the project to frame and guide our insights into energy geostructures.

About the team

RESEARCH, DEVELOPMENT AND INNOVATION

Our Research, Development and Innovation (RDI) cell work to develop and understand the *'evidence base'* for the current and future needs of the energy and climate transition for Dublin. We explore and learn in the areas of EU and national policy, and best practice examples from other European cities and energy agencies, to find out what works and what doesn't work for Dublin, through lots of conversations and collaborations. The following Codema RDI team members contributed to this document:

John O'Shea- Senior Energy Analyst / Heat & Electricity Lead

John holds a Post-Graduate Diploma in Sustainable Energy from University College Cork and a BEng in Civil Engineering from IT Carlow. He is a CIBSE-certified Heat Networks Consultant and a qualified Domestic BER Assessor. John has expertise in the design and hydraulic analysis of district heating networks, industrial energy auditing (across Europe and the US), large-scale district cooling thermo-dynamic analysis (in the Middle East), building energy compliance (in both the UK and Ireland) and energy strategy. John has also acted as an advisor on policy within the district energy sector in the UK and Ireland.

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James Lawson- Energy Systems Engineer

James joined Codema in May of 2023 as an Energy Systems Graduate in the Research, Development and Innovation cell. He completed a Master's in Civil, Structural and Environmental Engineering with a specialisation in renewable energy and structural design. His Master's thesis focused on the value of BIM for different stakeholders. Previously, he worked on projects calculating the value of geospatial information for the architecture, engineering, and construction (AEC) industry. At Codema, James works on energy planning and develops our sustainability reporting. He has recently pursued a micro-credential in energy system decarbonisation and is working toward Chartership with Engineers Ireland.

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Ciarán Murphy- Executive Manager, Research, Development & Innovation

Ciarán leads Codema's Research, Development and Innovation (RDI) area. RDI works to develop the evidence base for Dublin's climate transition and explores best practice climate action case studies from European cities and energy agencies, collaborating widely on research and demonstration projects to benefit Dublin's transition. Before Codema, Ciarán worked in SEAI with a coordination role on the National Heat Study. Before that, Ciarán worked for ESB Networks in various roles; modelling renewable connections, network design, smart metering, and also participating in ESB's innovation programme. Ciarán has a bachelor's in mechanical engineering and a master's in energy systems engineering from UCD.

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