National Heat Study

District heating and cooling: Spatial analysis of infrastructure costs and potential in Ireland

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

SUSTAINABLE ENERGY AUTHORITY OF IRELAND

Contents

I. Introduction

The National Heat Study aims to provide a rigorous and comprehensive analysis of the options to reduce CO_2 emissions associated with heating in Ireland. The Sustainable Energy Authority of Ireland (SEAI) commissioned Element Energy and Ricardo Energy and Environment to work with SEAI on the study. The project was carried out in close collaboration with the Department of the Environment, Climate and Communications.

As well as contributing to national policy, the findings also supported Ireland's second submission to the EU of a National Comprehensive Assessment of the Potential for Efficient Heating and Cooling, as required by Article 14 of the Energy Efficiency Directive. The data, assumptions and outcomes of the National Heat Study are detailed in eight technical reports. The concluding report is *Net Zero by 2050*, which outlines the study's key insights across scenarios that achieve net-zero emissions from heating and cooling. **The present slide deck is an appendix to the *District Heating and Cooling: Spatial Analysis of Infrastructure Costs and Potential in Ireland* report.**

The overall aim of the geothermal task was to identify geothermal heat sources within Ireland to feed into the district heating infrastructure model which will in turn feeds as input into the National Energy Modelling Framework (NEMF)* for scenario modelling, in addition to the requirements in the Commission Recommendation (EU) 2019/1659. The purpose of this geothermal assessment is to ascertain if including ground source heat pumps (GSHP) in the modelling for all areas. is a valid approach and if any further geothermal options, per small area, can be included in the main study modelling.

This slide deck summarises the results of reviewing the literature specific to geothermal potential in Ireland, and available geothermal modelling maps, before evaluating the gaps and the suitability of the data and recommending options for improving data availability and data sources.

Official Journal of the European Union, 2012. Directive 2012/27/EU of the European Parliament and of the council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

*More details about the NEMF are available in the *Net Zero by 2050* report.

II. Geothermal overview

"Geothermal energy refers to the heat energy generated and stored in the Earth" (Geological Survey Ireland, 2022). As shown in Figure 1, there are multiple applications possible with geothermal energy.

The possible applications are determined by e.g. the temperature of a geothermal heat resource, the technology used to extract the heat and the geological suitability for an installation.

A Ground Source Heat Pump (GSHP) is an example of technology used to extract the heat. It uses the geothermal energy and is a mechanical method of increasing the temperature of a heat resource. GSHP are primarily required for geothermal temperatures up to about 37 °C

Data from *Geothermal energy use, country update for Ireland* (Pasquali et al., 2019) indicate approximately 200 MWth was produced, in Ireland, by ground source heat pumps in 2018 via just over 18000 units with 85% being in residential, 14% in commercial and 4% industrial properties.

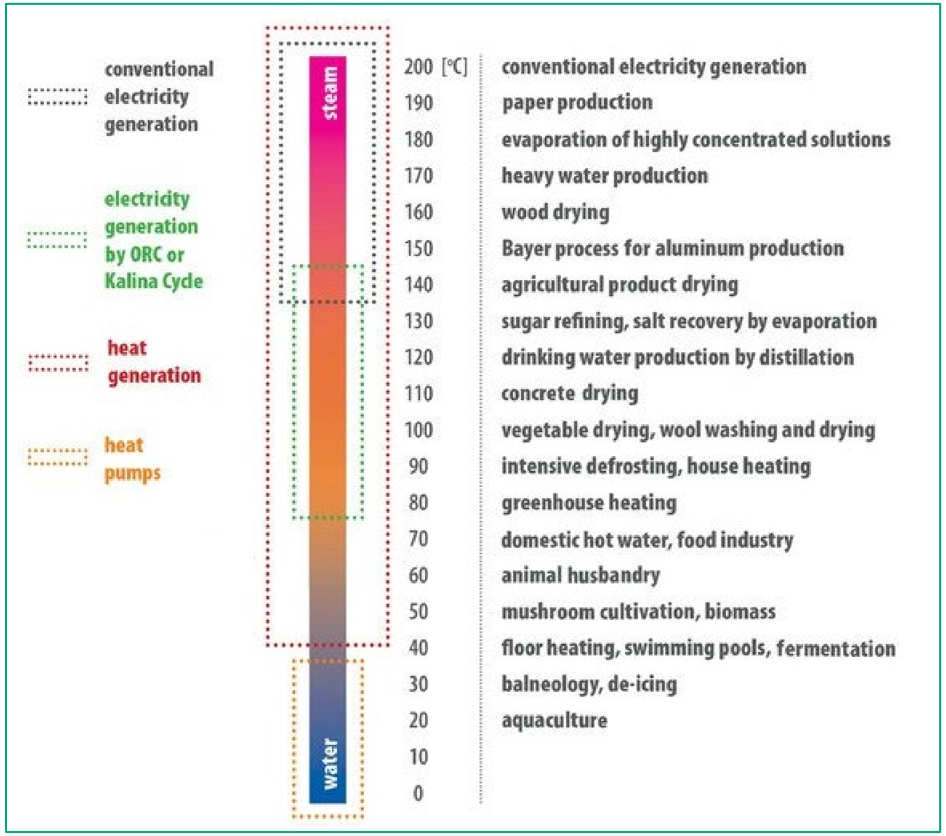

Figure 1: Possible geothermal applications by temperature range and associated technologies.

Geological Survey Ireland (GSI), 2022. Available at: Geothermal Energy (gsi.ie)
Pasquali, R., Hunter Williams, T., Blake, S., McAteer, J., 2019. Geothermal energy use, country update for Ireland European Geothermal Congress. Den Haag, The Netherlands. Available at: Microsoft Word - IRELAND EGC 2019 country update FINAL.docx (europeangeothermalcongress.eu) (Accessed 21/12/2021)
Figure is adapted from Watson, S. M., Falcone G., and Westaway R., 2020. Repurposing hydrocarbon wells for geothermal use in the UK: The onshore fields with the greatest potential. Energies 13, no. 14: 3541. https://doi.org/10.3390/en13143541

II. Geothermal overview

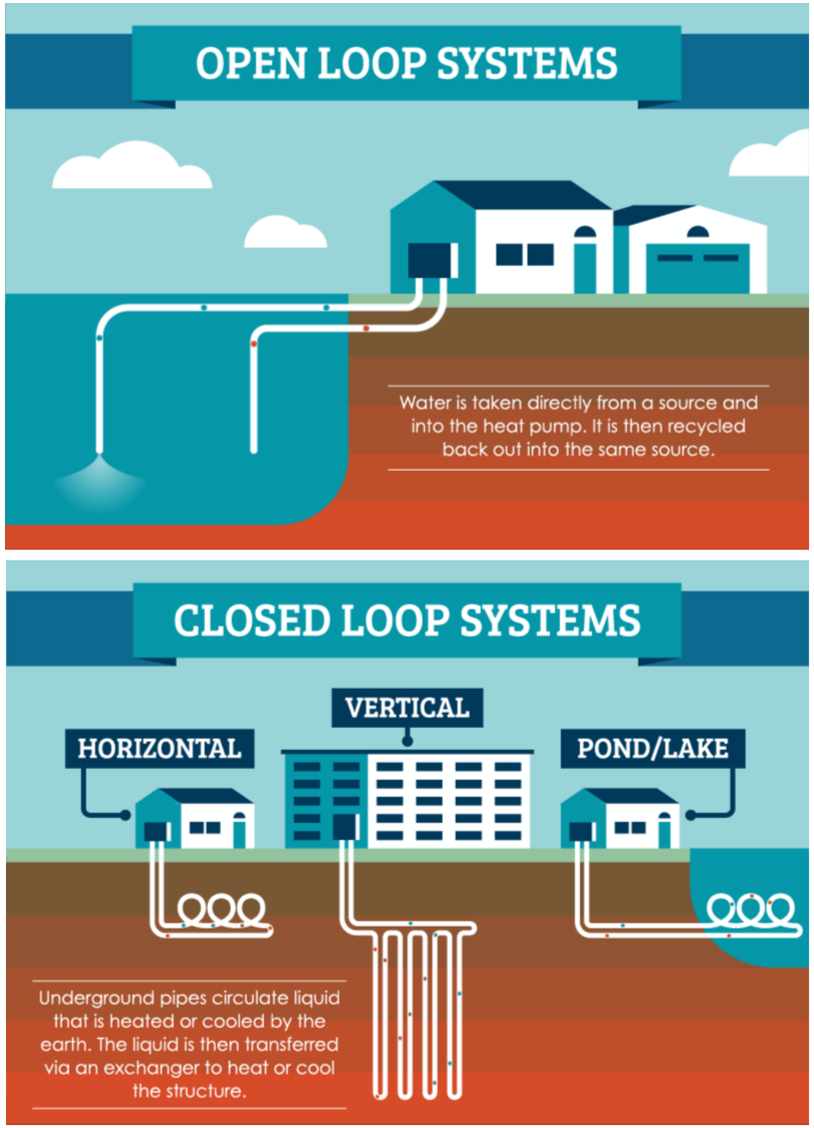

Figure 2: Schematic representation of open loop/closed loop systems

An open loop system requires fluid at depth. Usually an aquifer, these systems pump the fluid from depth to the surface where there is a transfer of the heat contained into a surface heat delivery system. Heat pumps are utilised if the temperature in the surface system is required to be higher than available from the ground. Heat exchangers are normally used to keep the systems separate. The slightly cooled fluid is usually reinjected into the subsurface to recirculate. The 'flow' and 'return' are usually separate boreholes set at distance from each other.

Closed loop systems are not dependent on the fluid at depths. They use pipework inserted into the ground. An artificial fluid is circulated within the closed pipework to depth, where heat is transferred from the bedrock/subsoil to the carrier fluid, before being returned to the surface for heat extraction. Heat pumps factor to raise the temperature to the required level as needed. Dependant on the fluid circulated, heat exchangers can be used.

Geological Survey Ireland (GSI) generated ground source heating/cooling suitability maps (2013) with a confidence level of 400m depth (based on the Water Framework Directive use of 400m as a lower limit for near surface aquifers) using a robust framework to identify different collector suitability. It is based on a scale of 1 to 5, with 4 classed as 'suitable' and 5 'highly suitable'. These cover closed loop, open loop for domestic and open loop for commercial.

There is the requirement to note that geothermal installations require comprehensive, site-specific design to ensure extracting heat from the ground does not lead to a deficit in temperature over time. Careful planning and engineering is needed in design.

Geological Survey Ireland, 2015. Geothermal homeowner manual. Available at: https://www.gsi.ie/documents/GeothermalHomeownerManual.pdf
Geological Survey Ireland, 2013, 2021. Ground source heating/cooling suitability maps. Available at: https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=9ee46bee08de41278b90a991d60c0b9e
Schemas on geothermal system types are from Save On Energy - How Geothermal Energy Works. Available at: https://www.saveonenergy.com/how-geothermal-energy-works

III. Main data sources reviewed

Main data reviewed	Source	Reference
Ground source heating/cooling suitability maps	GSI, 2013, 2021.	GSI, 2013, 2021. Ground source heating/cooling suitability maps. Available at: https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=9ee46bee08de41278b90a991d60c0b9e
Existing SEAI map	Based on Goodman et al., 2004	Geothermal map. Available at: Geothermal Energy Resources In Ireland | SEAI GIS Maps | SEAI based on work by Goodman, R., Jones, G., Kelly, J., Slowey, E., O'Neill, N., 2004. Geothermal energy resource map of Ireland - Final report. Sustainable Energy Ireland (SEI).
Revised modelled temperature data from Geological Survey Ireland (from 2000 m depth)	Published 2021. Based on Mather et al., 2019 and 2018	Mather, B., and Fullea, J., 2019. Constraining the geotherm beneath the British Isles from Bayesian inversion of Curie depth: integrated modelling of magnetic, geothermal, and seismic data, Solid Earth, 10, 839–850. https://doi.org/10.5194/se-10-839-2019 Mather, B., Farrell, T., Fullea, J., 2018. Probabilistic surface heat flow estimates assimilating paleoclimate history: New implications for the thermochemical structure of Ireland, Journal of Geophysical Research: Solid Earth 123(12):10,951 - 10,967. https://doi.org/10.1029/2018JB016555
An assessment of geothermal energy for district heating in Ireland	Blake et al., 2020	Blake, S., Braiden, A. K., Boland, M., 2020. An Assessment of geothermal energy for district heating in Ireland. Geological Survey Ireland. Available at: Geothermal Energy for District Heating in Ireland (gsi.ie)
Various Irish geothermal research projects, completed and ongoing	GSI, 2021.	List included in Appendix for further information on current and completed research projects in Ireland

IV. Ground source heating suitability map review

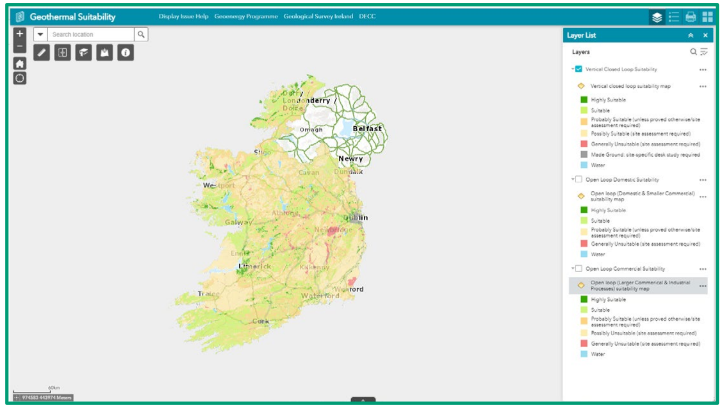

Figure 3: Ground source heating suitability map – Vertical closed loop suitability

Vertical 'shallow' closed loop suitability (left) is dependant on bedrock thermal properties, 35% of Ireland is classed as 'suitable' or 'highly suitable'. Of this, 26% of the country is defined as 'suitable' and 9% 'highly suitable' for an installation. The 'suitable' locations are spread throughout the country whereas the 'highly suitable is mostly around the northern and central west coast and central through to Dublin and down to the south-east' .

Open loop 'shallow' suitability is dependant upon the hydraulic properties of the aquifer (how well it transmits water). Both commercial and domestic (right), have similar suitability, mostly due to the requirement for an aquifer. 24% is deemed 'suitable' or 'highly suitable' for open loop domestic and 16% 'suitable' or 'highly suitable' for open loop commercial. The locational information places the majority of 'suitable' primarily in the northwest with a smaller proportion for commercial open loop to the centre and south in an almost linear fashion trending northeast to southwest. The highly suitable is mostly within the southern half linearly arranged trending northeast to southwest.

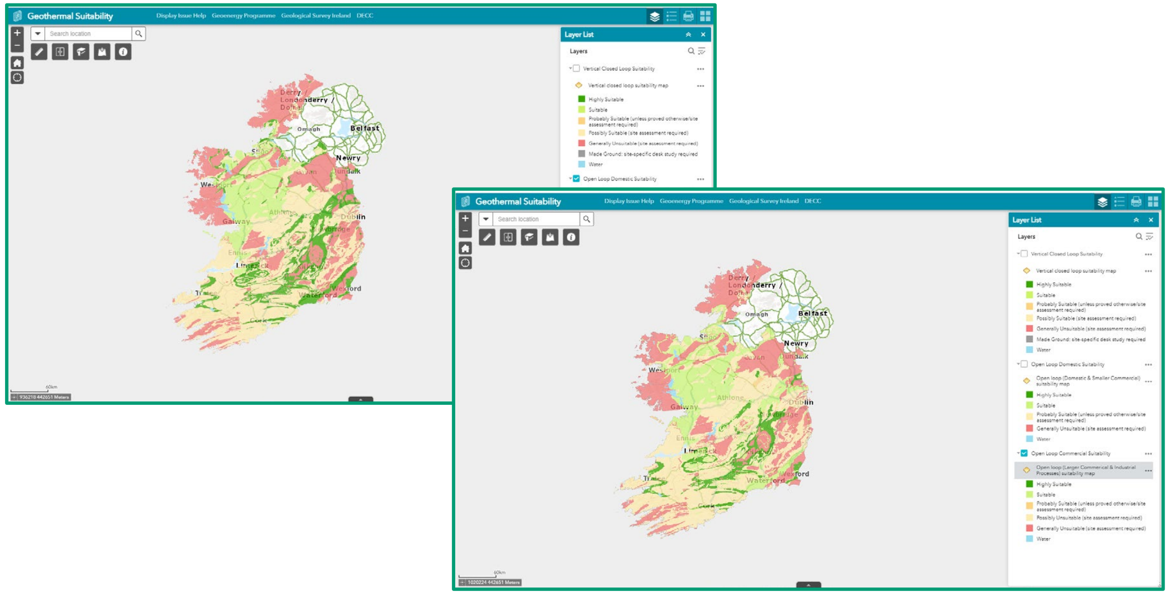

Figure 4: Ground source heating suitability map – Open loop suitability

Geological Survey Ireland, 2013, 2021. Ground source heating/cooling suitability maps. Available at https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=9ee46bee08de41278b90a991d60c0b9e

IV. Ground source heating suitability map review

System type	Total number of GSI areas assessed	‘Highly suitable’ (Class 5) %	‘Suitable’ (Class 4) %	Total (Classes 4 and 5) %
Open loop domestic	4774	13	11	**24**
Open loop commercial	9664	3	13	**16**
Vertical closed loop	88799	9	26	**35**
Total	**103,237**	**25**	**50**	**75**

Further assessment of the GSI ground source heating suitability maps is detailed in the table above and shows 75% of the areas assessed by GSI are deemed suitable or highly suitable for a heat collector installation of one or more types.

The small area dataset, of 18,641 small areas, based on the 2016 census (detailed in the main report) was then linked in GIS with the GSI ground source heating suitability datasets for analysis.

The results showed 73% of the 18,641 small areas have a suitability class of ‘highly suitable’ (5) or ‘suitable’ (4) in at least one system type, accounting for 94% of Ireland’s land mass. The remaining 23% accounts for 6% of the land mass. As the next categories are ‘probably suitable’ (3) and ‘possibly suitable’ (2) it was ascertained that applying the GSHP option to every small area is a valid assumption in the modelling.

The GSI suitability maps are currently the only datasets relating to geothermal potential available for Ireland. This restricts the input of analysis for the modelling to GSHP installations to a depth of 400 m.

Assessment was then required of the temperature modelling to ascertain if GSHP technology would be required for geothermal extraction across all small areas

Geological Survey Ireland, 2013, 2021. Ground source heating/cooling suitability maps. Available at https://dcenr.maps.arcgis.com/apps/webappviewer/index.html?id=9ee46bee08de41278b90a991d60c0b9e

V. Temperature data

At 100 m depth in Ireland, the estimated temperature is up to 22 °C.

Based on heat pump requirement for geothermal heat resources (Figure 1), the modelling decision to include the GSHP option, across all small areas, is, reinforced. This is the point at which analysis for geothermal inclusion in the modelling ceases.

However, further data exists in relation to the geothermal potential in Ireland. As Figure 1 shows, there are many possible applications over a range of temperatures. The remaining content looks further at this data to facilitate evaluating gaps and suitability of the data to recommend options for improving data availability and data sources.

SEAI. Geothermal map. Available at: Geothermal Energy Resources In Ireland | SEAI GIS Maps | SEAI

V. Temperature data

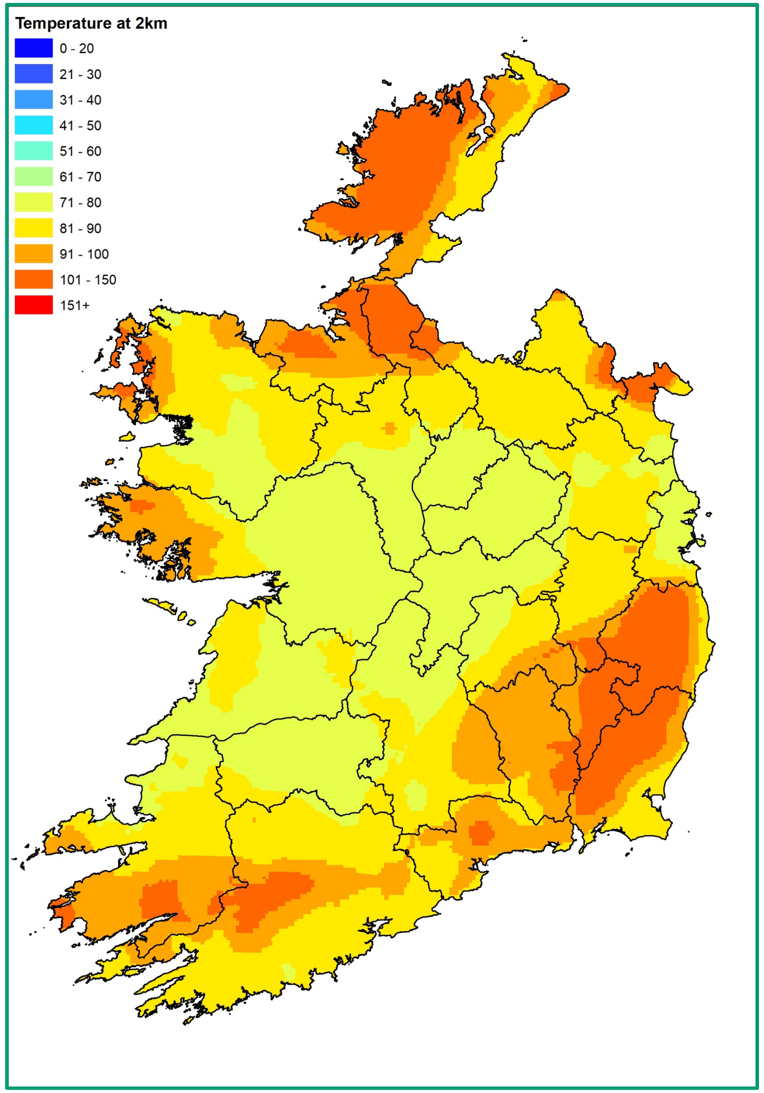

Figure 5: Temperature map – 2km

Based on work by Mather et al (2019, 2018), GSI provided data that revised the temperature model with a confidence level of below 2000 m. The revised model included data for 2000 m, 2500 m, 3000 m, 3500 m, 4000 m and 5000 m all of which were assessed. The revised data was fed into GIS by Ricardo for analysis.

The output model temperature estimates for 2000 m (left), show a dramatic increase in estimated temperatures. The temperature range is 72 °C to 131 °C. The rise to over 100 °C is primarily to the north, the southeast and southwest.

The output model temperature estimates for 5000 m (right), has a temperature range from 126 °C to 207 °C. The rise to above 150 °C primarily to the north, the southeast and southwest.

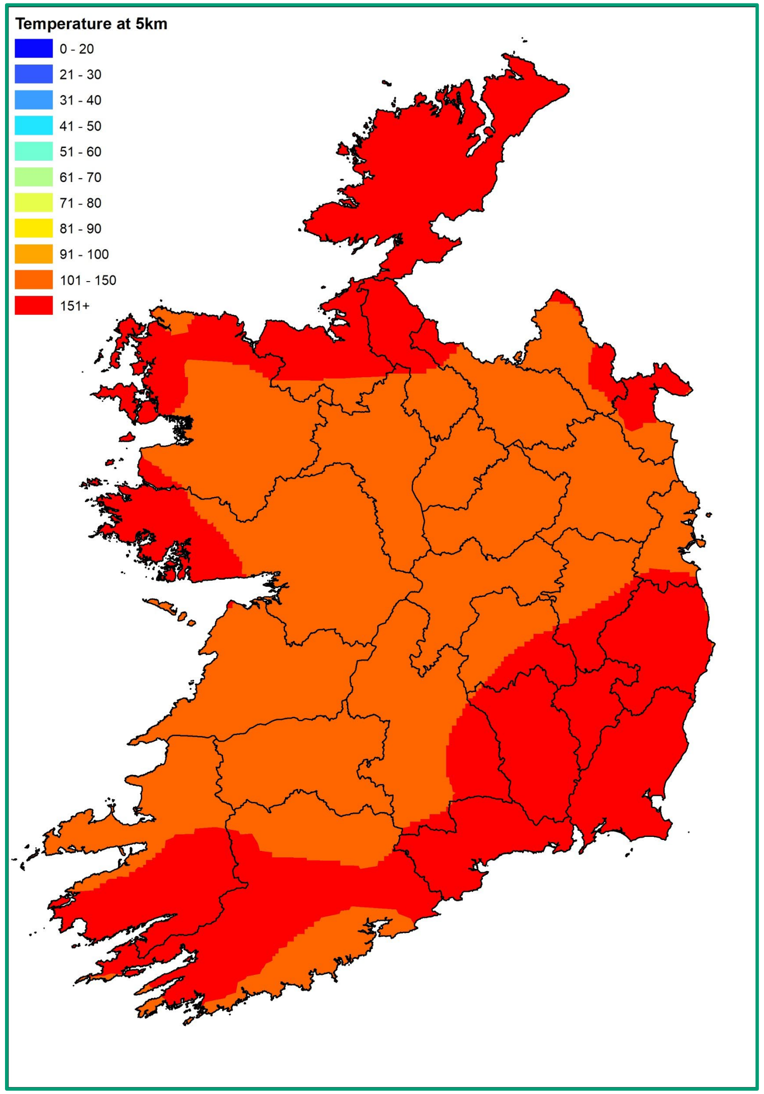

Figure 6: Temperature map – 5km

Blake, S., Braiden, A. K., Boland, M., 2020. An assessment of geothermal energy for district heating in Ireland. Geological Survey Ireland. Available at: Geothermal Energy for District Heating in Ireland (gsi.ie)
Mather, B., and Fullea, J., 2019. Constraining the geotherm beneath the British Isles from Bayesian inversion of Curie depth: integrated modelling of magnetic, geothermal, and seismic data, Solid Earth, 10, 839–850. https://doi.org/10.5194/se-10-839-2019
Mather, B., Farrell, T., Fullea, J., 2018. Probabilistic surface heat flow estimates assimilating paleoclimate history: New implications for the thermochemical structure of Ireland, Journal of Geophysical Research: Solid Earth 123(12):10,951 - 10,967. https://doi.org/10.1029/2018JB016555
SEAI. Geothermal map. Available at: Geothermal Energy Resources In Ireland | SEAI GIS Maps | SEAI

VI. Limitations of the data, addressing suitability and gaps

Due to limited data on the suitability of the geothermal resource at depth below 400 m, the analysis focussed on the potential for geothermal via ground source heat pumps up to a depth of 400 m. It should be noted that data from GSI shows that geothermal energy has significant potential in Ireland. Further characterisation and definition of this data in terms of the source suitability will allow further analysis to take place in order to fully investigate the potential of geothermal energy across Ireland.

The *Assessment of Geothermal Energy for District Heating in Ireland,* published by GSI in 2020, is a comprehensive report and an excellent source of information. It states that “further geological research is needed to estimate potential geothermal resources (flow rates, temperature, depth and generally improved subsurface and structural characterisation) through programmes including geological studies, geophysics, and drilling”.

There is considerably more national modelled temperature data, than geological suitability data, available for Ireland. Physical temperature measurements in holes drilled would be an asset to the dataset. The collection of actual temperature measurements would allow greater certainty of the temperature with depth profiles for Ireland. As further physical data is collected, the maps will benefit from regular updating. The large amount of ongoing study into the field in Ireland mean that the outlook is positive. A list of some of the recent Irish geothermal research is included in Appendix of this slide deck.

Examples from other European countries of successful geothermal operations can be used as a benchmark for conditions to be actively sought out in Ireland, examples of these are included in the appendix for reference.

Blake, S., Braiden, A. K., Boland, M., 2020. An assessment of geothermal energy for district heating in Ireland. Geological Survey Ireland. Available at: Geothermal Energy for District Heating in Ireland (gsi.ie)

VII. Appendix

Appendix 1 – Examples of geothermal research projects in Ireland

Project	Project details
GeoURBAN	Identification and assessment of deep geothermal heat resources in challenging urban environments. International geothermal resource assessment for district heating, with targets in Dublin city.
CoSeismiq - COntrol SEISmicity and Manage Induced earthQuakes	International project developing new methodologies for hazard assessment and monitoring around large-scale geothermal developments.
DIG – De-risking Ireland's Geothermal energy potential	Assessment of geothermal parameters and resource in Munster Basin.
Thermowell	Novel drilling techniques for geothermal installation at a thermal spring site in Co. Meath.
ShallowTherm	This project will test a methodology to estimate the underground heat exchange potential for shallow geothermal installations; in particular, vertical closed loop collectors.
Hotlime	This project will map and assess geothermal in deep carbonate rocks.
MUSE - Managing Urban Shallow Geothermal Energy	This project investigates resources and possible conflicts of use associated with shallow geothermal energy in European urban areas.
Go.Therm3D	Generated new 3-D thermal models of the Irish crust which could indicate the presence of deep untapped reservoirs of geothermal heat in Wicklow, Wexford, Waterford and Cork.
Feasibility project / GT Energy	Two specific geothermal boreholes were drilled to a depth of 1,400 m in Newcastle (Co. Dublin) by GT Energy, and the conditions identified in the boreholes combined with geophysical models of the area have suggested the presence of a geothermal reservoir at a depth of several kilometres.
Grangegorman, Dublin	Drilling Site at TU Dublin Campus – Temperature at approx. 1km depth was found to be 38 °C

Blake, S., Braiden, A. K., Boland, M., 2020. An assessment of geothermal energy for district heating in Ireland. Geological Survey Ireland. Available at: Geothermal Energy for District Heating in Ireland (gsi.ie) (Accessed 21/12/2021)
GSI, 2022. Events and News. Available at: Eco Eye Episode Featuring Groundwater and Geothermal Unit, Drilling and Research Programme - Tuesday 8 February (gsi.ie)

Appendix 2 – European examples of geothermal and relevance to Ireland

Examples from other European countries	
Thisted Denmark	Est 1984. 1150 m min depth. Sandstone aquifer average porosity c. 25% with Clayey intervals. Temperature: 45 °C
Lund, Sweden	Est approx. 1985. 500 m min depth. Loose Sand / Sandstone aquifer average porosity c. 30% (very high) and has a very high permeability (meaning there is a large volume of reservoir that can be tapped at shallower depths) occasionally interbedded with Clay and Limestone beds. Temperature: 21°C
Neustadt-Glewe, Germany	Est. approx. 1993. 2240 m min depth Sandstone aquifer, average porosity c. 21% occasionally interbedded with Clay beds. Temperature: 98°C
Neubrandenburg, Germany	Est approx. 1989. 1250 m average depth. Two Sandstone aquifers, average porosity c. 30% (very high) occasionally interbedded with Clay beds. Temperature: 54°C
Pyrzyce, Poland	Est 1990. 1550 m approx. depth. Sandstones average porosity c. 20% with minor amounts of Claystone. Temperature: 64°C
Benchmarks of successful geothermal operations and their relevance to Ireland	
Sandstone aquifers	Using the EU examples presented in the PlanEnergi Denmark report (2019): Sandstone aquifers of high porosity are the benchmark for high productivity open loop systems, although fracture flow may contribute significantly in Ireland.
Limestone formations	The example of district heat for the Paris Basin (approx. 1.8 km depth) has Limestone formations. The central belt of Ireland from East to West has Limestone and there has been exploration into the presence of hot springs within this area.
Magmatic intrusion	Some areas, globally, utilise magmatic intrusion radioactive decay as a potential heat source. There are magmatic intrusions to the south/southwest of Dublin among others.

PlanEnergi, 2019. Data on investment and operation expenses for geothermal energy production for district heating in Denmark. Available at: https://ens.dk/sites/ens.dk/files/Statistik/background_note_-_geothermal_energy_production_for_district_heating_in_denmark_-_2019-2020.pdf
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Appendix 3 – Additional assessment example

A paper by Franco and Donatini, in 2017, addresses methods for the estimation of energy stored in geothermal reservoirs. A key element is concluded to be natural heat flow, with the component of conductive heat flow (q) defined as the thermal conductivity of rocks multiplied by the temperature gradient: $q = K_T \times (\Delta T/ z)$

$\Delta T/ z$ is the temperature gradient. ΔT is the difference between temperature at the surface and the modelled temperature and “z” is the vertical depth between the two temperatures. A surface temperature of 10 °C was used.

K_T is a constant representing the thermal conductivity of rocks and is determined as the heat flow per second through an area of 1 m^2 when the thermal gradient is 1 °C per meter along the flow of direction.

For Sandstone, Limestone and crystalline rocks the average value of K_T is 2.5-3.5 W m^{-1} K^{-1}, for mudstones (clays and shales) it reduces to 1-2 W m^{-1} K^{-1}. Further Ireland specific estimates of K_T values can be found in the *Play fairway analysis of the geothermal potential of Ireland* report (2011) and range from 2.34 to 6.29 W m^{-1} K^{-1}. A conservative K_T value of 2.5 W m^{-1} K^{-1} was used for the example given here. A location specific geological review would allow the K_T values to be calculated for each layer, resulting in a more accurate heat flow prediction.

A basic value of the conductive heat flow in the range 45-90 mW/m^2 is expected, with general measured heat flow in the range between 20 and 60 mW/m^2, areas over 100 mW/m^2 can indicated an anomalous value of the thermal gradient.

The map in Figure 7 shows an example of heat flow estimation (mW/m^2) for a 2000 m depth. Estimate values of 60 mW/m^2 and above have been indicated by yellow shading, and for estimate values of 100 mW/m^2 and above, green shading was used.

It should be noted that all the numerical values attached to the estimates of temperature and vertical heat flow only provide a high-level analysis. Every system that is installed requires multiple stages of feasibility assessment and ground investigation to ensure its success.

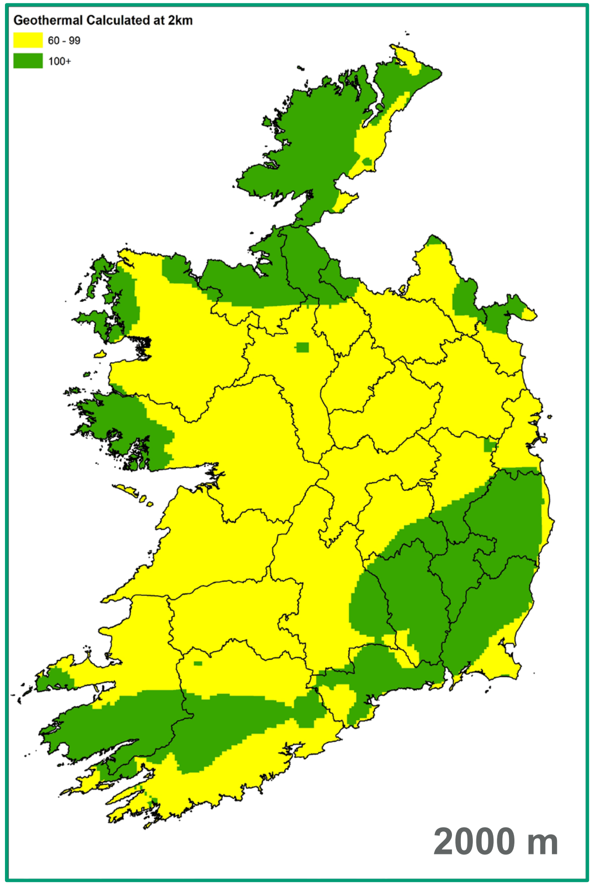

Figure 7: Heat flow map

Franco, A., Donatini, F., 2017. Methods for the estimation of the energy stored in geothermal reservoirs. Journal of Physics: Conference Series. 796 012025. http://iopscience.iop.org/1742-6596/796/1/012025
SLR, 2011. Play Fairway Analysis of the geothermal potential of Ireland Report for SEAI
Robertson, E. C., 1988. Thermal properties of rocks. United States Department of the Interior - Geological Survey. Open-file report 88-441. Available at: https://pubs.usgs.gov/of/1988/0441/report.pdf.
Everett, B., Boyle, G.A., Peake, S. and Ramage, J., 2012. Energy systems and sustainability: Power for a sustainable future (2nd edn), Oxford, Oxford University Press/Milton Keynes, The Open University