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Geothermal Development Archetypes: A Tool for High-Grading Public Sector Investment in Geothermal

R. Dunphy[1]* and S. Blake[2]
Build Geothermal Limited, Wexford, Ireland[1]
Geological Survey Ireland, Booterstown, Dublin, Ireland[2]
rdunphy@buildgeothermal.com

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INTRODUCTION

Exploration portfolios are frequently used in the oil industry to high grade investment opportunities. Leads or prospects are play-typed and often presented on graphs plotting Geological Chance of Success (GCoS) versus lead/prospect size (e.g. Nextinvestor, 2024). A third factor such as Expected Net Present Value (ENPV), or in mature basins the number of discoveries, can be applied by means of a bubble plot (Quirk et al. 2006). A useful attempt has been made to adopt petroleum sector play typing methodology, which is a first step in the exploration portfolio approach, for geothermal by Moeck (2014). The purpose of this paper is to outline an approach that builds out that play typing methodology into a geothermal exploration portfolio approach that can be used for portfolio ranking. In doing so it will be highlighted that in adapting petroleum sector processes to geothermal, care must be taken not just to mimic the criteria for ranking oil and gas prospects (e.g. risk and resource size) but instead consider what are the key drivers that both define a geothermal prospect, but also the investment decision to be made.

This paper will introduce the concept of a Geothermal Development Archetype (GDA) that will form the basis of geothermal portfolio ranking. To illustrate this concept its origin in the Geological Survey Ireland (GSI) led National Geothermal Database (NGD) project will be described, and an example of its use in defining investment opportunities for the Irish Government to mitigate economic consequences of missing legal-binding climate targets will be discussed. Ireland's heating sector is currently heavily reliant on fossil fuels, with heat-related carbon dioxide emissions accounting for 38% of the country's energy-related emissions as of 2020. This dependency poses a significant challenge to achieving Ireland's climate targets (SEAI, 2022). An Irish Fiscal Advisory Council (2025) report estimated that the economic cost of missing these targets could range from €8bn-€26bn and recommended not just following through on current decarbonization plans but enacting additional measures. Investing in developing geothermal resources in Ireland could be one such additional measure as this is an underrepresented heating and cooling technology in the market. Currently it is estimated that there is only 209MWth of geothermal heat pumps installed in Ireland and there are no deep geothermal plants (Blake et al. 2025a).

The National Heat Study (2022) commissioned by the Sustainable Energy Authority of Ireland (SEAI) emphasized the urgency of deploying available technologies, such as heat pumps and district heating systems, to decarbonize the heating sector effectively. This study also recognised geothermal energy as a significant potential source of renewable heating, whilst also highlighting that further work is required to better understand the suitability of deep geothermal resources for heating at various locations across Ireland. To address this gap in understanding, the Geological Survey Ireland commissioned the National Geothermal Database project.

The method section will outline the rationale, process and outcomes of the NGD project, the work of which defined the need for the development of the Geothermal Development Archetype approach. The results section will detail the application of the GDA approach within Ireland. The discussion section will highlight how different needs of Government led decarbonization drove the evolution of the exploration portfolio method and what benefits these investment opportunities can offer to the challenge of cost avoidance the Irish state faces. Finally, the conclusion section will point to how the GDA approach could be expanded further in Ireland.

1 METHODS – THE NATIONAL GEOTHERMAL DATABASE PROJECT

The transition toward low-carbon energy systems in Ireland requires the systematic development of geothermal resources as a reliable, indigenous, and decarbonized heat source. Despite the technical maturity of geothermal technologies globally, uptake in new regions such as Ireland can be hindered by fragmented data availability, uncertain subsurface characterizations, and limited stakeholder understanding of geothermal opportunities. To address these challenges, the National Geothermal Database initiative established a structured, stakeholder-centered knowledge management framework that integrates geoscience, engineering, economic, and regulatory data to guide geothermal exploration, support decision-making, and shape national policy. This section presents the conceptual basis, design principles and key outputs of the NGD project that led to the formulation of GDA process.

1.1 Purpose

Geothermal deployment requires an understanding of resource potential that spans a broad spectrum of geological, engineering, economic, and social factors. Unlike single-factor renewable technologies (e.g., solar or wind), geothermal potential can arise from the interaction of rock properties, heat production, structural permeability, stress regimes, drilling feasibility, and the specific heat needs of end users. This complexity can make it difficult for geothermal to be adequately evaluated as part of broad renewable energy portfolio studies that inform Government policy. Additionally in an underdeveloped market the pathways for interested potential end-users to access reliable data on performance and cost to make investment decisions are challenging. Furthermore the perceived complexity has potential to create a negative public image of geothermal. The NGD was conceived as a national-scale initiative to address these complexities by creating a unified, accessible information system. Its purpose is threefold:

1. To define geothermal play types and identify associated technologies suited to developing heating (or cooling) from these play types, (e.g hydrothermal, engineered geothermal systems (EGS), shallow geothermal, and deep borehole heat exchange configurations.)

2. To quantify the geothermal resource, incorporating subsurface temperature distributions, heat-in-place calculations, deliverability assessments and techno-economic modelling.

3. To enable evidence-based regulation and policy, while increasing public and industry awareness of geothermal as a viable low-carbon heat source.

The NGD thus would function not only as a database but as a comprehensive knowledge management system that empowers stakeholders to explore, evaluate, and utilize geothermal opportunities.

1.2 Design Process

Traditional geoscience databases are built around collating available data into a coherent, accessible format rather than around identifying the needs of users. The NGD project inverted this paradigm by adopting a stakeholder-focused design process, recognizing that geothermal deployment depends on a complex ecosystem—government agencies, NGOs, developers, service providers, planners, community groups, and end users. Each stakeholder group influences and is influenced by geothermal development, and each requires distinct information products. This stakeholder-led design process consisted of a stepwise framework linking several thematic domains that informed the development of data types and products for geothermal decision-making. It begin with a review of “Best in Class” analogues, determining what information systems other countries use and what data they contain. The next step was defining stakeholder needs and considered the different stakeholder groups in Ireland (Government, Industry, Knowledge Institution, Societal, and End-users) and their potential role in geothermal through conducting a formal interest and influence assessment. A high-level geoscience review was then undertaken that focused on identifying potential geothermal play types (Moeck et al. 2019) and the technologies that could be applied to these. The subsequent stage was a literature review and expert interview process to determine how geothermal companies use data to guide their decisions as part of a geothermal exploration process. This was followed by an interface consideration step, which determined the tools and actions needed to drive effective engagement. Together, these elements converged into creating a synthesis of data types and products that the NGD would need to house.

The result of utilizing this process was to emphasize that rather being a static repository of data and maps the NGD should focus on purpose-drive outcomes. To achieve these outcomes, it was determined that not only does the requisite data need to be in place, but it also needs to be easily found by non-expert users who don’t necessarily know what they are looking for. Therefore the first purpose should be to act as a guided interface to data, for example via maps in a thematic GIS layer. Critically the data should also be analysed and interpretated

to create the knowledge products identified in the stakeholder design process that would serve the second purpose of enabling exploration and education. Finally it was important to recognize that in a country that had little onshore oil and gas exploration, and thus little legacy subsurface data, creating a knowledge management system that would facilitate the identification of critical data gaps and the development of plans to fill those gaps was necessary.

These three elements of the NGD product are shown in Figure 1a. One of the simplest examples of geothermal relevant data is subsurface temperature data. This example will be used to illustrate the linkages between these three elements. In a basic database a shapefile of temperature measurements gathered on mining and water wells would be available in a geothermal GIS webviewer. To guide access to this data for non-expert users an advancement over this would be to develop depth to temperature (Isotherm) maps that would communicate to a potential geothermal user how deep a geothermal system would need to be to provide temperatures they need. A further step of using those temperature maps to develop targeted products such as geothermal resource maps, that can readily communicate the scale of resources available, would serve the purpose of enabling exploration or awareness. Finally gaps in knowledge or data identified in the process of making these knowledge products can be addressed by, for example, creating a data harvesting process with industry or by designing research programs with academia that will target these gaps. This forward-looking knowledge management approach ensures that the geothermal knowledge framework remains adaptable and scientifically robust.

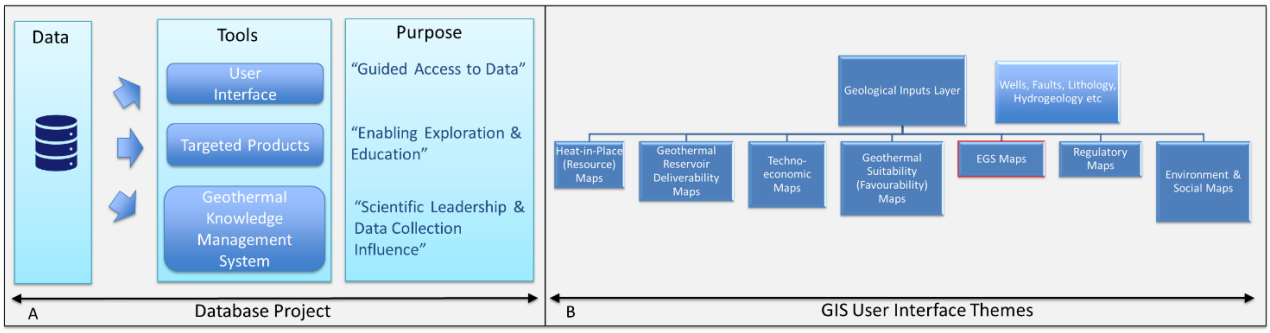


Figure 1. A) Tripartite approach to defining the National Geothermal Database purpose. B) Thematic groups for a geothermal GIS webviewer to function as a user interface and to house targeted products.

With the overall design concept in place for the NGD the decision was made to utilize a web-based GIS system to act as the user interface. This would be organized into several core themes (Figure 1b.) In order to generate collate and create data and products for these themes five work packages (WPs) were defined. WP1 was Heat-in-Place Assessment which would involve the compilation of thermal conductivity, temperature gradient measurements, and heat production estimates to quantify subsurface heat availability. WP2 was Reservoir Deliverability which would involve the evaluation of permeability, fault/fracture networks, stress conditions, and reservoir architecture to assess fluid and heat transfer capability. WP3 was Techno-Economic Analysis which involves the integration of engineering designs, drilling cost functions, operating constraints, and economic modelling to estimate €/kWh and/or levelized cost of geothermal heat. WP4 was Environmental & Regulatory Framework which involves mapping environmental constraints, seismicity considerations, permitting pathways, and monitoring requirements. WP5 was Stakeholder Engagement which involved the co-design of end-user tools, product development, public communication strategies, and community engagement.

1.3 Geothermal Screening Tool

In undertaking the work to generate these products it was identified that by structuring the database around stakeholder use-cases rather than solely around scientific data types, the NGD could enhance accessibility, applicability, and impact. To achieve this would require the creation of a geothermal screening tool. This is envisaged as map-based interface, which aligns geoscience and engineering data with user-specific needs such as geothermal technology options or cost of supply. It would do so by drawing off the underlying maps without requiring the user to investigate or interpret these maps. The structure of this tool is outlined in Figure 2. The process would start with a user in a given location in Ireland defining what they need heat for (e.g. municipal district heating), which determines the temperature range required (e.g 60-90°C). This temperature range would act a spatial filter to highlight the depth of reservoir required to supply these temperatures utilizing isotherm maps (e.g. 2000-3000m). Once the depth range is set the play types present at the depth can be established (e.g. CD1- dolomitized limestone) which in turn determines heat extraction technology options. In the example highlighted by the red boxes in Figure 2 the presence of CD1 dolomitized limestone would indicate potential to

utilize hydrothermal doublet. For this play type and technology the user would then be guided to technology specific technical information such as chance of success maps for fault zone intersection (Roche et al. 2025). The final output would be ranges of key metrics liable to drive the user to consider evaluating geothermal further such as cost of supply, the size of supply available, and the carbon emissions saving possible versus a counter factual.

A gap analysis was undertaken to establish the feasibility of developing such a screening tool. This determined the degree of subsurface mapping, understanding of reservoir deliverability, and availability of techno-economic data in Ireland was insufficient to do so. A second phase of the NGD was undertaken over a pilot area covering 40% of the country to generate the necessary data and inputs to develop a tool. This work utilized a "maps to metrics" workflow that went from regional scale geoscience to prospect scale economics (detailed in Dunphy et al. 2025, Roche et al. 2025, Rodgriguez-Salgado et al. 2025). The basis of this approach was the development of a mechanism to combine geothermal play typing with generic stakeholder use-cases that could be used within the prospect maturation process. This mechanism is the Geothermal Development Archetype.

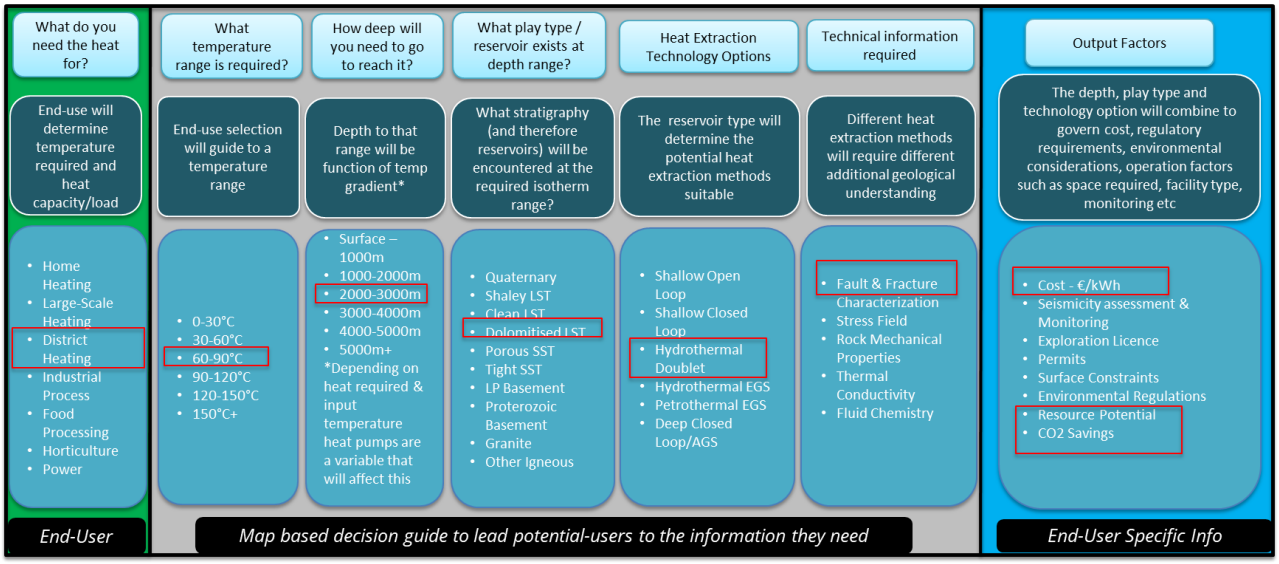


Figure 2. Proposed architecture of a map based geothermal screening tool that would guide interested heat end-users to the information required to facilitate decision-making in pre-feasibility/feasibility decarbonization studies

1.4 Geothermal Development Archetypes

1.4.1 Background

As outlined in Figure 2 the type and nature of heat use set both the temperature required and the broad scale of heat required. For example, in an Irish context a cluster of pharmaceutical manufacturing operations will have multi-MWth scale requirements for heat at 120°C+ for drying processes, whereas a small-scale horticultural operation may have sub-MWth demand for heat in the 30-50°C range. Thus, the nature of the geothermal resource that would be suitable to meet demand, and potentially the geothermal technology used to exploit the resource, are heavily dependent on the end use. Therefore, a typical geoscience based play-type method that generates a single estimate of geothermal resource potential for a given area is inadequate to describe the geothermal opportunity. This is a fundamental difference of low-enthalpy geothermal exploration versus exploration for other resources such as hydrocarbons which tend to be resource led. The petroleum industry approach is generally to explore for the best resource and transport the product to market. The economics of this approach are heavily guided by the size of the resource being sufficient to warrant the capital and operational costs of extraction and transport to market in a given price environment. In contrast the approach for low-enthalpy geothermal is to identify the market and explore for the optimal geothermal resource near to the market. A further difference to conventional petroleum exploration is that heat is a continuous, rather than discrete, accumulation. While certain heat extraction technologies such as shallow open loop geothermal heat pumps and deep hydrothermal doublets are dependent on finding discrete aquifers, others such as closed loop geothermal heat pumps, deep borehole heat exchangers and engineered geothermal systems are not. Therefore low-enthaply geothermal exploration can perhaps be defined as exploring for the most economic heat extraction technology to supply a given end use within a defined market region. The consequence of this is that uses of

practices and processes (such as using resource size-based portfolio screening) from the petroleum sector need to be appropriately considered, and adapted, for the development of low-enthalpy geothermal resources.

Recognizing the above, a key concept developed in the National Geothermal Database project is that of the Geothermal Development Archetype (GDA). GDAs are defined by combining geothermal play types, extraction technologies, heat demand characterization and geographic environment.

1.4.2 Defining Geothermal Development Archetypes

There are four key variables involved in defining a GDA:

1. Geothermal Play Type (Geology)
2. Nature of demand (End-use)
3. People & Place (Operating Environment)
4. Extraction Technology (Engineering)

The first step in the GDA process involves reviewing the play fairway maps and information gathered from the screening stage of the "maps to metrics" workflow (Dunphy et al. 2025). This is to determine what geothermal leads or prospects ***could*** be present based on geothermal gradient, depth to basement, reservoir units, structure etc. In a data poor region like Ireland there is unlikely to be sufficient data resolution to identify specific leads or prospects. This creates the need to conceptualize generic prospects that could theoretically be present anywhere within the screening area or play fairway in question.

The second step involves identifying specific end use types present in, or potentially relevant to, the play fairway. Information on the heat demand (temperature required and kWh's used) for these uses is critical with information on peak load characteristics, cooling demand, seasonality of load etc also relevant.

Prior to the final stage of identifying the potential extraction technology it is necessary to gain understanding on the nature of the physical environment and the communities present within the play area. The purpose of this is to carry out an assessment of constraints or issues that may arise from these. For example a multi-horizontal well EGS project might be the most suitable extraction technology for a given reservoir and end-use identified in the play area. However if the location is a dense urban environment, or within a community with a history of opposition to development, it may not be a viable solution.

Once a potentially viable extraction technology (or technologies) is identified the definition of the GDA is complete. The nomenclature of a GDA that captures the 4 relevant defining factors is likely to be challenging to use in practice (e.g. CD1 Fractured Dinantian Carbonate 60°C District Heating Urban Open Loop System) so the development of an alphanumeric code and related lookup table for particular jurisdictions or regions is recommended.

The relevant techno-economic information can now be generated for the GDA. The key metrics from a public sector investment perspective will be the cost of supply and the consequent reduction in Carbon Dioxide emissions (relative to a counter factual heating or cooling solution).

Once this information is generated for GDAs it can then be used to screen for pilot opportunities and inform business cases required to secure funding to move to specific prospect definition in line with play level analysis proposed by Moeck et al. (2019). Executing these pilots would then build a database of fully realized GDAs which would have actual costs, well performance, and stakeholder issue information associated with them.

The key goal of the GDA process is to capture information relevant for decision making (e.g potential cost of supply) and translate that information to as widely an applicable area as possible. A process or framework for assessing applicability therefore needs to be developed. The following section will go through a conceptual example of how the pre-feasibility or "Identify" stage assessment of geothermal as a heat source for an end-user at a given location could to evaluated to determine what information from an existing GDA could be leveraged.

1.4.3 Applying Geothermal Development Archetypes in Screening Assessments

A strong understanding of regional geology and geothermal play types can facilitate being able to use the information from one GDA to assess geothermal project opportunities in an area where little to no geothermal development information exists. A simplistic example is shown in Figure 3. In this example a GDA (A) has been defined within a screening area of interest (AOI). Outside of that AOI a heat-user at location B (Figure 3A) is

interested in understanding potential supply cost for geothermal heat as part of early-stage feasibility of a decarbonization project. A determination needs to be made on how applicable the supply cost estimated (or proven if the project has reached development) for GDA A is to location B.

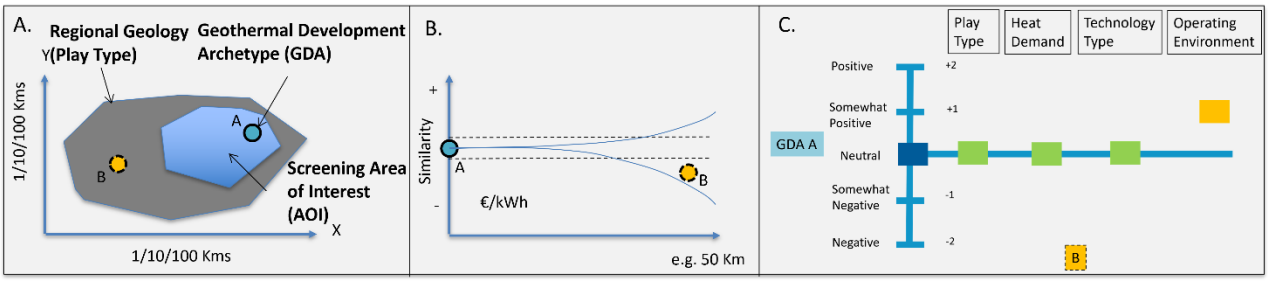


Figure 3. A) Conceptual Framework for applying GDA information from one location to another. B) A cartoon of a variogram approach to applying GDA derived metrics to a new proposed location. C) Illustrative example of a semi-quantitative approach to determining similarity of a GDA to a new location.

The highest order comparison will initially be for geothermal play type. If A is CD-1 Fractured Dinantian Limestone and B is CD-3 Granite it is clear there may be notable differences in cost, heat output, or technology type that negate transferring learnings.

The next step is to compare nature of demand. If A is 3MWth system supplying 10GWh/year to a district heating system at 80°C and B is beverage manufacturer that requires 40GWh/a at 90°C it may appear there is no commonality. However, given the similar temperature needs the application of a simple scaler or adjustment to run-time hours (industrial demand being more in a year than heating would be) may make the information useable. At this point regional isotherms or temperature gradients could be reviewed to establish if the depth required to achieve the temperature is similar. If for example the temperature gradient is estimated to be higher at B than A then well depth required (and therefore cost) may be less.

If it has been established in step 2 that there is sufficient similarity in demand step 3 then involves comparing likely extraction technology. If GDA A (a fractured limestone reliant on secondary permeability) is based on a deep open loop doublet then clear evidence (e.g. fault map, play type) would be needed to suggest that such a permeability system could exist at B. If it were the case that for example GDA A utilized deep borehole heat exchanger technology, the thermal conductivity profile of B was similar to A, and both were a conduction dominated play type, there may be sufficient similarity between them to transfer information even if the lithology was different.

Finally, assuming sufficient similarity in steps 1-3, a comparison of operating environment would be made. If GDA A was defined in dense urban residential area and B was a semi-rural industrial area then there could be potentially different cost profiles due to, for example, lower requirements on noise levels during drilling.

The process of comparing a potential new geothermal development against an existing GDA is essentially an exercise in degree of similarity across the four components that define a GDA. Given the spatial aspect to this a variogram approach (a geostatistical tool that describes how spatial similarity between data points decreases as the distance between them increases) could be applied to the workflow (Figure 3B). Alternatively in a data poor region like Ireland a simplistic semi-quantitative approach of scoring similarity in each component could be used (Figure 3C). For example if the play type, heat demand and technology type for GDA A was similar to B, but B was in a cheaper operating environment it could not be classified as a different GDA. However the cost of supply could reasonably be assumed to be more positive (less) than GDA A due to this. In this manner comparing against existing GDAs can provide a simple mechanism to transfer learnings on exploration risk, heat supply cost and potential stakeholder issues from one area of interest /geothermal play fairway to another.

2 RESULTS – DUBLIN HEAT DECARBONISATION GEOTHERMAL PORTFOLIO ASSESSMENT

The GDA concept originated to inform a geothermal screening tool that would be part of public-facing GIS system being developed as part of the NGD. End-users would enter a query (e.g. desired heat load) at a given location and information would be returned for that location (e.g cost of supply) based on similarity of geology, end-use, operating environment, and extraction technology to that of GDAs available in database. While the development of that tool is ongoing (and dependent on further investment) the principles of the GDA concept can be applied immediately utilizing data generated in the NGD. This section details an application of GDAs as a prioritization tool for governmental led investment in decarbonization.

Dublin is the largest city in Ireland and represents a significant portion of the countries heat load (SEAI, 2022) and therefore heat related CO2 emissions. Given the heat density in the city the development of district heating networks is of strategic interest to the Government as part of heat decarbonization. Geothermal is a common source of heat for district heating networks in European cities however no such systems exist in Ireland. To establish the viability of this heat source, investment in data gathering (such as seismic and exploration drilling) and piloting is needed. To inform the business case for funding this investment, an inventory of GDAs was created for Dublin city and used to model the impact a portfolio of successful geothermal investments could have on decarbonization targets, the associated economic benefits from carbon cost avoidance, and the impact on energy security.

2.1 Geothermal Development Archetype Inventory

Utilizing mapping and analysis from the NGD project (Dunphy et al. 2025, Blake et al. 2025, Rodriguez-Salgado et al. 2025, Roche et al. 2025) along with publicly available geothermal feasibility studies funded by the GSI, five distinct GDAs (Table 1.) were defined for Dublin. Additional GDAs such a CD-3 shallow and deep closed loop opportunities are present but were not defined due to similarity to GDA 1 and GDA 2. An additional GDA for CD-3 Granite Electricity Generation Urban EGS may be present, but insufficient information was available to determine metrics.

Table 1. Inventory of GDAs developed for the Dublin AOI geothermal portfolio analysis

GDA	GDA Name	Play Type	End-Use	Operating Environment	Technology	Number of systems
1	0.5 MW Shallow Closed Loop	CD 1- Basinal Dinantian Limestone	55°C Space Heating & Cooling (Hotels, offices, public buildings, healthcare facilities etc)	Urban	Shallow Closed Loop GTHP	795
2	1 MW Deep Closed Loop	CD 1- Clean Dinantian Limestone	80°C District Heating (small heat networks such as older campuses)	Urban	Deep Closed Loop GTHP	183
3	3MW Open Loop Doublet	CD 1- Fractured Dinantian Limestone	60°C District Heating (small heat networks such as modern campuses)	Urban	Deep Open Loop Doublet	10
4	11MW Hybrid	CD 1- Fractured Dinantian Limestone	80°C District Heating (large heat networks connected to mixed building stock)	Urban	Deep Open Loop Doublet & Hi-Temp GTHP	10
5	13MW Open Loop Doublet	CD 1- Karsted Dinantian Limestone	80°C District Heating (large heat networks connected to mixed building stock)	Urban	Deep Open Loop Doublet	10

A nominal area of interest within Dublin was chosen to determine how many of the GDAs identified could be present based on the presence of play types, the subsurface footprint of the systems, and the nominal surface constraints. In the case of the Open Loop Doublet and Hybrid systems surface constraints were not considered important due to the relatively low amount of such systems that could be present based on subsurface constraints (maximum 80 within the AOI). For the shallow open loop 5% of the AOI was considered developable for the 90 well array. For deep open loop <2% of the AOI was considered developable for the 8 well array due to greater constraint of access for larger drilling rigs required.

2.2 Geothermal Development Archetype Portfolio Analysis

Utilizing the inventory of the GDAs and following the process outline in 1.4.3 to infer where they could be replicated in the AOI, a number of strategic portfolio cases were built. As there is risk as to whether open loop doublets will be a viable technology, and uncertainty as to how repeatable success would be, end member portfolios where created. In the pessimistic case GDAs 3 to 5 were excluded. In the optimistic case these GDAs were assumed to be available everywhere the geological constraints were met. A mid-case was chosen that assumed 25% of available drilling locations for GDAs 3 to 5 would be successful. This was based on uplift of current assessed prospect risk that would result from investment in derisking data such a seismic.

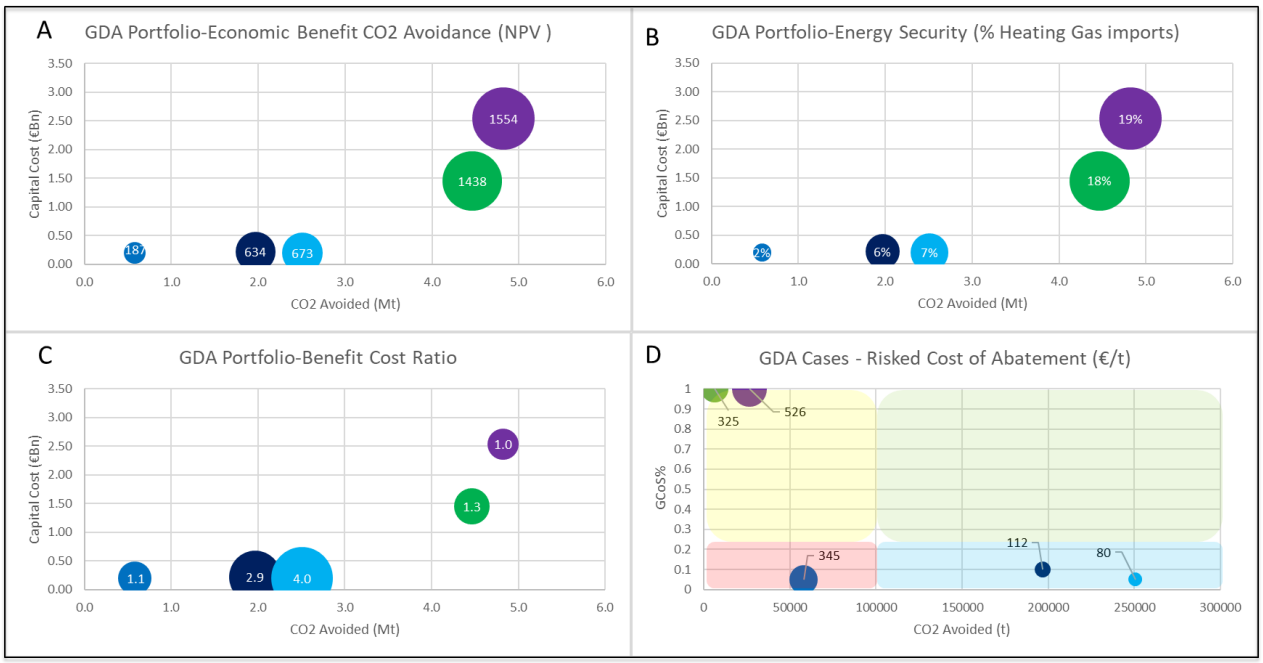


Figure 4. Graphical outputs of the GDA based economic analysis of the Dublin Geothermal portfolio. Green - GDA1, Purple – GDA 2, Blue – GDA 3, Navy - GDA 4, Light Blue – GDA 5

The results of this case are shown in Figure 4. Graph D in Figure 4 illustrates the cumulative carbon savings (compared to a counter factual of natural gas) versus the geological chance of success for each GDA in Table 1. The bubbles represent a simple abatement cost (initial investment divided by total carbon avoided, €/t). Using these metrics GDAs 4 & 5 are the "game-changing" options in the portfolio, offering high carbon avoidance for the lowest unit cost but at high risk. GDA 3 represents a high risk, low reward case with a relatively high unit cost. Such opportunities are usually avoided from an investment perspective. However, it is worth noting that for this case (and also 4&5) the very high Coefficient of Performance (COP) means that if a higher load factor than was assumed (3200hrs) is applied the carbon savings will increase almost linearly (and the unit cost would similarly decrease). GDAs 1 & 2 represent low risk, low reward investment with relatively high unit costs for abated carbon nonetheless the Marginal Abatement Costs (MAC) of these GDAs, €199/t & €507/t are still competitive with other renewable heating solutions such as air source heat pumps, biofuels and green hydrogen (Daly et al 2024). The real value and impact of GDAs 1 & 2 is their scalability within the Dublin AOI where geological conditions are relatively consistent across the area meaning these technologies can be deployed at scale in the portfolio.

This portfolio level analysis (Graphs A-C in Figure 4) demonstrates that for a cumulative capital investment of €4.6Bn in 1008 geothermal systems (the breakdown by GDA is indicated in Table 1), 14.3Mt of CO2 avoidance could be achieved over 30 years. The economic benefit of this investment would be €4.5Bn. This is the NPV of carbon avoided by displacing natural gas and was based on a table of carbon costs published by Irish Government in 2024 for use in infrastructure projects (DPENDR, 2024b). The average Benefit Cost Ratio (BCR, discounted revenue divided by discounted cost) of the investments is calculated to be 2.1 (≥1 is considered investable, DPENDR, 2025a). The BCR is calculated by treating the avoided cost of carbon as revenue and adding this to the revenue generated from heat sale (assumed at €0.1/kWh in line with current gas prices). A discount rate of 4% was used (DPENDR, 2024a). The total energy produced from the portfolio is 3.1 TWh per year. From an energy security perspective this would represent a reduction of 3.1TWh/yr of gas imports, which represents over 50% of the gas consumption for residential and non-residential heating in Dublin (CSO, 2024).

3 DISCUSSION – REALISING DUBLINS GEOTHERMAL HEAT DECARBONISATION POTENTIAL

It is apparent that when comparing the scale of investment needed to the deliver the modelled geothermal portfolio (€4.6Bn) to the potential cost of Ireland missing legally binding targets (€8-26bn) that there is a compelling case to pursue geothermal as a heat decarbonization technology in Dublin. The case could be further improved by investment in data and piloting within the region. GDAs 3,4, and 5 could be moved into the "low risk, high impact" area of Graph D in Figure 4 (green quadrant) with acquisition of 2D and 3D seismic and by drilling deep exploration wells. GDA 2 is a poorly understood technology option in Ireland. There are also few examples of cost and performance to draw analogues from in other similar jurisdictions. With investment in further feasibility studies and pilots of this technology the BCR of 1 could be improved by identifying cost improvements and by establishing real-world costs, COPs, and outputs of these systems. Similarly, the BCR of GDA 1 may be improved if cost gains from economies of scale achieved by mass deployment of the technology are investigated, and the impact of conservatism in collector performance modelling understood.

To do this it is proposed that the period 2026-2030 is used to address these knowledge gaps. A proposed work program to achieve this would be as follows: €15MM for regional 2D and 2 large scale 3D seismic acquisitions, €15MM for the drilling of two deep open loop exploration wells, €40MM for piloting of two deep open loop systems (GDA 3-5), €20MM for piloting a large scale deep closed system (GDA 2), and €20MM for deploying 10 shallow closed loop demonstration projects for different public sector uses and/or for connection to residential district heating system (GDA 1).

In addition, a further €20MM should be allocated to investigating geothermal potential nationally including €8mm for regional drilling programme, €10MM for a national 2D seismic program and €2MM for a national petrophysical programme to create a digital national core repository. Thus an investment of €130MM is proposed to unlock the potential €186MM NPV of modelled economic benefit of the Dublin AOI.

4 CONCLUSIONS

The work presented in this paper demonstrates that adapting petroleum-style exploration portfolio concepts to geothermal requires more than a direct transfer of methods: it requires a reframing of what defines a geothermal opportunity, how it is evaluated, and how it should be valued for public-sector investment. The Geothermal Development Archetype (GDA) framework developed through the National Geothermal Database (NGD) project provides such a reframing. By integrating play type, end-use characteristics, operating environment, and extraction technology, the GDA approach creates a coherent mechanism for translating regional geoscience into decision-ready metrics for heating decarbonisation.

Applying the GDA framework to Dublin illustrates its value as both a screening tool and an investment-ranking methodology. The portfolio analysis shows that a mix of shallow closed-loop, deep closed-loop, and open-loop doublet GDAs could deliver substantial decarbonisation impacts if deployed at scale, with up to 14.3 Mt of CO_2 avoided over 30 years and a benefit-cost ratio of 2.1 for a €4.6 billion investment. These results highlight that geothermal can make a meaningful contribution to Ireland's legally binding climate targets while simultaneously reducing dependence on imported natural gas thereby strengthening energy security. Importantly, the analysis also shows that the highest-impact GDAs currently sit in the high-risk, high-reward quadrant of the portfolio, and therefore justify targeted public investment in derisking activities such as seismic acquisition, exploration drilling, and early demonstration projects.

The GDA framework also offers a path toward standardisation and scalability. As more GDAs are piloted and validated, the resulting performance, cost, and stakeholder-learning datasets will enable increasingly accurate and transferable assessments across Ireland's diverse geological and demand contexts. Further development of the GDA-driven based geothermal screening tool envisaged in the NGD project is being investigated with a focus on integrating AI tools. It is hoped that if developed it can become a national asset: a user-friendly, evidence-based platform to support public bodies, planners, developers, and communities in evaluating geothermal as a viable low-carbon heat source.

Ultimately, the approach outlined here shows that geothermal can move from a niche and poorly understood option to a strategically managed component of Ireland's decarbonisation portfolio. Expanding the GDA methodology nationwide—supported by coordinated investment in subsurface data acquisition, techno-economic research, and pilot deployments—will be essential to unlocking Ireland's geothermal potential and enabling meaningful progress toward 2030 and 2050 climate commitments.

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